Smart Hydroponic Plant Growing System using IoT

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1. Abstract

Growing plants and vegetables is not only a great hobby, it is also a healthy and sustainable way of obtaining food and medicine. Nowadays, not every person has access to a piece of land nor the time to take care of crops. This situation intensifies in urban areas, where most people live in small spaces and have busy lifestyles.

The aim of this project is to build an automated grow box to allow users to produce plants and vegetables indoors in a time-saving and inexpensive way. In order to achieve this, the system must provide everything that plants need to grow healthy, such as nutrients, air, water, light, temperature and space.

This report covers the whole process that has been undertaken to complete and reflect on the project, classified in the following main sections: introduction, investigation, design, development and evaluation.

Due to the nature of this project, research is not only limited to the area of Software Engineering.

This project includes two deliverables: A plastic container with electric components attached where the plants can grow and a front-end application that allows the end user to interact with and monitor the system.

Contents

Abbreviations

ADC	Analog-to-digital converter
API	Application Programming Interface
BASH	Bourne-again shell
BSc	Bachelor’s of Science
CLK	Clock
CSS	Cascading Style Sheets
CSV	Comma-separated values
DC	Direct Current
DIN	Digital Input
EU	European Union
GDPR	General Data Protection Regulation
GPIO	General Purpose Input/Output
GUI	Graphical User Interface
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IDE	Integrated Development Environment
IP	Internet Protocol
LED	Light Emitting Diodes
MISO	Master Input Slave Output
MOSI	Master Output Slave Input
PAR	Photosynthetically active radiation
QMUL	Queen Mary University of London
RAM	Random Access Memory
RPi	Raspberry Pi
SCK	Serial Clock
SDLC	Software Development Life Cycle
SHU	Sheffield Hallam University
SMD	Surface Mount Device
SPI	Serial Peripheral Interface
SUS	System Usability Scale
UIDs	Unique Identifiers
UI	User Interface
UoM	University of Manchester
URL	Uniform Resource Locator
V	Volt
VDD	Voltage Drain Drain
VNC	Virtual Network Computing
VSS	Voltage Source Supply
Wi-Fi	Wireless Fidelity

Figures

2. Introduction

2.1. Concept and Aims

- The physical deliverable must include a microcontroller or small computer to control electronic components placed in a plastic container.

- The user will have the possibility to monitor the growing process inside the container via a second deliverable: a web application where data will be graphically displayed along with a control panel in a dashboard.

- The user will be able to interact with components such as camera, pump, lights and fan. It should also allow the user to see a graphical representation of the parameters gathered by sensors.

Some of the operations such as light cycle and airflow will be also automated, therefore the amount of time that the user needs to invest from seed to harvest is extremely small compared to traditional growing methods.

This project requires extensive research in the areas of software development, electronics and agriculture. A survey will be conducted to analyse user’s needs and design the system accordingly.

2.2. Project Approach

Since this project is an interdisciplinary effort, choosing a development approach is not a straightforward task. The feasibility of the design and approach was not guaranteed, which means that further amendments would likely need to be done, therefore the chosen model was Prototyping. The reason for selecting the Prototyping Model was that “it encourages progressive strategic development with the course of time” (Essays, 2018).

2.2.1. Prototyping Model

According to the software development agency Ingsoftware, “a Prototyping Approach allows the users to evaluate developers' proposals for the design of the eventual product by actually trying them out, rather than having to interpret and evaluate the design based on descriptions. Software Prototyping provides an understanding of the software's functions and potential threats or issues”.

A prototype is an initial model of an object built to test a design; the word comes from a Greek word for ‘primitive form’. “Prototypes are widely used in design and engineering to perfect items and processes before implementing them on a large scale” (Blackwell & Manar, 2015).

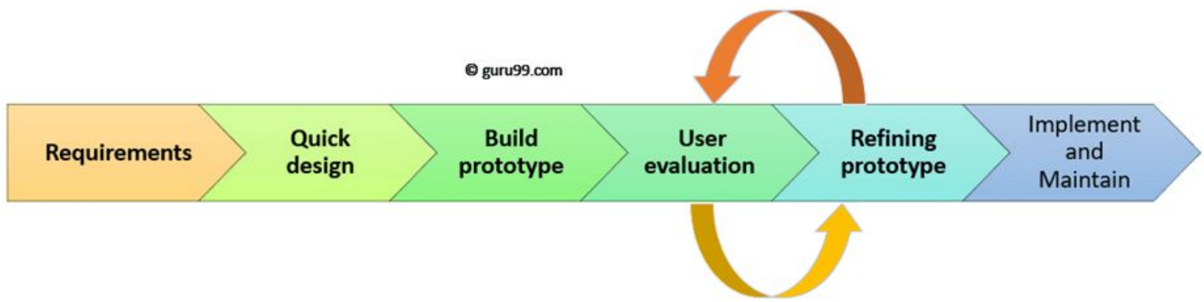


Figure 1: Stages of the project using a Prototyping Model

In this project, the software developer and the supervisor act as stakeholders in the sense of analysing the proposed system and identifying what aspects need to be improved, discarded or included in the final version. This approach offers a high level of flexibility that other popular approaches do not provide. Prototype is a model that is akin to the Software Development Life Cycle (SDLC).

2.3. Solutions available

A variety of indoor, smart hydroponic growing solutions are currently available on the market:

	Seedo	**Niwa**	**Grobo**	**This project**
Size	Height 40”, 101cm Width 24.4”, 62cm Depth 24.4”, 62cm	Height 24”, 61cm Width 18.5”, 47.5cm Depth 10.2”, 26cm	Height 48”, 122cm Width 14”, 35.5cm Depth 14”, 35.5cm	Height 19.7”, 50cm Width 13.4”, 34cm Depth 16.5”, 42cm
Monitoring App	Mobile App only	Mobile App only	Web App (Mobile and Desktop access)	Web App (Mobile and Desktop access)
Camera	Yes	Yes	No	Yes
Automation	Yes	Yes	Yes	Yes
Maintenance	Low	Low	Medium	Low
Cost	£1970 + £285 delivery fee	£285	$2299 (Shipping to Canada and US only)	£170 (components cost)

Used sources suggest not many solutions fulfill all the needed criteria at an affordable price. Some systems like ‘Seedo’ and ‘Grobo’ are very complete solutions but are not cost-effective due to a market price of around £2000. The product ‘Niwa’ is the only one which balances functionality and cost with a similar concept.

There are also pieces of academic research available, such as the study by Mehra *et al.* (2018) from the SRM Institute of Science and Technology in Chennai, India: an IoT based hydroponics system using Deep Neural Networks, that describes “a prototype for tomato plant growth as a case study”, developed with Arduino, Raspberry Pi Model 3 and TensorFlow. It shows how IoT and AI interact together to impact agriculture. The article also includes a list of other intelligent IoT based Hydroponics systems used towards farming in several countries around the world and also research in the field by NASA.

3. Investigation

3.1. Hardware

According to Rouse (2019), “the Internet of Things is a system of interrelated computing devices, mechanical and digital machines provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction”. In order to create a system of these characteristics, extensive research was needed throughout the project. The following pieces of hardware play a crucial role in the system:

3.1.1. Raspberry Pi 4 Model B

As per the requirements, a microcontroller or small computer is needed to allow user interaction with components and data transfer.
A microcontroller motherboard device is an Arduino, for example. “Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online, etc.” (Arduino, 2020).
With Arduino, only one program can be run at a time, so they are good for quick set-ups and “when it comes to controlling small devices but it is not possible to run an entire operating system. Arduino cannot connect to the Internet without a Shield which adds Internet connectivity” (Educba, 2020). Research suggests that Arduino microcontroller boards should be used for simple and repetitive tasks, therefore an alternative will be used for this project.

Research also suggests that there are several series of small computers that could be used to set up a system with a concept like this Smart Hydroponic Plant Growing System. Some examples are:

- Raspberry Pi
- Orange Pi
- Banana Pi
- Rock Pi
- Huawei HiKey 960

The devices listed above are some of the best single board computers available in the market (All3DP, 2020). For this project, Raspberry Pi will be the chosen board because of its strong and active community (Bridgwater, 2012), examples of this are:

- “The community developed a fanzine around the platform called The MagPi which in 2015, was handed over to the Raspberry Pi Foundation by its volunteers to be continued in-house” (Raspberry Pi Foundation, 2015),
- “Community ‘Raspberry Jam’ events have been held across the UK and around the world” (Raspberry Jam, 2020), such as the one held in Sheffield Hallam University on 10th March 2020. This event was organised by the South Yorkshire branch of the British Computer Society (BCS, 2020).

“The Raspberry Pi is a series of small single-board computers developed in the United Kingdom by the Raspberry Pi Foundation to promote teaching of basic computer science in schools and in developing countries” (Bush, 2011).
The single board consists of a fully functional computer with its dedicated memory and processor. It runs an operating system: Raspbian (a Debian-based, 32-bit Linux distribution). Raspberry Pi is best to use in projects where requirements include more complicated systems doing intense calculations and performing multiple tasks.

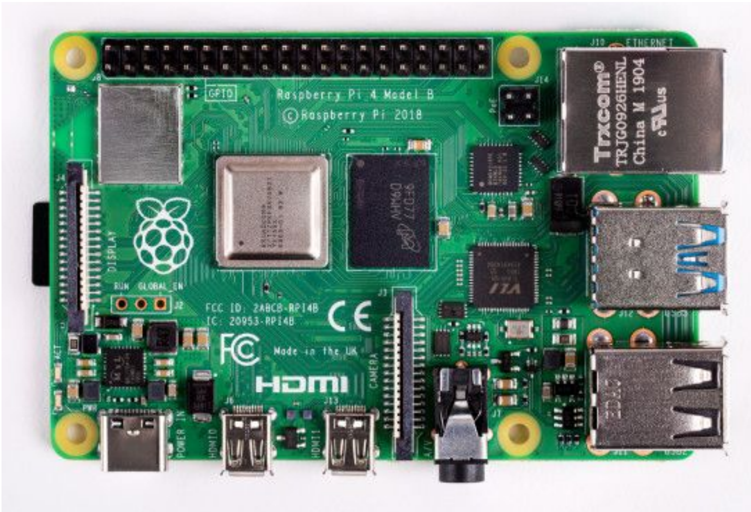


Figure 2: Raspberry Pi Model B

The model chosen for this project is Raspberry Pi Model B with 4gb of RAM. This model is the most powerful Raspberry Pi computer available. The system could perfectly run in a more basic model such as Raspberry Pi Zero Wireless -which costs just £15- but the Model B provides a much faster environment thanks to a more powerful processor and more RAM. The Raspberry Pi will be protected by a plastic case.

3.1.2. Raspberry Pi Camera Module v1

A camera module is needed to monitor the growing system. The chosen camera is the official Raspberry Pi Camera Module due to its full compatibility with the single-board computer and its compact design. Its resolution is 5 Megapixel at 1080p.

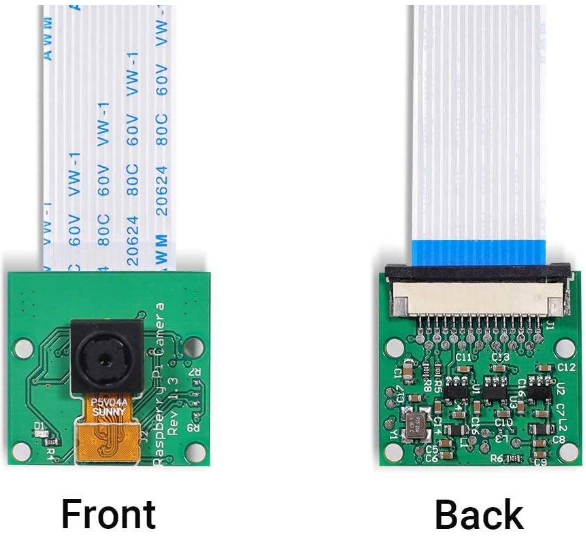


Figure 3: Raspberry Pi Camera module without holder

It would be possible to use a standard webcam, but this camera module comes with a plastic holder which makes it easy to set up and attach to a surface in a fixed position and that is ideal for this project.

3.1.3. Peristaltic pump

According to Richards (2017) “a peristaltic pump is a type of positive displacement pump used for pumping fluids, they are also commonly known as roller pumps. The fluid is contained within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A rotor with a number of "rollers", "shoes", "wipers", or "lobes" attached to the external circumference of the rotor compresses the flexible tube. As the rotor turns, the part of the tube under compression is pinched closed (or "occluded") thus forcing the fluid to be pumped to move through the tube”.

A peristaltic pump was chosen because the only part of the pump in contact with the fluid being pumped is the interior of the tube and this is ideal for dealing with substances such as nutrients solutions. As well as because of its “lack of valves, seals and glands which makes them comparatively easy to maintain” (Sprayer Supplies, 2018).
A peristaltic pump is needed in this project in order to move liquids - i.e nutrients solution - from container A (nutrients solution) to container B (six liters water container). According to the concept, plants will be located over a container that keeps roots in contact with a solution of nutrients and water, allowing the plant to use these nutrients to develop. The pump will be used to add the nutrients from a reservoir to the main water container and can be remotely operated by the user via the web application.

Figure 4: Peristaltic pump

Its flow rate is 80ml per minute and it drives by 12V DC motor. The recommended amount of nutrients is 10ml per litre (according to the manufacturer). Since there are 6 liters of water in the main container, 60ml of nutrients solution are required for a successful harvest. To achieve this, the pump will have to be operating for 45 seconds to provide 60ml of nutrients solution.

3.1.4. LED lights

The chosen lighting for this project is a 5 meters LED strip light. The LED type is SMD 5050 (surface-mount device) and the LED colours are red and blue (Red:Blue = 4:1) with a wavelength of:

- Red: 660nm. “These wavelengths encourage stem growth, flowering and fruit production, and chlorophyll production”.
- Blue: 445nm. “These wavelengths encourage vegetative growth through strong root growth and intense photosynthesis” (Watkins, 2018).

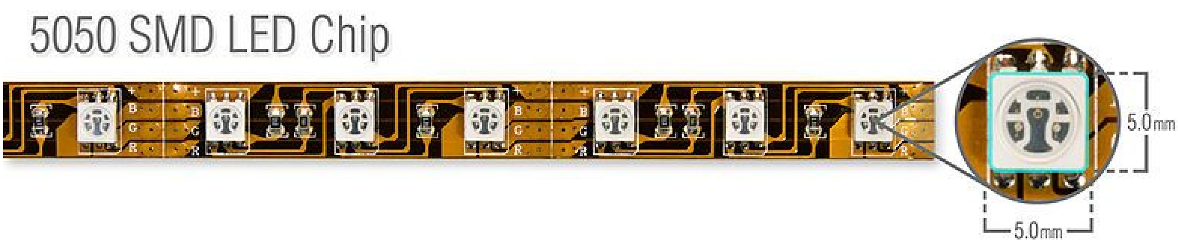


Figure 5: 5050 SMD LED strip fragment and chip.

“Photosynthetically active radiation (PAR) is light of wavelengths 400-700 nm and is the portion of the light spectrum utilised by plants for photosynthesis” (Carruthers *et al.*, 2001).

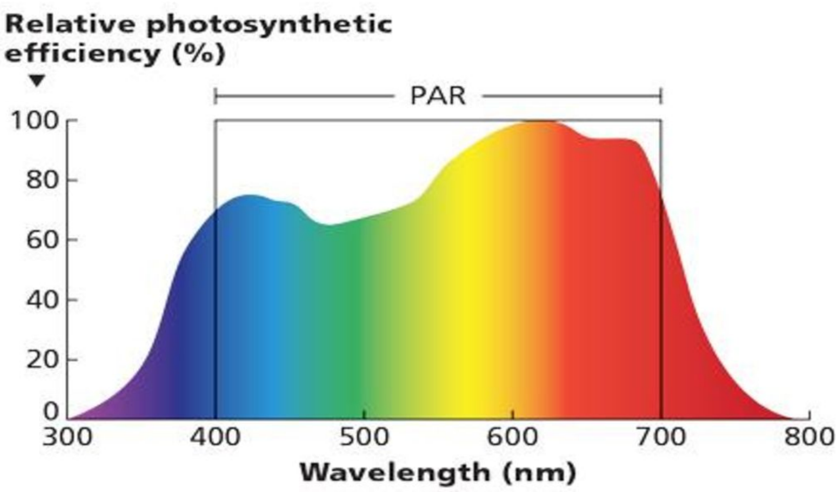


Figure 6: Photosynthetically active radiation (Hamuda et al., 2018).

Research at the Michigan State University (MSU, 2015) explains that “it is known from the study of photomorphogenesis that green, red, far-red and blue light spectra have an effect on root formation, plant growth, and flowering, but there are not enough scientific studies or field-tested trials using LED grow lights to recommend specific color ratios for optimal plant growth under LED grow lights”. “It has been shown that many plants can grow normally if given both red and blue light” (Yorio *et al.*, 2001).

3.1.5. Fan

A fan will provide airflow to the growing system, which can adjust the relative humidity values as needed. The fan is made of a 3.3V DC motor and a plastic propeller.

3.1.6. Temperature and Humidity sensor AM2302

In order to gather environmental parameters from the growing space, sensors are needed. Specific temperature and relative humidity values are critical for a healthy plant growth. “The relative humidity of an air–water mixture is defined as the ratio of the partial pressure of water vapor in the mixture to the equilibrium vapor pressure of water over a flat surface of pure water at a given temperature”: (Lide, 2005)

$$\phi = \frac{p_{\mathrm{H_2O}}}{p^*_{\mathrm{H_2O}}}.$$

Figure 7: The formula for Relative Humidity

The DHT22 is a basic, low-cost digital temperature and humidity sensor.
“The AM2302 is a wired version of the DHT22, in a large plastic body. It is a basic, low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits out a digital signal on the data pin (no analog input pins needed)” (Adafruit Industries, 2019). It's fairly simple to use, but requires careful timing to grab data.

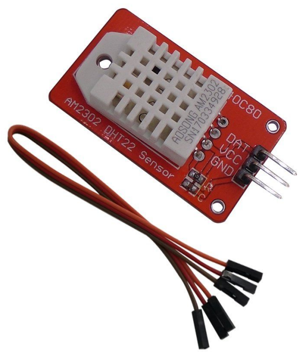


Figure 8: AM2302 sensor and wires

3.1.7. Relays

In order to control a circuit, a switch is needed. A relay is an electrically operated switch. In this project relays will be used to switch on/off the following components:

- Peristaltic pump
- LED lights
- Fan

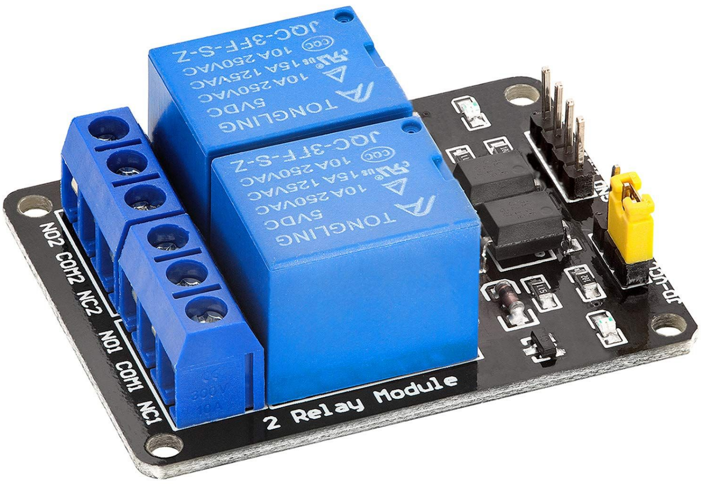


Figure 9: 2-Channel relay module

There will be 3 relays in the system, each one would link the Raspberry Pi with each one of the components mentioned above.

Figure 10: Raspberry Pi and Peristaltic Pump are located on top of the grow box

Figure 11: Grow box with LEDs off (left) and on (right), and Curly cress (Lepidium sativum) ready to harvest (8 days from sowing to cropping).

3.2. Front-end

A user interface that allows the end user to monitor the system and interact with its components is crucial for this project. Simplicity and cross-platform support are key aspects of this concept. The core requirements are:

- Display historical data from sensors graphically
- Allow the user to interact with the hardware

Initially, Sign Up & Log In operations were suggested as requirements but this decision was ruled out after discussion and mutual agreement with the project supervisor. The reason for this was to focus on more challenging requirements, since Sign Up & Log In operations are widely researched and do not require new skills due to developing these repeatedly for different course modules during previous years.

3.2.1. Bootstrap

After reflecting on the survey results (see section 3.4), allowing the user to access the web application using a mobile device is a must. The tool chosen to achieve this is Bootstrap. “Bootstrap is a free and open-source CSS framework directed at responsive, mobile-first front-end web development. It contains CSS- and (optionally) JavaScript-based design templates for typography, forms, buttons, navigation, and other interface components” (Bootstrap Team, 2019).
Bootstrap uses a grid system, which will be really helpful when it comes to positioning of the different elements in the dashboard in the user interface, as per the requirements of the project.. Bootstrap’s grid system uses a series of containers, rows, and columns to layout and align content.

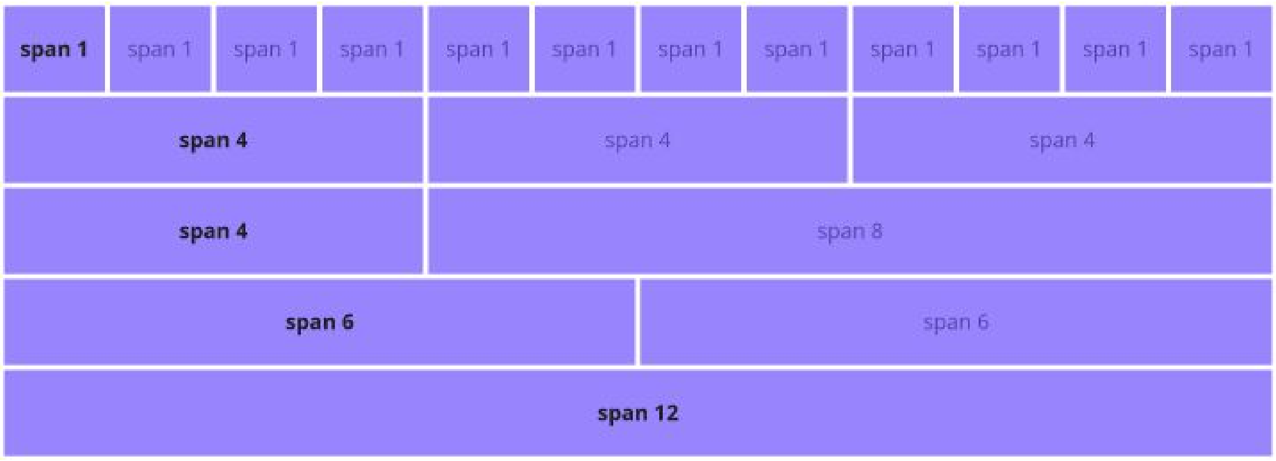


Figure 12: Bootstrap grid system

3.2.2. Dygraphs

The environmental parameters gathered by sensors, and then converted in mathematical values need to be formatted to create a graphical representation. There are many tools available to do this. Since the data will be stored in a local CSV file, the chosen tool must be compatible with CSV. Some sort of interaction is also needed to support the end user to better read and understand the data (dygraphs, 2019).
According to its documentation, “dygraphs is a fast, flexible open source JavaScript charting library. It allows users to explore and interpret dense data sets”, for example stored in CSV. According to a StackOverflow search of the tag ‘dygraph’, it has an active community.
In the dashboard, there will be two graphs -temperature and relative humidity- and the user can use the mouse cursor to zoom in and rescale the graph, which really helps to analyse the data in a specific time frame. Hovering the mouse cursor over a specific position in the graph shows the user the exact value at that specific time.

3.2.3. Jinja2

“Jinja2 is a web template engine for the Python programming language and allows customization of tags, filters, tests, and globals” (Pallets, 2007).
Jinja is Flask's default template engine and will be used in this project because Flask will be the chosen application's web framework.

The following line of code is an example of jinja templating included in the file *base.html*:

{% block title %}Smart Hydroponic System{% endblock %}

It sets the page title.

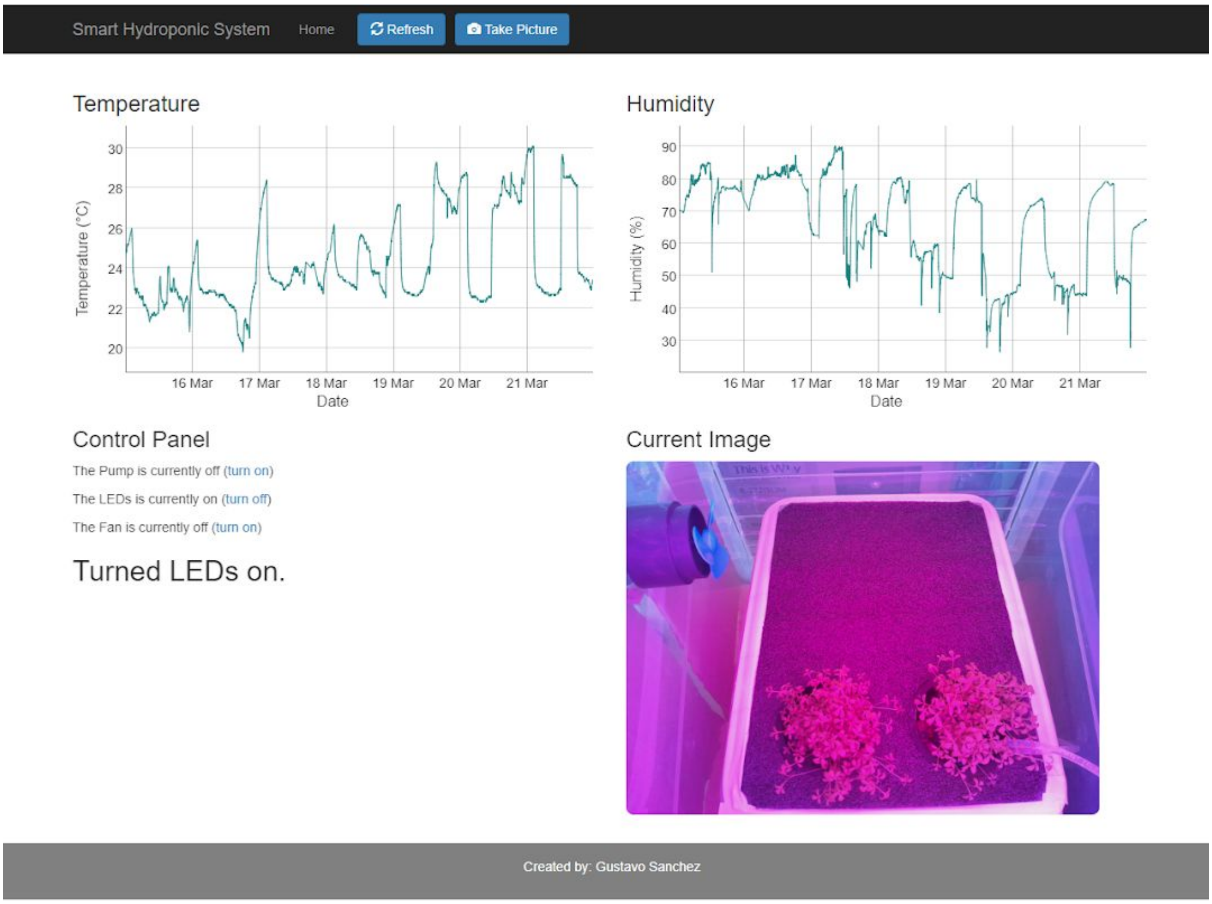


Figure 13: The desktop view

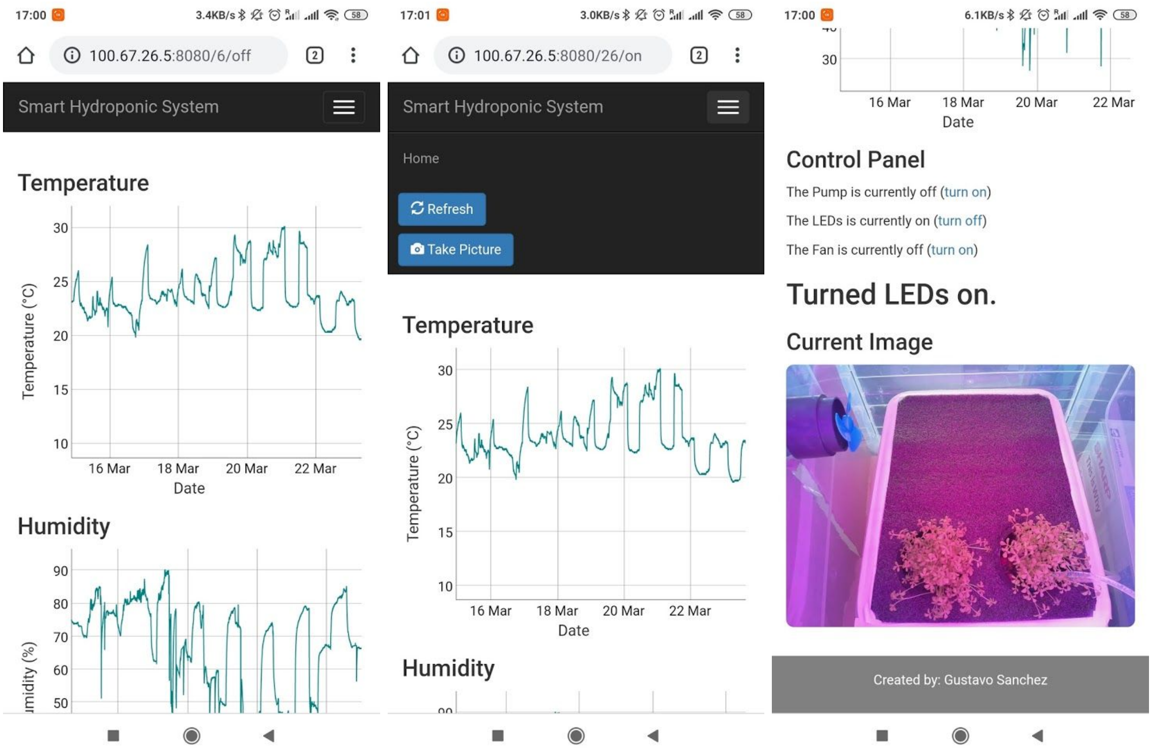


Figure 14: The mobile view (responsive)

3.3. Back-end

“The web application for this project follows a Client-server model, which is a distributed application structure that partitions tasks or workloads between the providers of a resource or service, called servers, and service requesters, called clients” (Christensson, 2016), i.e. desktop computers, laptops, tablets and smartphones.

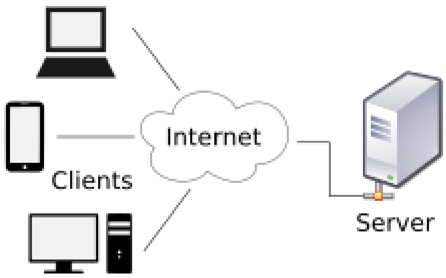


Figure 15: A computer network diagram of clients communicating with a server (Vignoni, 2011)

3.3.1. Flask

Flask is a micro web framework written in Python. Flask was created by Armin Ronacher (he also developed Jinja2) of Pocoo, an international group of Python enthusiasts formed in 2004 (Ronacher, 2011). This was the chosen web framework for this project since it has extensive documentation, there are specific extensions available to enhance desired features and there is integrated support for unit testing.

3.3.2. Python

Python is an interpreted, high-level, general-purpose programming language.
Most of the code in this project is written in Python.
A variety of python libraries will be installed using pip as later explained in section 5.1.3.

3.3.3. Virtualenv

Virtualenv is a tool to create isolated Python environments. The basic problem being addressed is one of dependencies and versions, and indirect permissions since it is easy to end up in a situation where two packages have conflicting requirements (Python Software Foundation, 2011) as later explained in section 5.5.3.

3.3.4. Cron

Cron plays a major role and it is irreplaceable in this system.
The software utility cron is a time-based job scheduler in Unix-like computer operating systems. The actions of cron are driven by a crontab (cron table) file, a configuration file that specifies shell commands to run periodically on a given schedule.

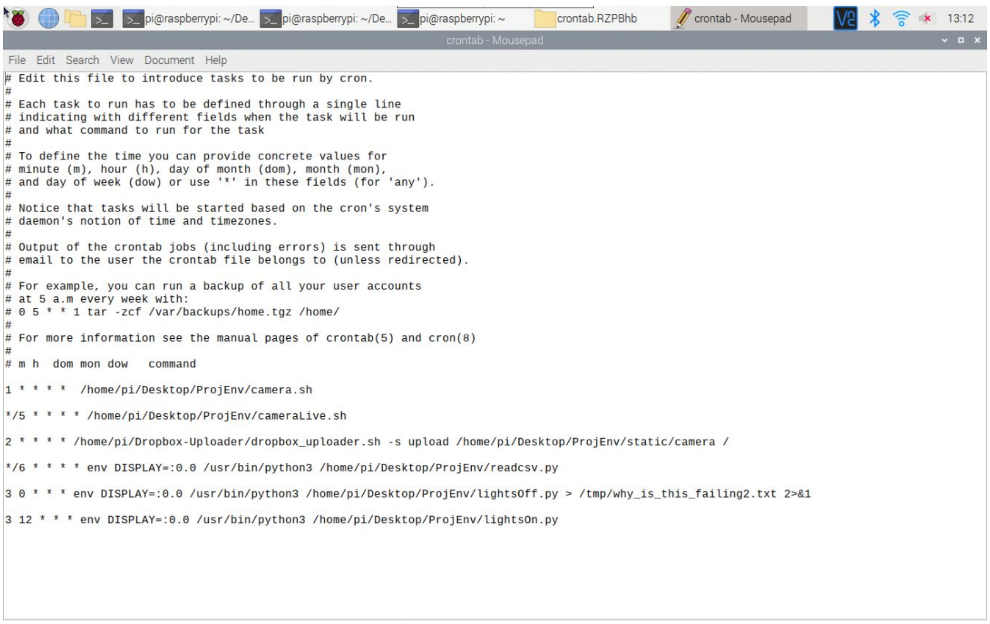
```
# ┌───────────── minute (0 - 59)
# │ ┌───────────── hour (0 - 23)
# │ │ ┌───────────── day of the month (1 - 31)
# │ │ │ ┌───────────── month (1 - 12)
# │ │ │ │ ┌───────────── day of the week (0 - 6) (Sunday to Saturday;
# │ │ │ │ │                                   7 is also Sunday on some systems)
# │ │ │ │ │
# │ │ │ │ │
# * * * * * command to execute
```

```
# m h dom mon dow   command
```

Figure 16: Each line of a crontab file represents a job and follows this structure (Raspberry Pi Foundation, 2019)

Its official documentation explains that “the configuration file for a user can be edited by calling *crontab -e* in a terminal, regardless of where the actual implementation stores this file”. This tool will add automation to the following components and operations:

- Taking pictures with camera
- Turn lighting on/off at a specific time every day
- Fan turning on to lower humidity
- Backup of images to the cloud



```
# Edit this file to introduce tasks to be run by cron.
#
# Each task to run has to be defined through a single line
# indicating with different fields when the task will be run
# and what command to run for the task
#
# To define the time you can provide concrete values for
# minute (m), hour (h), day of month (dom), month (mon),
# and day of week (dow) or use '*' in these fields (for 'any').
#
# Notice that tasks will be started based on the cron's system
# daemon's notion of time and timezones.
#
# Output of the crontab jobs (including errors) is sent through
# email to the user the crontab file belongs to (unless redirected).
#
# For example, you can run a backup of all your user accounts
# at 5 a.m every week with:
# 0 5 * * 1 tar -zcf /var/backups/home.tgz /home/
#
# For more information see the manual pages of crontab(5) and cron(8)
#
# m h  dom mon dow   command

1 * * * *  /home/pi/Desktop/ProjEnv/camera.sh

*/5 * * * * /home/pi/Desktop/ProjEnv/cameraLive.sh

2 * * * * /home/pi/Dropbox-Uploader/dropbox_uploader.sh -s upload /home/pi/Desktop/ProjEnv/static/camera /

*/6 * * * * env DISPLAY=:0.0 /usr/bin/python3 /home/pi/Desktop/ProjEnv/readcsv.py

3 0 * * * env DISPLAY=:0.0 /usr/bin/python3 /home/pi/Desktop/ProjEnv/lightsOff.py > /tmp/why_is_this_failing2.txt 2>&1

3 12 * * * env DISPLAY=:0.0 /usr/bin/python3 /home/pi/Desktop/ProjEnv/lightsOn.py
```

Figure 17: Crontab file used in the system. Editable via crontab -e in a terminal.

Scheduling two or more tasks at the same time, for example: turning on lights, reading sensor values to activate/deactivate fan and backup images to Dropbox all at midnight was noted to cause conflicts between scripts, therefore the tasks are scheduled to run one by one as seen in Figure x:

Task 1: Take a picture every hour and one minute and store it.
Task 2: Take a picture every five minutes, overwriting the last picture each time.
Task 3: Backup images taken in task 1 to Dropbox every hour and two minutes.
Task 4: Read a CSV file containing the last sensor value and turn on/off fan every 6 minutes.
Task 5: Turn off LED lights at three minutes past midnight every day.
Task 6: Turn on LED lights at three minutes past midday every day.

This way each task is executed individually, i.e. the fan will never be triggered at the same time as taking a picture.

3.3.5. Dropbox Uploader

“Dropbox Uploader is a BASH script which can be used to upload, download, delete, list files from Dropbox, an online file sharing, synchronization and backup service” (Fabrizi, 2016). This will provide a scheduled backup of images to a specific account within the file hosting service Dropbox, using the tool cron. The user can use a Dropbox account to see the 24 pictures that are taken every day (1 per hour) during the whole growing period.

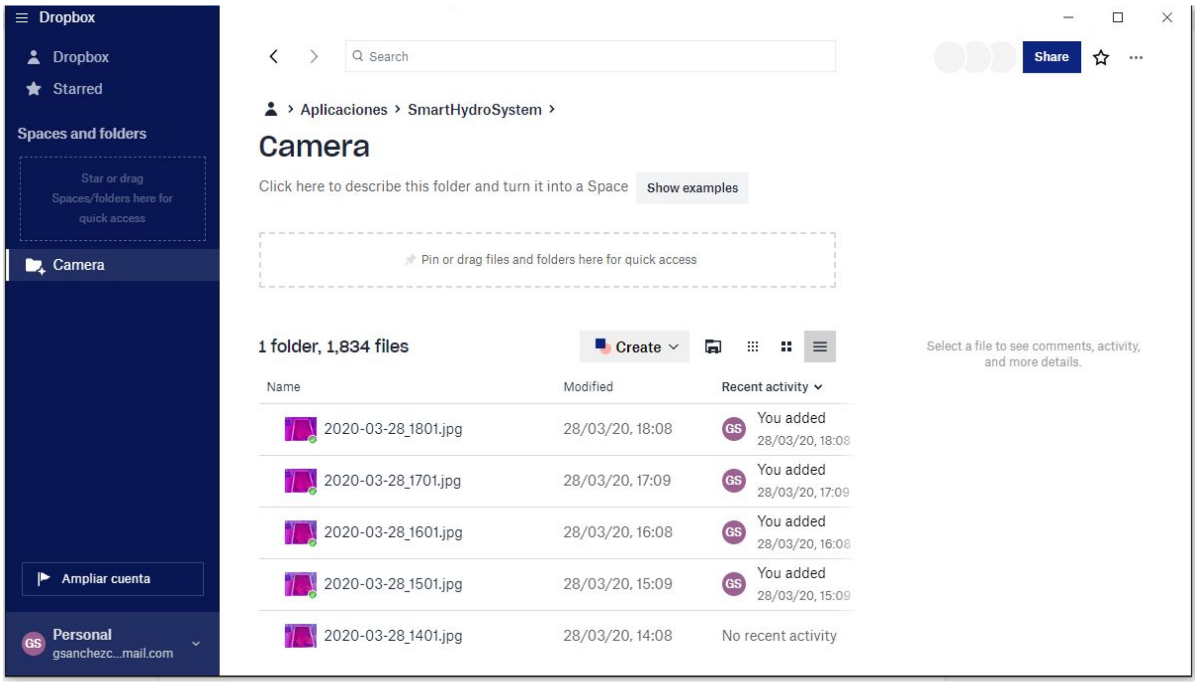


Figure 18: Overview of the backed up images, remotely accessed with a Dropbox personal account credentials via the Dropbox desktop application.

3.4. Survey

In order to identify the users needs, a survey was designed and 25 participants from my social networks volunteered. The survey asked general questions about users preferences, but it did not ask to disclose any personal information. This was delivered online via SurveyMonkey, “its an online survey development cloud-based software as a service company” (Inc. Staff, 2010)

After analysing the results, these are the most relevant insights that were gathered:

- Most people (84%) of those who already grow plants and vegetables at home (80%) would be interested in a Smart Hydroponic Growing System.

- Those who already grow plants at home are interested in: (34%) growing leafy greens (i.e. lettuce, spinach, curled cress, etc.) and (52%) spices (i.e. parsley, basil, etc.), which would adapt perfectly to be grown within a Smart Hydroponic Growing System.

- 100% of the users would prefer to access the monitoring tool on their mobile devices.

According to the insights gathered, the web application should be optimized to be accessed on mobile devices such as smartphones and tablets.

Participants from a wide variety of backgrounds and nationalities undertook the survey, which is ideal to see different points of view. There was a question in the survey that asked the participants to specify what they would be interested in growing and this collected compelling responses. Several participants claimed that it would be interesting if the system could allow them to grow legal cannabis, which is one of the fastest-growing industries in the world (Weed, 2020). Research suggests that the medical and recreational cannabis industry would be a feasible market for this Smart Hydroponic Growing System.
Disclaimer: This project does not encourage production of controlled substances. Participants who suggested growing cannabis were located in countries where this activity is allowed by law. Please abide by local regulations.

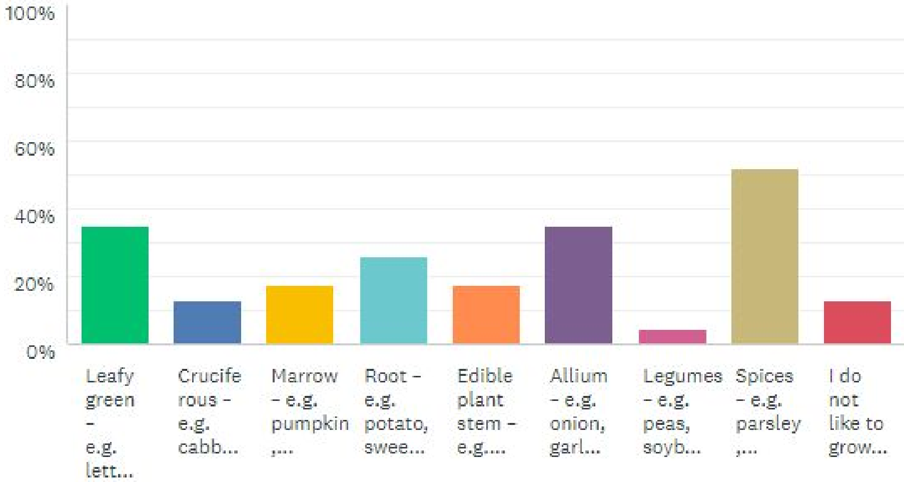


Figure 19: The different vegetables that participants already grow

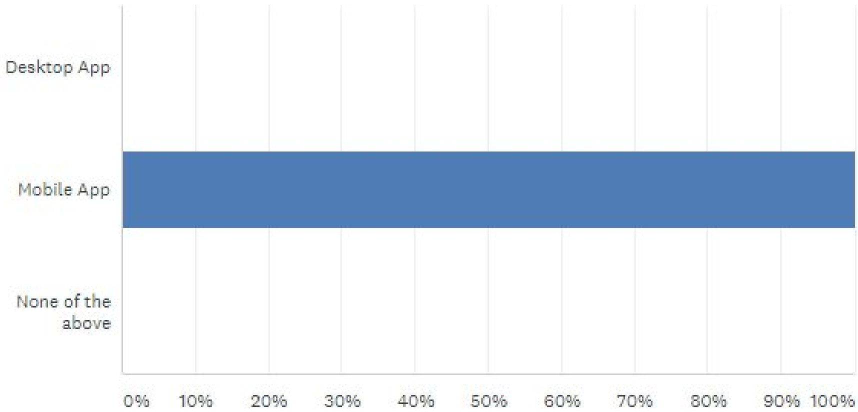


Figure 20: Graph shows 100% of participants prefer Mobile App access

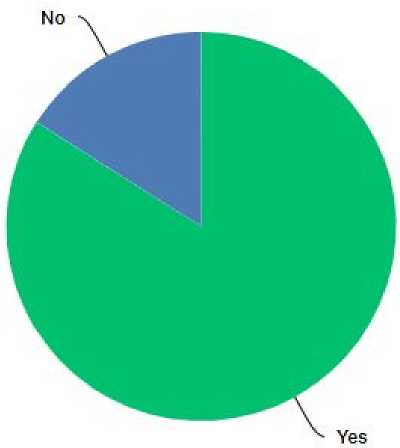


Figure 21: Most participants (84%) of those who already grow plants at home are interested in a Smart Growing System

4. Design

4.1. Specification

4.1.1. Business Model

This system could be purchased by two main groups of users:

- Individuals with an interest in growing plants and vegetables at home for consumption.
- Businesses/Companies looking to produce plants and vegetables for commercial purposes.

Users would purchase the grow box with a one-off payment via an online marketplace or physical shop. Access to the monitoring tool could be subject to a subscription model where users pay a fee to be able to use the service during a period of time i.e. a monthly subscription. Subscriptions could be set to auto-renew what would automatically renew a subscription without the user having to request it every now and then. A referral offer would waive a percentage of the subscription cost if one user refers a new user.

4.1.2. User Interactions

Personas

Persona 1	
Name	Mike Stevens
Job Title	Pediatric psychologist
Demographics	• 40 years old • Married and two children • Lives in a flat in Glasgow • Vegetarian • Medical Degree from UoM
Biography	Mike is a middle-aged man who has many years of experience under his belt as a pediatric psychologist. Mike has just moved to Glasgow to pursue a new job at the Royal Hospital for children. He previously worked at a small local Doctors in Hyde, where he would commute from his village in the Peak District. He recently decided to move because he got the opportunity to progress in his career by taking a leading role in an E-Health scheme at the Royal Hospital in Glasgow. This required him to take some courses to learn how to interact with specific software and hardware, therefore he is a competent user of technology and understands how most common systems work.
Environment	He is comfortable using a computer and would classify himself as a competent computer and internet user. He has internet access at home and has fiber optic at work. He uses his smartphone continuously and uses a tablet at home on a regular basis.
Quote	“I have a demanding job and miss the rural lifestyle”

Persona 2	
Name	Molly Sanders
Job Title	Hotel owner
Demographics	• 29 years old • Single • Lives in a studio in central London • Enjoys new technologies • BSc International Tourism Management from SHU
Biography	Molly is a woman in her late twenties that inherited a hotel after her parents retired. She is single and lives close by her hotel in Finsbury, London. She spends most of her day at the hotel undertaking tasks like planning maintenance work, events and room bookings, as well as ensuring compliance with health and safety legislation and licensing laws. She is always looking for new ways to improve her business. She recently installed a home automation system to control the curtains located in her Hotel common areas, so that the employees can open or close all the curtains at the same time via a Touch Panel.
Environment	She keeps herself updated on the new technology trends for her business. She is used to dealing with mobile devices and PCs as she is always connected to take care of her business. She invests money in training staff to use technology in her Hotel, which has a powerful Internet connection.
Quote	“I like to optimise my daily tasks using technology”

Scenarios

"Scenarios describe the stories and context behind why a specific user or user group comes to your site. They note the goals and questions to be achieved and define the possibilities of how the user(s) can achieve them on the site. Scenarios are critical both for designing an interface and for usability testing" (U.S. Department of Health & Human Services, 2019).

- Scenario for Persona 1:

Mike Stevens is worried about the amount of sound food that is wasted by supermarkets and the huge amount of useless packaging that comes with every piece of food. Since he is a vegetarian, his diet is based on vegetables, and he is concerned that the ones he purchases in big supermarket chains are not as good as the ones he used to produce and consume when he used to live in the countryside. Mike has the knowledge required to grow vegetables, but he does not have the space nor the time to take care of crops in a traditional way.

Research and analysis:

"[...] packaging of food products presents considerable challenges to the food and drink industry. Significant opportunities exist for modifying both primary and secondary food packaging. However, whilst packaging requirements principally consider health and safety, the demands of the major supermarket chains and consumers have taken little or no account of criteria designed to meet the wide-ranging demands of waste minimisation." (Hyde *et al.*, 2001)

Mike could use the Smart Hydroponic Plant Growing System to harvest fresh produce which would allow him to avoid some supermarket products that contribute to avoidable food loss and plastic waste production. His busy lifestyle would not be affected since this system does not require him to invest any substantial amount of time in order to maintain it thanks to a high level of automation and remote monitoring.

- Scenario for Persona 2:

Molly Sanders is looking for a way to provide fresh vegetables such as lettuce for her Hotel customers, but she does not want to purchase them from a third party because she wants to be in full control of the quality of the produce. Due to the nature of her job, she is aware of the latest regulations regarding marketing standards which would allow her to sell homegrown produce in her Hotel restaurant but unfortunately she does not have an appropriate location to place her crops outdoors. She has plenty of unused spaces indoors.

Research and analysis:

"Although you can provide direction in regard to what you need to accomplish, you give up some control when you outsource.

There are many reasons for this, including the fact that you are often hiring a contractor instead of an employee. And since the person is not working on-site, it can be difficult to maintain the level of control you desire.” (Patel, 2017)

Since Molly Sanders is familiar with the REGULATION (EU) No 543/2011 (European Union, 2011) regarding Marketing Standards for lettuces and similar vegetables, Molly could use the Smart Hydroponic Plant Growing System to fulfill her needs, since she could place growing boxes in different indoor locations within the Hotel and personally monitor the quality of the lettuces anytime on her smartphone.

4.1.3. Architectural Model

System context

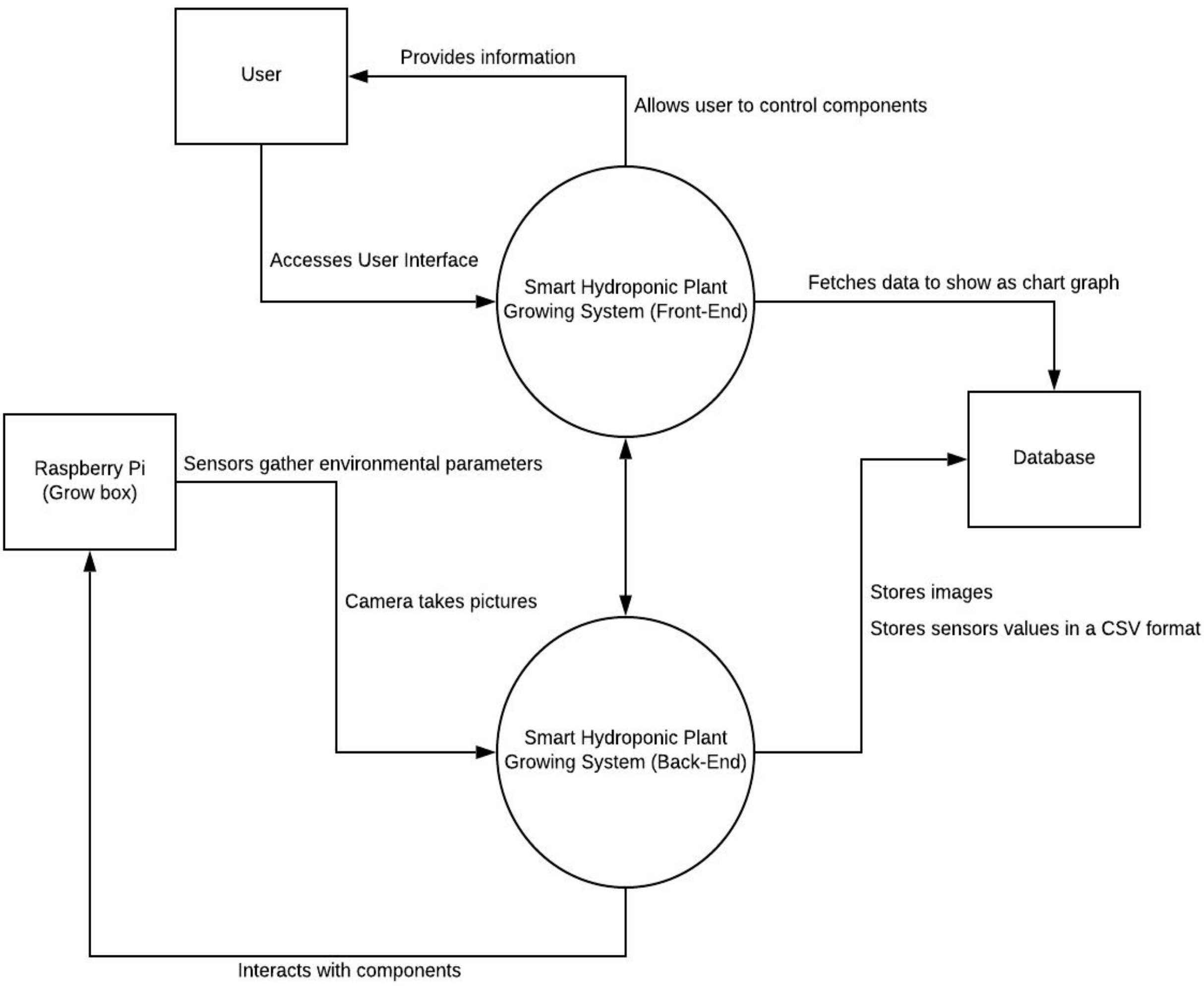


Figure 22: the system boundary and its interaction

Architecture Overview

Users	Delivery Channels	Presentation Layer/UI	Application Services	Resources
Individuals	PC/Laptop	Dashboard	Display of sensors data	CSV Files
Companies	Smart Phone		User control of camera, pump, lights and fan	Image files
	Tablet		Download of images	
	Raspberry Pi			

Prototyping Approach, Security

Figure 23: The major subsystems of the system and how they communicate with each other

5. Development

5.1. Tools and Services

5.1.1. RealVNC

In order to control a Raspberry Pi there are two options:

- Connect peripherals to the Pi itself
- Use remote access software

The first option was not ideal for this project since the Raspberry Pi would have to be continuously connected to a screen monitor, mouse and keyboard. In order to avoid the need to purchase new peripherals, the second option allows the developer to control it with another computer.
RealVNC is a company that provides remote access software. The software consists of a server (VNC Server) and client (VNC Viewer) application. This piece of software is recommended by Niemann-Ross in his LinkedIn course Raspberry Pi Essential Training, accessed via the LinkedIn Learning platform free of charge as a Sheffield Hallam University student.
RealVNC was used throughout the project to control the Raspberry Pi from a fully equipped desktop computer, laptop and mobile phone i.e. without any extra peripherals.
Some of the limitations of using RealVNC are the fact that it depends on an internet connection (not possible to use offline), and the need to restart the Raspberry Pi after a long period of inactivity.
There was also a recurring issue regarding the use of a Dynamic IP Address as later covered in section 5.5.2.

5.1.2. Thonny

"Thonny is an integrated development environment for Python that is designed for beginners. It supports different ways of stepping through the code, step-by-step expression evaluation, detailed visualization of the call stack and a mode for explaining the concepts of references and heap" (Annamaa, 2015). This was the preferred IDE to use because it is bundled with the Raspberry Pi operative System NOOBS.
Thonny comes with Python built in, so no further installs are needed.

5.1.3. pip

pip is the package installer for Python. You can use pip to install packages from the Python Package Index and other indexes. This tool was used to install every package needed in this project by running the following commands:

- *pip install Rpi.GPIO*
- *pip install Flask*
- *pip install Flask_bootstrap*
- *pip install Adafruit_DHT*
- *pip install pytest*
- *pip install apscheduler*

5.2. Project Management

5.2.1. Trello

Trello is a web-based Kanban-style list-making application. On January 26, 2017, PC Magazine gave Trello a 3.5 / 5, calling it “flexible” and saying that “you can get rather creative”, while noting that “it may require some experimentation to figure out how to best use it for your team and the workload you manage”.

Different colours are used to specify the completion stage of each task, and using drag and drop it is possible to prioritise tasks within the pipeline.

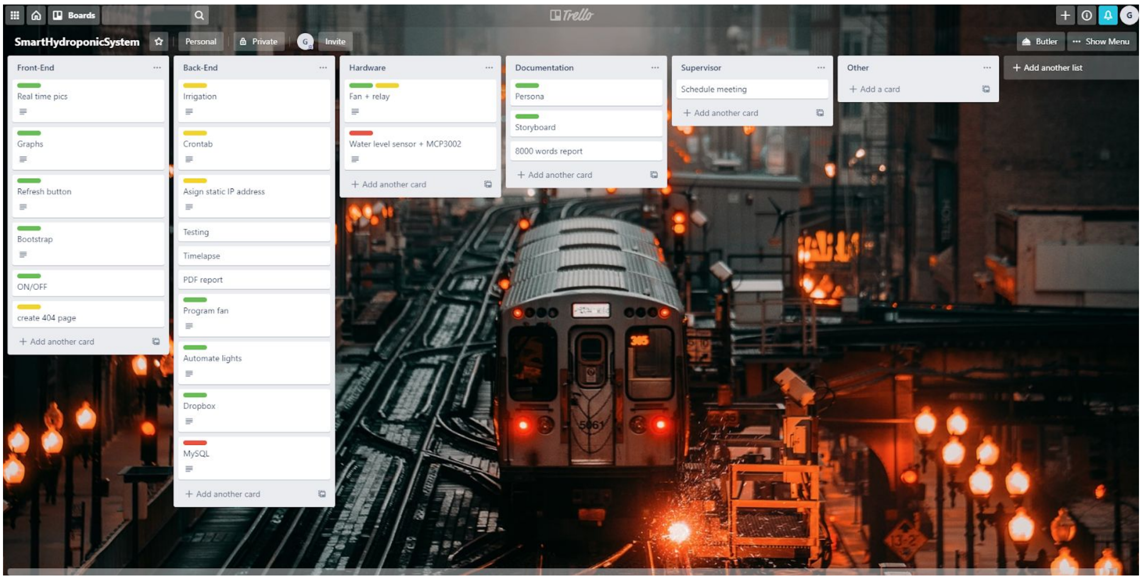


Figure 24: Trello board during the development phase

5.3. Version Control

A Github repository was created at the beginning of the project:

- https://github.com/gus5298/SmartHydroponicSystem

It contains backups of different working versions pushed throughout the prototype developing process and a readme file with instructions to run the system.

5.4. Implementation

```
├── bin
├── lib
├── static
│   ├── camera
│   ├── favicon.ico
│   ├── humidity_temp&humi_latest_value.csv
│   ├── humidity_temp&humi_log_2020.csv
│   ├── temperature_temp&humi_latest_value.csv
│   └── temperature_temp&humi_log_2020.csv
├── templates
│   ├── base.html
│   └── index.html
├── app.py
├── camera.sh
├── cameraLive.sh
├── lightsOff.py
├── lightsOn.py
├── readcsv.py
├── takePic.php
├── temperature-and-humidity-to-csv-logger.py
└── test_app.py
```

Figure 25: Files in project root directory ProjEnv/

5.4.1. Graphical User Interface

A GUI “enables a person to communicate with a computer through the use of symbols, visual metaphors, and pointing devices” (Levy, 2018).
There are two main files which structure the GUI: *base.html* and *index.html*.

- *base.html* builds up the navigation bar and static elements.
- *index.html* builds up the dashboard and dynamic elements.

These files are located inside the folder *templates/* as seen in figure 25.
These HTML files are called by app.py (when the *flask* server is running, as described in the next section) when a user accesses the page URLs.

5.4.2. Running server

The main file of the system is app.py. This file will be run in the terminal to initialise the flask server. This sets up the application routes and templates. The file app.py also includes the headers that allow the content to get updated on refresh using cache control.
The code for GPIO control i.e. interacting with relays (digital switches) which trigger the fan, lights and pump, is also included in this file as later explained in 5.4.2.

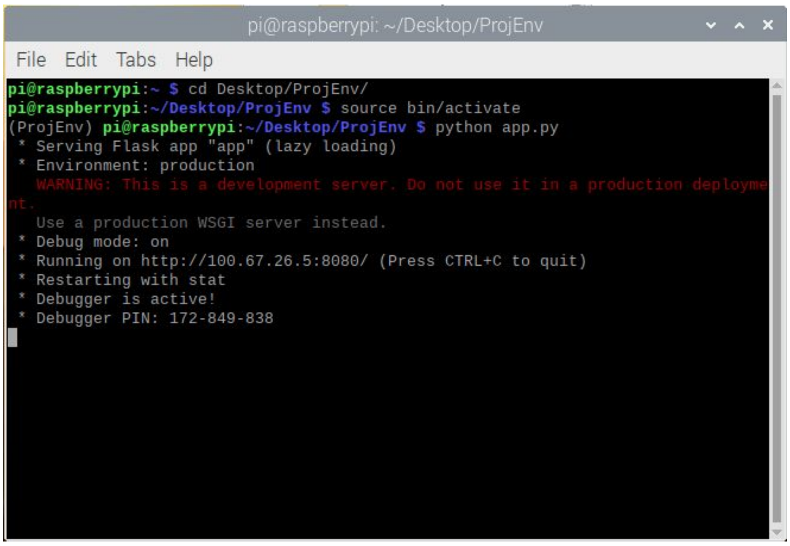


Figure 26: app.py running in the terminal

5.4.3. Implementing GPIO control

The book "Getting Started With Raspberry Pi, 3rd Edition" by Wallace & Richardson (2016) describes how to set up a web server with Python and Flask to turn a lamp on and off as a case study.
The initial requirement after wiring the Raspberry Pi and components is to install the *Rpi.GPIO module:*

- *pip install Rpi.GPIO*

In file app.py, a dictionary of pins is created to store the pin number, name and pin state i.e. on or off.
Then, dynamic routes are added with a pin number and the action as variables.
A function is executed when someone requests a URL with the pin number and action in it, for example */6/on*, when the user requests to turn the fan on. This function reads the URL and updates the dictionary accordingly to update the info on the dashboard and perform the action GPIO.HIGH ⇒ relay switch-on ⇒ fan on, for example.

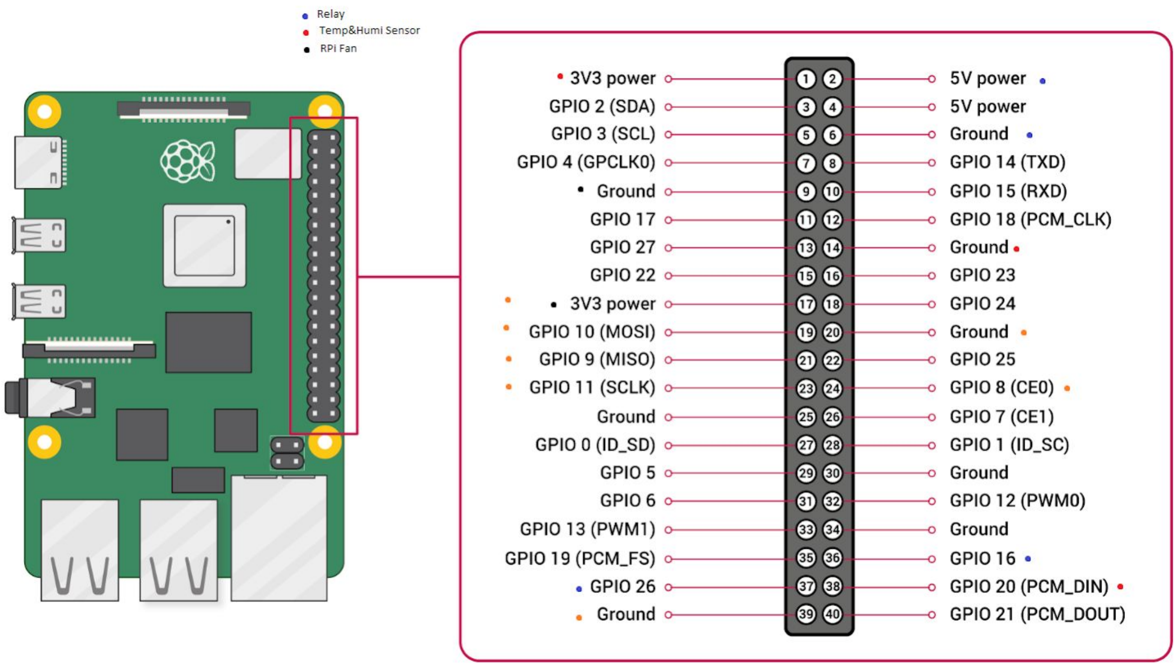


Figure 27: Raspberry Pi ports being used by Relays (blue), Temperature & Humidity Sensor (red) and RPi fan (black)

5.4.4. Using Temperature and Humidity sensors

To communicate with the sensor, the Adafruit_Python_DHT library is used. This can be installed using the following commands in the terminal (anteca GmbH, 2014):

mkdir -p /home/pi/sources
cd /home/pi/sources
git clone https://github.com/adafruit/Adafruit_Python_DHT.git
cd Adafruit_Python_DHT
sudo python setup.py install

At this point it is possible to get the temperature and humidity with the command:

sudo /home/pi/sources/Adafruit_Python_DHT/examples/AdafruitDHT.py 2302 20

The first argument is the sensor type, it is 2302 because we are using an AM2302 sensor (see section 3.1.6), the second argument is the RPi GPIO pin which is connected to the sensor data pin (see figure 27). To allow time-series analysis or visualization of the temperature and humidity, the values must be stored. The script that is used, appends a value every 60 seconds to a CSV file. To achieve this, a dependency must be installed with:

sudo pip apscheduler

Advanced Python Scheduler (APScheduler) is a Python library that lets you schedule your Python code to be executed later, either just once or periodically. It will be needed to schedule the sensors to gather values every 60 seconds. The main difference between this tool and cron (see section 3.3.4) is that it provides start/end times in accordance with the moment it was run and not the device's time and date (Grönholm, 2018). The file containing the code to do this is temperature-and-humidity-to-csv-logger.py.
Now it is possible to start the Temperature and Humidity to CSV Logger with:

python temperature-and-humidity-to-csv-logger.py

This command must also be run within a virtual environment (as later explained in section 5.5.3).

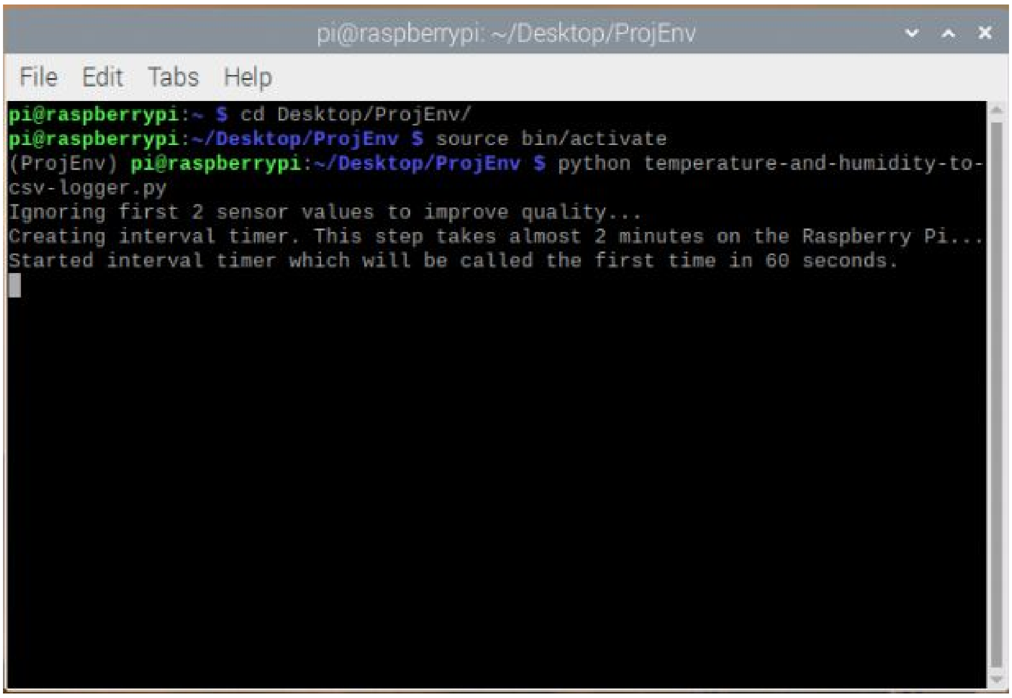


Figure 28: Running temperature-and-humidity-to-csv-logger.py in the terminal

5.4.5. Using PiCamera

Once the camera is wired and the Raspberry Pi interface is configured, "*raspistill* is the command line tool for capturing still photographs" (Raspberry Pi Foundation, 2019).

In this system the following script will be used:

```
#!/bin/bash
DATE=$(date +"%Y-%m-%d_%H%M")
raspistill -o /home/pi/Desktop/ProjEnv/static/camera/$DATE.jpg
```

This script will be placed inside camera.sh and a very similar one is placed in cameraLive.sh. These files are BASH files. Bash is a command processor that typically runs in a text window where the user types commands that cause actions, but in this project Bash files will be run on background in a fixed schedule thanks to cron.

The file *camera.sh* will be run every minute past the hour and stores the images in the location static/camera. The file *cameraLive.sh* will be run every five minutes to overwrite the file pic.jpg in the location *static/camera*, which is the image that we consider to be live since it will always be less than five minutes old. The file *pic.jpg* is also overwritten by a new image when the user clicks the 'Take Picture' button which calls *takePic.php.*

5.4.6. Using Fan

The file which triggers the fan is *readcsv.py.* This file reads the csv file that stores the latest relative humidity value and if this is above 80%, the fan activates.
To activate the fan, the python script opens the */6/on* route on a browser window and closes the browser afterwards. If the relative humidity value is below 80%, the python script opens the */6/off* route on a browser window and closes the browser afterwards. Research shows no evidence of a similar approach or concept like this one, planned and developed from square one to achieve this functionality.

5.4.7. Using Dropbox

As introduced in section 3.3.5, Dropbox Uploader is a BASH script that is scheduled to run via cron every two minutes after the hour to upload a backup of images to the cloud. This is installed using the following *curl* command (there is no need to do this in a virtual environment since this is installed in the Raspberry Pi root environment):

```
curl
"https://raw.githubusercontent.com/andreafabrizi/Dropbox-Uploader/master/dropbox_upload
er.sh" -o dropbox_uploader.sh
```

curl is a command line tool to transfer data to or from a server.
The next step is to give the execution permission to the script and run it:

```
$chmod +x dropbox_uploader.sh
$./dropbox_uploader.sh
```

Then, the first time to run dropbox_uploader, an install wizard prompts in order to configure access to your Dropbox. In this step, Dropbox account credentials have to be inputted. This configuration will be stored in *~/.dropbox_uploader*.

The last step is to run *crontab -e* in the terminal to include the following cron job (see section 3.3.4):

*2 * * * * /home/pi/Dropbox-Uploader/dropbox_uploader.sh -s upload /home/pi/Desktop/ProjEnv/static/camera /*

Now the Dropbox uploader is all set up and the images can be accessed remotely using the Dropbox infrastructure.

5.5. Issues

A number of problems were encountered during the installation of hardware components as well as during the development of back-end and front-end functionalities.

5.5.1. Water level sensor and MCP3002

An interesting functionality to implement in this project was to use a water level sensor to monitor the amount of water or nutrient solution that is left in the containers.
Research suggests that this is an ambitious thing to do with cheap sensors and a Raspberry Pi, due to most inexpensive sensors being analog. And those are normally not very accurate.
Most devices that you connect to the raspberry Pi are either digital or analog.
The first issue was that “unlike Arduinos, the Raspberry Pi doesn’t have an ADC, which stands for Analog to Digital Converter. An ADC measures voltage on a pin and translates it to a number” (Rototron, 2016).
In order to connect an analog water sensor to the Raspberry Pi, a 10-bit resolution SPI analog to digital converter chip with 2 ADC channels is needed.

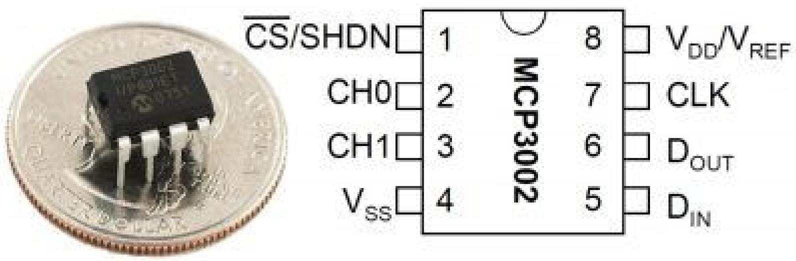


Figure 29: The MCP3002 (Rototron, 2016)

“The MCP3002 is connected using Pi’s hardware SPI GPIO pins. DIN goes to GPIO 10 (MOSI: master out slave in). DOUT goes to GPIO 9 (MISO: master in slave out). CLK goes to GPIO 11 (SCK: serial clock). CS goes to GPIO 8 (chip enable zero often called chip select). VDD pin goes to 3.3 V on the Pi and the VSS goes to a ground pin. The water level sensor’s ‘S’ pin is connected to CH0 (ADC channel 0). The plus and minus pins go to 3.3V and ground respectively” (Rototron, 2016).

After successfully connecting the components in a breadboard, and running a python script provided by Rototon to test the sensor, not only it started heating up and released a burnt plastic smell, but the sensor values were completely inaccurate. After carefully checking that the connections were correct, these components were discarded from the project as they are fire safety hazards.

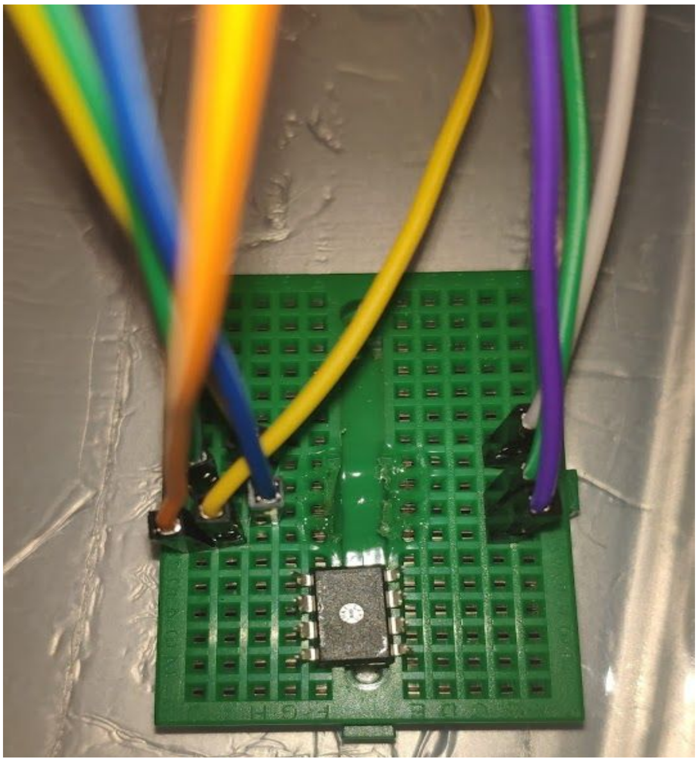


Figure 30: MCP3002 and melted breadboard

5.5.2. Dynamic IP Address

In order to test the web application on a mobile device such as a smartphone, an IP Address must be specified to allow a device connected to the same Wi-Fi network to access it. "There are two main forms of IP address, dynamic and static. By default, a Raspberry Pi will have a dynamic IP address. This means that the IP address can change at any time and is not ideal when running a Raspberry Pi headless, as this would require checking and updating the IP address in your system on a regular basis. A static IP address however will not change, it assigns your Raspberry Pi a permanent address on your network, so you know exactly where it is at all times" (The Pi Hut, 2015).
This was fixed following the following steps:

- Run *sudo nano /etc/network/interfaces* in the terminal . This opens the configuration file for the network settings in the nano text editor.
- The line that reads 'iface eth0 inet dhcp' is telling the ethernet 'eth0' networking interface to use 'dhcp' (dynamic IP). Firstly, replace 'dhcp' with 'static'.
- Add the following lines directly below the line just altered, filling the [ ]'s with the data gathered from the Raspberry Pi information files by running *ifconfig* (network information) and *sudo route -n* (router information).

  address [chosen IP address]
  netmask [netmask]
  network [destination]
  broadcast [broadcast range]
  gateway [gateway]

5.5.3. Virtual environment

At the beginning of the project, many different approaches and packages were tested to identify the best tools for the project. This process requires installing many different versions of modules/libraries (one API might require python version 3 another might need version 2), which caused conflicts

This was fixed by installing and setting up a virtual environment using *virtualenv* (Friedrich, 2017):

- Installing virtualenv using pip: *sudo pip install virtualenv*
- Create your first virtualenv, run: *virtualenv ProjEnv*
- Change into the new directory and run the following:

  pi@raspberrypi ~ $ *cd Desktop/ProjEnv*
  pi@raspberrypi ~/Desktop/ProjEnv $ *source bin/activate*
  (ProjEnv) pi@raspberrypi ~/Desktop/ProjEnv $

After doing the steps above, any python libraries will only be installed in that virtual environment and will not affect the rest of the system.

5.5.4. Cache

While developing the graphic user interface, an issue was noted after new data was pushed into the CSV files. The issue was that even though the data would have changed and the page refreshed, the charts would still look unaltered since the first time that the browser was opened. The same was happening with the new images that overwrite old ones.

In order to allow the user to see updated pictures and graphs dynamically on refresh, it is required to disable browser caching.

The way to do this in a Python-Flask stack is to disable browser caching with meta HTML tags, being “the correct minimum set of headers that works across the most important browsers the following” (Sulea, 2014):

Cache-Control: no-cache, no-store, must-revalidate
Pragma: no-cache
Expires: 0

Where “Cache-Control is for HTTP 1.1, Pragma is for HTTP 1.0 and Expires is for proxies” (The Internet Society, 1999a).

This is achieved by including the following lines of code in app.py:

```
resp.headers["Cache-Control"] = "no-cache, no-store, must-revalidate"
resp.headers["Pragma"] = "no-cache"
resp.headers["Expires"] = "0"
```

5.6. Testing

The chosen approach to test the UI is an evaluation in the Lab, since “it can help optimize UI designs, work flows, understanding the voice of the customers, and understanding what customers really do” (Kaushik, 2006).
To test the flask server APIs, pytest will be used due to its convenient install via *pip* (DZone, 2019).

5.6.1. User Interface

The feedback can be found in section 6.2.1 and the evaluation documents are attached in the appendix.

Evaluation in the Lab

Scope:

- Test turn LEDs on/off, turn fan on/of, turn pump on/off and take a picture and find exact temperature value at a specific date and time. Test all of these for both mobile and desktop interface.

Purpose:

- Test if users can perform all of these tasks on both interfaces
- See if users prefer one interface to the other
- Measure how usable each system is
- Find out which parts of each interface the users like or dislike

Schedule & Location:

- Online at times requested by users.

Sessions:

Sessions will take 15 to 30 minutes.
Sessions will begin with an explanation of the project.
Users read information sheets and sign consent forms.
Users are randomly assigned 1 interface to test first.
Users perform all tasks for this interface.
Users complete SUS form.
Users perform all tasks for the second interface.
Users complete SUS form.
Users are interviewed about their experience with the 2 interfaces.

Equipment:

- Camera and remote desktop software to allow the participant to access/observe both deliverables.
- Notes will be taken but recording will not take place.

Participants:

- Recruit 5 participants. Participants to be recruited from social networks. All participants received an information sheet and a consent form.

Scenarios:

- Desktop:

Turn LEDs on and off.
Turn the fan on and off.
Turn the pump on and off.
Take a picture and open it.
Check the exact temperature of the environment at a specific time and date.

- Mobile:

Turn LEDs on and off.
Turn the fan on and off.
Turn the pump on and off.
Take a picture and open it.
Check the exact temperature of the environment at a specific time and date.

Subjective metrics:

- SUS questionnaire (Alathas, 2018)

Objective metrics:

- Time taken.
- Number of errors.

Roles:

- Single person acts as facilitator and takes some notes.

5.6.2. Server

API Testing with pytest

Pytest is a testing framework which allows us to write test codes using python. It is possible to write code to test anything like databases , API, even UI if needed. But pytest is mainly being used in industry to write tests for APIs.
According to Nandyala (2019), some of the advantages of pytest are:

- “Very easy to start with because of its simple and easy syntax.”
- “Can run tests in parallel.”
- “Can run a specific test or a subset of tests”
- “Automatically detect tests”
- “Skip tests”
- “Open source”

An example of a test is:

def test_homepage():
  response = app.test_client().get('/')
  assert response.status_code == 200

This piece of code tests the Web Application’s homepage and sets the test result to pass if there is a 200 status code, which is the standard response for successful HTTP requests (The Internet Society. 1999b).

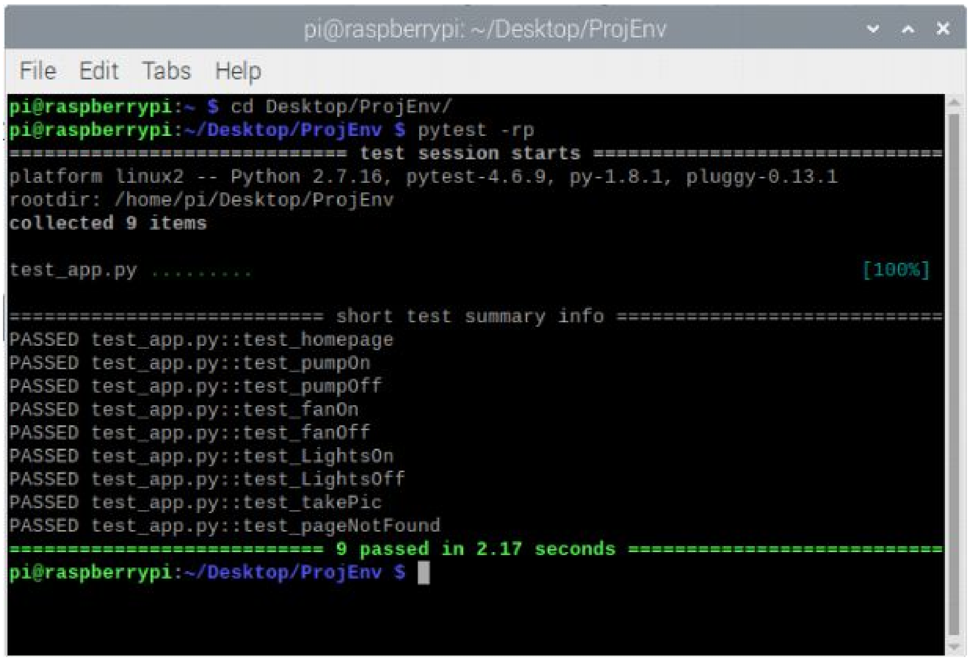


Figure 31: Output after running tests for every APIs

6. Evaluation

6.1. Critical Reflection

The final project deliverables keep the original concept and perform according to the original aims objectives, as has been observed during the evaluation process. Therefore, it can be said confidently that the project was a success.
Not only has it been a technically enriching experience but it also was a quite enjoyable journey, and even though certain aspects of the project required a huge investment of time, money and effort, it was a learning process with a positive outcome.

At the beginning of the project, there were a lot of open questions that needed answers. The investigation was a long process of identifying what functionalities were required in order to be able to grow plants in an environment monitored and controlled by elements of hardware and software. The need to research new hardware components and software technologies in depth was clear, since an Internet of Things based project like this was a completely new concept which was never covered in course modules or personal ventures in the past.

The decision to start the investigation with the creation of a survey was spot on, but there was a lack of relevant information to be fetched from the answers, as the insights would be unrelated to software principles. This was discussed and pointed out by the project supervisor, who suggested including survey questions that would provide quantitative data that could then be used to substantiate decisions rather than subjective information which can be less relevant. For example, instead of asking about the level of school completed, focus on questions like ‘Would you prefer to monitor your system via a Desktop App or Mobile App?’ which then led to an optimization of the mobile view of the Web Application. This issue was identified early on in the investigation process and could still be amended so it did not influence the overall project negatively but it still was a big lesson learned for the future to avoid wasting both the participants and the developer’s time.

When it came to choosing a hardware component to be used in the project, in addition to the reasons stated in section 3.1 (which were the ultimate reasons), there were two big variables: price and shipping time. If price and shipping time were not variables in the equation, it is more than likely that some choices would have been different. An example of this was the ordeal that led to a burnt breadboard because of a MCP3002 malfunction as explained in section 5.5.1. The water sensor was the cheapest solution available, which incur very inaccurate sensor readings and a fire safety hazard, but the only way to know that for sure was via a trial and error process.

Regarding the chosen approach, prototyping performed flawlessly as it allowed refining the design when errors or unsuitable elements were found, while using a waterfall or agile methodology the system would have been limited by a single faulty component or tool, causing a bottleneck. This approach also helped to identify the most difficult aspects of the system -such as automation- during the initial stages of the project, making clear the need to focus more on those.

In terms of the software technologies used i.e. programming languages and tools, priority was given to those which were not covered in course modules or during placement. In some cases, this attitude required facing a steep learning curve, and the level of difficulty and effort to be made was not easy to predict beforehand. For example, the Python-Flask stack required learning it from scratch as it was not practised in any of the modules throughout the Software Engineering course at Sheffield Hallam University or previous personal projects. Python is a general-purpose language but has plenty of peculiarities that others like JavaScript or C++ (previously practised in several modules) do not have at all, such as whitespace indentation. Flask is relatively similar to NodeJS -prior experience with this was gathered during placement and one of the final year modules- but again with big differences such as the use of Jinja templating (see section 3.2.3). Overall, the chosen stack was perfectly adequate as it fulfills the current needs and research suggests that it allows good scalability by adding resources to the system in the future.

At the time of testing, the intention was to test both front-end and back-end functionalities. The graphical user interface can be tricky to evaluate since different users would have different opinions depending on their personal preferences and past experiences. For this evaluation, four participants volunteered, what is indeed a small number. The current legal and social circumstances due to the Covid-19 crisis made this process difficult as participants were supposed to test the deliverables on-site. Eventually, the evaluation took place online and this was not ideal, but the feedback was still quite helpful.

6.2. Security and Ethical Concerns

Since the Web Application is currently running locally and the user does not have the possibility of inputting any kind of data (the system will not gather personal data neither, therefore the GDPR law and its ethical principles are not violated), security was not a priority topic for research and was out of the scope of this project. In spite of this, there are some security concerns that are worth mentioning:

- Camera: The pictures are not only stored locally, they are also accessible on the Internet from anywhere via Dropbox. This could raise some concerns but in that case it is the cloud storage provider who is taking care of the security. The camera only faces the interior of the box i.e. the growing area so the user’s privacy is not at risk.

- Insecure firmware: The Raspberry Pi’s firmware was updated before starting the project so it is fairly protected against the new vulnerabilities discovered, but “it is almost inevitable that new vulnerabilities will come out” (Intellectsoft, 2019).

- Cryptomining With IoT Bots: Since the Raspberry Pi is a powerful device (see section 3.1.1), potential attackers might want to take advantage of this. According to

Intellectsoft (2019) “botnets are automated programs developed as lines of code by their creators and are made to sneak on to a user’s computing device. Botnets use the machine’s processing power, electricity, and the Internet bandwidth, to mine a particular cryptocurrency”. Attackers could try to do this accessing the device via RealVNC (see section 5.1.1) and the most critical infection vector could be default passwords (Wueest, 2019), therefore all of them were changed for secure ones at the beginning of the project.

6.3. Personal and Professional Development

This project has been my first solo experience creating software and deliverables through its whole life cycle, from goal-setting and visioning to seeing how they succeeded in a real life scenario, and reflecting on this.
It was a demanding but exciting experience which I really enjoyed, due to the fact that I have a legitimate interest on the topic. My personal maturity has improved, as I engaged in events and discussions like the local Raspberry Jam and the British Computer Society events and lectures (such as the ‘Securing the Data Generated by IoT Devices’ lecture delivered by Mike Faulks -CTO and Co-Founder at Ioetec Ltd- which turned out to be extremely relevant to my project) held at Sheffield Hallam University, as well as keeping regular contact with my project supervisor who not only was a stakeholder in the whole process but also provided extensive positive feedback, what kept me engaged and performing to my best.

This project also increased my interest in entrepreneurship, since I believe that my idea has some market potential. Therefore, I recently teamed up with two friends who study other disciplines at University of Hertfordshire and Queen Mary University of London to develop a proper business idea, because I have an exclusively technical background. The idea is still in early stages, but we just received £500 of funding to kick start our plan from the ‘Try it Awards’ held by the enterprise team at QMUL. We plan on developing my concept further and creating five prototypes during this Summer 2020, with the aim of delivering them to five key potential users in September, in order to gather feedback from them after using the system medium- to long-term and develop the further steps from that point.

6.4. Future Work

New ideas and work that is beyond the current scope of the project:

6.4.1. Feedback from UI Evaluation

After testing the User Interface (see section 5.6.1 and appendix), the participants pointed out the following interesting future improvements:

- ‘Current picture’ could be refreshed automatically after taking a picture without clicking the ‘refresh’ button.
- Information on how to interact with the chart could be provided.
- After interacting with the control panel on mobile view, the user could be redirected to the specific HTML element that contains the control panel to avoid scrolling down to interact again.
- The current temperature/humidity values could be printed on screen so the user does not need to zoom in the chart to find the current temperature/humidity values.

In spite of that, both mobile and desktop view performed very well, obtaining a score of 93/100 and 91/100 respectively (according to the SUS questionnaires completed by participants).

6.4.2. Register/Log In

As explained in section 3.2, Sign Up & Log In operations were suggested as requirements but this decision was ruled out after discussion and mutual agreement with the project supervisor. This would be very interesting to escalate the system to allow many users. Then users would be also able to monitor several devices from the same account since each growing box would be located using a unique identifier (even using a single Raspberry Pi).

6.4.3. Water Level

After an unsuccessful attempt to design a water level monitoring functionality as explained in section 5.5.1, research was conducted on alternative methods.

6.4.4. Skeuomorphic graphical user interface

“A skeuomorph is a derivative object that retains nonfunctional ornamental design cues (attributes) from structures that were inherent to the original” (Basalla, 1988).

It would be interesting to redesign the control panel located in the dashboard of the web application front-end as a skeuomorph GUI resembling the actual looks of the growing box, where the user would click on a graphical representation of the fan to turn it on/off, click on a representation of the pump on top of the grow box to activate/deactivate it and so on.

6.4.5. Settings page

A settings page would be very useful to deal with operations such as:

- Restart growing cycle (this would delete the old images and sensor values after harvest, leaving empty folders ready to store new data).
- Dark mode: "easier on eyes and battery" (Cummings, 2018).

6.5. Conclusion

The initial project idea has been proved to be feasible and -to some extent- successful. Research suggests that with further development it could be a fully working product that could compete with the solutions currently available on the market.

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8. Appendix

8.1. Survey

Smart Plant Growing System

⊕ PAGE TITLE

The purpose of this research project is to gather user preferences about plant/vegetables growing according to their demographics. This is a research project being conducted by Gustavo Sánchez Collado at Sheffield Hallam University. Your participation in this research study is voluntary. You may choose not to participate. If you decide to participate in this research survey, you may withdraw at any time. If you decide not to participate in this study or if you withdraw from participating at any time, you will not be penalized.

The procedure involves filling an online survey that will take approximately 1 minute. Your responses will be confidential and we do not collect identifying information such as your name, email address or IP address. The survey questions will be about plant/vegetables growing and a Smart Plant Growing System.

We will do our best to keep your information confidential. All data is stored in a password protected electronic format. To help protect your confidentiality, the surveys will not contain information that will personally identify you. The results of this study will be used for scholarly purposes only and may be shared with Sheffield Hallam University representatives.

If you have any questions about the research study, please contact b6025590@my.shu.ac.uk This research has been reviewed according to Sheffield Hallam University ethical procedures for research involving human subjects.

ELECTRONIC CONSENT

Continuing with the survey below indicates that:

• you have read the above information
• you voluntarily agree to participate
• you are at least 18 years of age

If you do not wish to participate in the research study, please close the survey window.

1. Please select you age group

○ 18-24 years old

○ 25-34 years old

○ 35-44 years old

○ 45-54 years old

○ 55-64 years old

○ >65 years old

2. Please select your country of residence

3. What is the highest degree or level of school you have completed?

- ○ No schooling completed
- ○ Nursery school to 8th grade
- ○ Some high school, no diploma
- ○ High school graduate, diploma or the equivalent (for example: GED)
- ○ Some college credit, no degree
- ○ Trade/technical/vocational training
- ○ Associate degree
- ○ Bachelor’s degree
- ○ Master’s degree
- ○ Professional degree
- ○ Doctorate degree

4. Are you currently...?

- ○ Employed for wages
- ○ Self-employed
- ○ Out of work and looking for work
- ○ Out of work but not currently looking for work
- ○ A homemaker
- ○ A student
- ○ Military
- ○ Retired
- ○ Unable to work

5. Do you grow any vegetables or herbs at home?

- ○ Yes
- ○ No
- ○ No but I would like to

5. Do you grow any vegetables or herbs at home?

- ◯ Yes
- ◯ No
- ◯ No but I would like to

6. What kind of vegetables or herbs do you currently grow or would like to grow at home?

- ☐ Leafy green – e.g. lettuce, spinach, silverbeet
- ☐ Cruciferous – e.g. cabbage, cauliflower, Brussels sprouts, broccoli
- ☐ Marrow – e.g. pumpkin, cucumber, zucchini
- ☐ Root – e.g. potato, sweet potato, yam
- ☐ Edible plant stem – e.g. celery, asparagus
- ☐ Allium – e.g. onion, garlic, shallot.
- ☐ Legumes – e.g. peas, soybeans, lentils
- ☐ Spices – e.g. parsley, oregano, basil
- ☐ I do not like to grow vegetables or herbs at home

Other (please specify)

7. Would you be interested in a smart growing system that would help you to monitor and automate your grows indoors?

- ◯ Yes
- ◯ No

8. Would you prefer to monitor your system via a Web App or Mobile App?

- ◯ Web App
- ◯ Mobile App
- ◯ None of the above

8.2. UI Evaluation in the Lab

Consent form:

Consent form for use of project data
Smart Hydroponic Plant Growing
System using IoT

The aim of this stage of the research is to evaluate an Smart Hydroponic Plant Growing System. You have been asked to participate in the research randomly. What will be required of you is to carry out set of tasks using a piece of software that has been developed, this will be observed by Gustavo Sanchez. After the tasks have been completed, there will be a questionnaire and time to share about your experiences that accoutered during the evaluation. This evaluation should take between 15 to 30 minutes but can exceed, this will be a single event. This evaluation will be taking place via online tools. The benefits for being involved in the evaluation will be possible insight into how software processes can be improved and specialized for a Plant Growing System, allowing online software to be more understanding and accessible to use.

If during the evaluation, for any reason, you would wish to stop the evaluation, this is your right. All data that was collected during the evaluation will then be destroyed and will no longer be part of the findings of the research project. If after the evaluation, for any reason, you wish your data not to be used in the research, this is your right. At the end of the evaluation you can ask questions about the evaluation and research or offer any feedback about the research.

The developer is responsible of the data 12 months after the research has been conducted and will be deleted after this time limit. The raw data that is collected will be presented in a report.

In each of these publications and presentations we will illustrate the project findings using descriptions of the activities that took place and quotations. These quotations may be presented anonymously through using pseudonyms (e.g. "Jane Smith, an artist said…", "Bob, a teacher said….").

The University undertakes research as part of its function for the community under its legal status. Data protection allows us to use personal data for research with appropriate safeguards in place under the legal basis of public tasks that are in the public interest. However, all University research is reviewed to ensure that participants are treated appropriately, and their rights respected. Further information at:
https://www.shu.ac.uk/research/ethics-integrity-and-practice

The findings of our research will be shared with researchers at Sheffield Hallam University and the findings may also be published. This may be in the form of academic papers, reports, presentations, and talks.

If you would like to receive a copy of the report by email, if you have any concerns, or if you want to ask more questions about the research please contact:

Gustavo Sanchez,

Phone:

+34 693776592

email: gsanchezcollado@gmail.com

Please answer the questions below and then sign the form.

I agree to participating in this research project: (Please circle)	Yes/No
I agree to text quotations from me being included in publications and presentations anonymously: (please circle)	Yes/No

Name:		**Contact number/email:**	
Signature:		**Date:**	
Researcher signature:		Date:	

Details of who to contact if you have any concerns or if adverse effects occur after the study are given below.

You should contact the Data Protection Officer if: - you have a query about how your data is used by the University - you would like to report a data security breach (e.g. if you think your personal data has been lost or disclosed inappropriately) - you would like to complain about how the University has used your personal data DPO@shu.ac.uk	**You should contact the Head of Research Ethics (Professor Ann Macaskill) if** - you have concerns with how the research was undertaken or how you were treated a.macaskill@shu.ac.uk
Postal address: Sheffield Hallam University, Howard Street, Sheffield S1 1WBT Telephone: 0114 225 5555	

Notes taken during evaluation:

Desktop view:	1. John	2. Jane	3. James	4. Jack
Task 1: Turn LEDs, fan and pump ON and OFF	Time: 26s Errors: None Comments: None	Time: 35s Errors: None Comments: None	Time: 25s Errors: None Comments: None	Time: 40s Errors: None Comments: None
Task 2: Take a picture and open it	Time: 20s Errors: Comments: User suggested that implementing auto refresh after taking a picture would make the process much more slick.	Time: 10s Errors: None Comments: None	Time: 26s Errors: None Comments: None	Time: 15s Errors: None Comments: None
Task 3: Identify temperature value yesterday at 5pm	Time: 32s Errors: None Comments: None	Time: 25s Errors: None Comments: User suggested to show current temperature value on screen.	Time: 40s Errors: 1 (wrong temperature) Comments: User did not think of zooming in the chart to see values properly so he got the wrong value.	Time: 20s Errors:None Comments: Chart interactions difficult to guess.

Mobile view:	1. John	2. Jane	3. James	4. Jack
Task 1: Turn LEDs, fan and pump ON and OFF	Time: 22s Errors: None Comments: None	Time: 40s Errors: None Comments: None	Time: 25s Errors: None Comments: Scroll down when refreshing can be avoided if the refresh script points to the control panel instead of the top of page.	Time: 27s Errors: None Comments: None
Task 2: Take a picture and open it	Time: 25s Errors:None Comments: User suggested getting rid of burger button to minimise user actions.	Time: 20s Errors: None Comments: None	Time: 13s Errors: None Comments: None	Time: 10s Errors: None Comments: None
Task 3: Identify temperature value yesterday at 5pm	Time: 10s Errors: None Comments: None	Time: 15s Errors: None Comments: None	Time: 30s Errors: None Comments: The zoom functionality in mobile view is more straightforward.	Time: 15s Errors: None Comments: None

SUS Questionnaire:

System Usability Scale (SUS)

This is a standard questionnaire that measures the overall usability of a system. Please select the answer that best expresses how you feel about each statement after using the system today.

	Strongly Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Strongly Agree
1. I think I would like to use this tool frequently.					
2. I found the tool unnecessarily complex.					
3. I thought the tool was easy to use.					
4. I think that I would need the support of a technical person to be able to use this system.					
5. I found the various functions in this tool were well integrated.					
6. I thought there was too much inconsistency in this tool.					
7. I would imagine that most people would learn to use this tool very quickly.					
8. I found the tool very cumbersome to use.					
9. I felt very confident using the tool.					
10. I needed to learn a lot of things before I could get going with this tool.					

Results table:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	**SUS Calculation:**															
2	Desktop view															
3	**Participant**	**q1**	**q2**	**q3**	**q4**	**q5**	**q6**	**q7**	**q8**	**q9**	**q10**	**SUS Score**				
4	1	5	1	5	1	4	1	5	1	5	2	**95.0**			Average	91.6
5	2	4	1	2	1	5	1	4	1	5	1	**87.5**				
6	3	2	1	5	2	4	1	5	1	5	1	**87.5**				
7	4	4	1	5	1	5	4	5	1	5	1	**90.0**				
8																
9																
10																
11																
12	**SUS Calculation**															
13	Mobile view															
14	**Participant**	**q1**	**q2**	**q3**	**q4**	**q5**	**q6**	**q7**	**q8**	**q9**	**q10**	**SUS Score**				
15	1	5	2	5	1	4	1	5	1	5	1	**95.0**			Average	93.1
16	2	5	1	2	1	5	1	5	1	5	1	**92.5**				
17	3	3	1	5	2	5	1	5	1	5	1	**92.5**				
18	4	5	1	5	1	5	4	5	1	5	1	**92.5**				
19																

8.3. Project Specification

PROJECT SPECIFICATION - Project (Technical Computing) 2019/20

Student:	**Gustavo Sanchez Collado**
Date:	**24/10/2019**
Supervisor:	**Michael Bass**
Degree Course:	**BEng (Hons) Software Engineering**
Title of Project:	**Smart Plant Growing Hydroponic System using IoT**

Elaboration

Growing plants and vegetables is not only a great hobby, it is also a healthy and sustainable way of obtaining food and medicine. The aim of the project is to build an automated grow box to allow urban users to produce organic, local products from all over the world in an ethical, social and ecological way.

In order to achieve this, the system must provide everything that plants need to grow healthy such as nutrients, air, water, light, temperature and space. The device must include a microcontroller or a small computer to control electronic components like lighting and irrigation system.

The user will have the possibility to monitor the growing process via a web application where historical data will be graphically displayed in a dashboard.

Project Aims

- Investigate what growing method adapts better to a smart growing system.
- Undertake surveys to analyse users' needs
- Investigate what hardware is more advantageous.
- Set up version control software to organise the documentation and source code logically.
- Find a container to place the components balancing compactness and proper growing space.
- Design an irrigation and feeding process.
- Implement light cycles which are adequate for plants.
- Implement a continuous air input and output cycle.
- Record real time images with a camera.
- Create a user friendly web application for remote monitoring
    - Create Sign Up/Log In
    - Link with databases
    - Build a dashboard to graphically display historical data stored in databases.

Project deliverable(s)

Using a prototyping approach I will develop a compact growing box that uses electronic components to create an adequate growing environment which can be placed indoors just like any other domestic appliances . The system will be monitored online via a web application, where the user will be able to log in and see historical data and images of the growing system. Therefore, there must be wired or wireless data transfer i.e. from the sensors which will be formatted into a user friendly dashboard in the web application.

Action plan

Action	Deadline date
Find a Supervisor	**11/10/2019**
Project Specifications and Ethics form	**25/10/2019**
Find/build a container to place the components balancing compactness and proper growing space	25/10/2019
Investigate what growing method adapts better to a smart growing system.	01/11/2019
Investigate what hardware is more advantageous.	01/11/2019
Set up version control software to organise the documentation and source code logically.	01/11/2019
Undertake surveys to analyse users' needs	08/11/2019
Design a smart irrigation and feeding process.	22/11/2019
Implement light cycles which are adequate for plants.	29/11/2019
Implement a continuous air input and output cycle.	6/12/2019
Submit Information Review	**6/12/2019**
Record real time images with a camera.	12/12/2019
Create a user friendly web application for remote monitoring. 1. Create Sign Up/Log In 2. Link with databases 3. Build a dashboard to graphically display data stored in databases.	24/1/2020

Test system	7/2/2020
The provisional Contents page	**21/2/2020**
The draft critical evaluation	**27/3/2020**
Sections of a draft report	**27/3/2020**
Submit the body of the project report to Turnitin	**22/4/2020**
Submit Project Report (physical and electronic) and copies in the deliverable in the report and in BB or the Q drive (for summative - 100%CW)	23/4/2020
Demonstration of the work	Before 12/5/2020

BCS Code of Conduct

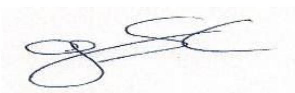
I confirm that I have successfully completed the BCS code of conduct on-line test with a mark of 70% or above. This is a condition of completing the Project (Technical Computing) module.

User	Gustavo Sanchez Collado
Module	PROJECT (TECHNICAL COMPUTING) (LONG1 AF-2019/0)
Test	BCS Code of Conduct & Research Ethics Test
Started	27/09/19 09:57
Submitted	27/09/19 10:15
Status	Completed
Attempt Score	88.75 out of 100 points
Time Elapsed	17 minutes
Results Displayed	Submitted Answers, Correct Answers

Signature: 

Publication of Work

I confirm that I understand the "Guidance on Publication Procedures" as described on the Bb site for the module.

Signature: 

GDPR

I confirm that I will use the "Participant Information Sheet" as a basis for any survey, questionnaire or participant testing materials. This form is available on the Bb site for the module.

Signature:

Ethics

Complete the SHUREC 7 (research ethics checklist for students) form below. If you think that your project may include ethical issues that need resolving (working with vulnerable people, testing procedures etc.) then discuss this with your supervisor as soon as possible and comment further here.

Both you and your supervisor need to sign the completed SHUREC 7 form.

Please contact the project co-ordinator if further advice is needed.

8.4. Ethics Form

RESEARCH ETHICS CHECKLIST FOR STUDENTS (SHUREC 7)

This form is designed to help students and their supervisors to complete an ethical scrutiny of proposed research. The SHU Research Ethics Policy should be consulted before completing the form.

Answering the questions below will help you decide whether your proposed research requires ethical review by a Designated Research Ethics Working Group.

The final responsibility for ensuring that ethical research practices are followed rests with the supervisor for student research.

Note that students and staff are responsible for making suitable arrangements for keeping data secure and, if relevant, for keeping the identity of participants anonymous. They are also responsible for following SHU guidelines about data encryption and research data management.

The form also enables the University and Faculty to keep a record confirming that research conducted has been subjected to ethical scrutiny.

For student projects, the form may be completed by the student and the supervisor and/or module leader (as applicable). In all cases, it should be counter-signed by the supervisor and/or module leader, and kept as a record showing that ethical scrutiny has occurred. Students should retain a copy for inclusion in their research projects, and staff should keep a copy in the student file.

Please note if it may be necessary to conduct a health and safety risk assessment for the proposed research. Further information can be obtained from the Faculty Safety Coordinator.

General Details

Name of student	Gustavo Sanchez Collado
SHU email address	b6025590@my.shu.ac.uk
Course or qualification (student)	BEng (Hons) Software Engineering
Name of supervisor	Michael Bass
email address	MICHAEL BASS <mbass@my.shu.ac.uk>
Title of proposed research	**Smart Plant Growing Hydroponic System using IoT**
Proposed start date	October 2019
Proposed end date	April 2020
Brief outline of research to include, rationale & aims (250-500 words).	Using a prototyping approach I will develop a compact growing box that uses electronic components to create an adequate growing environment which can be placed indoors just like any other domestic appliances . ● Investigate what growing method adapts better to a smart growing system. ● Investigate what hardware is more advantageous.

	• Find a container to place the components balancing compactness and proper growing space. • Set up version control software to organise the documentation and source code logically. • Design an autonomous irrigation and feeding process. • Implement light cycles which are adequate for plants. • Implement a continuous air input and output cycle. • Record and view real time images with a camera. • Create a user friendly web application for remote monitoring • Undertake surveys to analyse users' needs
Where data is collected from individuals, outline the nature of data, details of anonymisation, storage and disposal procedures if required (250-500 words).	Data is collected anonymously from individuals from different backgrounds and age groups. This takes part at the beginning of the development process via an online survey form in order to gather user needs and then apply those insights to the project. The survey will ask individuals to provide their personal opinion and preferences regarding some aspects of the device I am planning to develop. No personal data or any sensitive information will be provided by the respondent. All the data collected will be anonymous and it will be deleted at the end of the project.

1. Health Related Research Involving the NHS or Social Care / Community Care or the Criminal Justice Service or with research participants unable to provide informed consent

Question	**Yes/No**
1. Does the research involve? • Patients recruited because of their past or present use of the NHS or Social Care • Relatives/carers of patients recruited because of their past or present use of the NHS or Social Care • Access to data, organs or other bodily material of past or present NHS patients • Foetal material and IVF involving NHS patients • The recently dead in NHS premises • Prisoners or others within the criminal justice system recruited for health- related research***** • Police, court officials, prisoners or others within the criminal justice system***** • Participants who are unable to provide informed consent due to their incapacity even if the project is not health related	No
2. Is this a research project as opposed to service evaluation or audit? *For NHS definitions please see the following website* http://www.hra.nhs.uk/documents/2013/09/defining-research.pdf	No

If you have answered **YES** to questions **1 & 2** then you **must** seek the appropriate external approvals from the NHS, Social Care or the National Offender Management Service (NOMS) under their independent Research Governance schemes. Further information is provided below.
NHS https://www.myresearchproject.org.uk/Signin.aspx

* All prison projects also need National Offender Management Service (NOMS) Approval and Governor's Approval and may need Ministry of Justice approval. Further guidance at: http://www.hra.nhs.uk/research-community/applying-for-approvals/national-offender-management-service-noms/

NB FRECs provide Independent Scientific Review for NHS or SC research and initial scrutiny for ethics applications as required for university sponsorship of the research. Applicants can use the NHS pro-forma and submit this initially to their FREC.

2. Research with Human Participants

Question	**Yes/No**
Does the research involve human participants? This includes surveys, questionnaires, observing behaviour etc.	Yes
Question	**Yes/No**
1. *Note If YES, then please answer questions 2 to 10* *If NO, please go to Section 3*	
2. Will any of the participants be vulnerable? *Note: Vulnerable people include children and young people, people with learning disabilities, people who may be limited by age or sickness, etc. See definition on website*	No
3. Are drugs, placebos or other substances (e.g. food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	No
4. Will tissue samples (including blood) be obtained from participants?	No
5. Is pain or more than mild discomfort likely to result from the study?	No
6. Will the study involve prolonged or repetitive testing?	No
7. Is there any reasonable and foreseeable risk of physical or emotional harm to any of the participants? *Note: Harm may be caused by distressing or intrusive interview questions, uncomfortable procedures involving the participant, invasion of privacy, topics relating to highly personal information, topics relating to illegal activity, etc.*	No
8. Will anyone be taking part without giving their informed consent?	No
9. Is it covert research? *Note: 'Covert research' refers to research that is conducted without the knowledge of participants.*	No
10. Will the research output allow identification of any individual who has not given their express consent to be identified?	No

If you answered **YES only** to question **1,** the checklist should be saved and any course procedures for submission followed. If you have answered **YES** to any of the other questions you are **required** to submit a SHUREC8A (or 8B) to the FREC. If you answered **YES** to question **8** and participants cannot provide informed consent due to their incapacity you must obtain the appropriate approvals from the NHS research governance system. Your supervisor will advise.

3. Research in Organisations

Question	**Yes/No**
1. Will the research involve working with/within an organisation (e.g. school, business, charity, museum, government department, international agency, etc.)?	No
2. If you answered YES to question 1, do you have granted access to conduct the research? *If YES, students please show evidence to your supervisor. PI should retain safely.*	
3. If you answered NO to question 2, is it because: A. you have not yet asked B. you have asked and not yet received an answer C. you have asked and been refused access. *Note: You will only be able to start the research when you have been granted access.*	

4. Research with Products and Artefacts

Question	**Yes/No**
1. Will the research involve working with copyrighted documents, films, broadcasts, photographs, artworks, designs, products, programmes, databases, networks, processes, existing datasets or secure data?	Yes
2. If you answered YES to question 1, are the materials you intend to use in the public domain? *Notes: 'In the public domain' does not mean the same thing as 'publicly accessible'.* • *Information which is 'in the public domain' is no longer protected by copyright (i.e. copyright has either expired or been waived) and can be used without permission.* • *Information which is 'publicly accessible' (e.g. TV broadcasts, websites, artworks, newspapers) is available for anyone to consult/view. It is still protected by copyright even if there is no copyright notice. In UK law, copyright protection is automatic and does not require a copyright statement, although it is always good practice to provide one. It is necessary to check the terms and conditions of use to find out exactly how the material may be reused etc.* *If you answered YES to question 1, be aware that you may need to consider other ethics codes. For example, when conducting Internet research, consult the code of the Association of Internet Researchers; for educational research, consult the Code of Ethics of the British Educational Research Association.*	Yes

3. If you answered NO to question 2, do you have explicit permission to use these materials as data? *If YES, please show evidence to your supervisor.*	
4. If you answered NO to question 3, is it because: A. you have not yet asked permission B. you have asked and not yet received and answer C. you have asked and been refused access. *Note: You will only be able to start the research when you have been granted permission to use the specified material.*	**A/B/C**

Adherence to SHU policy and procedures

Personal statement	
I can confirm that: – I have read the Sheffield Hallam University Research Ethics Policy and Procedures – I agree to abide by its principles.	
Student	
Name: Gustavo Sanchez Collado	Date: 24/10/2019
Signature: 	
Supervisor or other person giving ethical sign-off	
I can confirm that completion of this form has not identified the need for ethical approval by the FREC or an NHS, Social Care or other external REC. The research will not commence until any approvals required under Sections 3 & 4 have been received.	
Name: Mike Bass	Date: 24/10/2019
Signature: **M. Bass**	