An Indoor Gardening Solution

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1. Introduction

This project was conducted as part of the GCSE Electronics Products course. It is designed to meet the requirements of the Exam Board's Design Task 7 – Environmental Control: *"Design and make a system which can monitor, and possibly control, different environments. It could be checking the temperature of the bath water before the baby is given a bath, monitoring the temperature levels in room, fridge and freezer alarms, controlling light levels or water use, even checking temperature levels when sun bathing – there are many other situations where a system could be devised and used for environmental benefit."* The project was complete within the Design & Technology Department at Merchant Taylors' School, Northwood during the 2016/17 academic year.

2. The Problem to be Solved

Many people live in small flats or houses where there is little room to grow fresh fruit and vegetables. It is well known e.g. [1] that organic, home-grown food is healthier than its mass-market counterparts. There are already some products on the market that allow the user to grow plants indoors and in an artificial environment. However, these are either expensive or difficult to use and require specialist knowledge and frequent maintenance. For the average, time-poor consumer, this is not a viable option. In order to solve the aforementioned problems, this paper sets out the design and making of a product that, once set up, allows the user to cultivate fresh fruit and vegetables with minimal maintenance.

3. Research

3.1 Users

The product would appeal to many groups of people of different ages and cultures because it makes it easy to eat more healthily. This is something that all people, regardless of background and generation, realise is important.

- Students: They are usually very busy, but often try to eat healthily and stay fit. This product would allow them to easily achieve this.
- Adults: This is the main target market for this product because, just like students, many are busy (with careers or family), but they are also more likely than students to purchase a product such as this as they usually have more disposable income.
- Elderly People: They often enjoy the hobby of gardening. However, many live in homes without a garden. This product would mean that they could explore a new way to cultivate plants. Conversely, they would not need a time-saving device, so this product may not be as suitable for this market

Fig.1: The product will appeal to a wide range of people

3.2 Existing Products

The Click and Grow™ Smart Herb Garden is a product currently on the market which is potentially able to solve the problem being addressed in this paper [2]. However, this product features only one automated feature: the lighting, which is on a basic timer. The garden has no way of controlling the plants' environment, meaning that they are at greater risk of dying. It does not even alert the user if the conditions are unsuitable. Finally, this hydroponic garden costs around £45.00 which is quite expensive for a product as simple as this.

Fig. 2 The Click and Grow™ Smart Herb Garden

The current paper aims to rectify these issues as far as possible in order to create a device which is independent of the user. For example, the addition of temperature and humidity sensors which will activate a water pump and fans when certain conditions are detected.

3.3 Technical

In order to explore these aspects of a possible solution a weather station was given a 'tear down' to identify its sensing mechanisms. The main components are shown in Figures 3 and 4 below.

This is a piezo buzzer. It is used as an audible alarm to alert the user to certain parameters and presses on the touchscreen

This crystal is used for timekeeping. It is likely a 32.768 KHz watch crystal, which is common to timekeeping circuits

This second crystal is probably used as the microcontroller's clock to determine its processing speed

Fig.3: Components on one side of the weather station

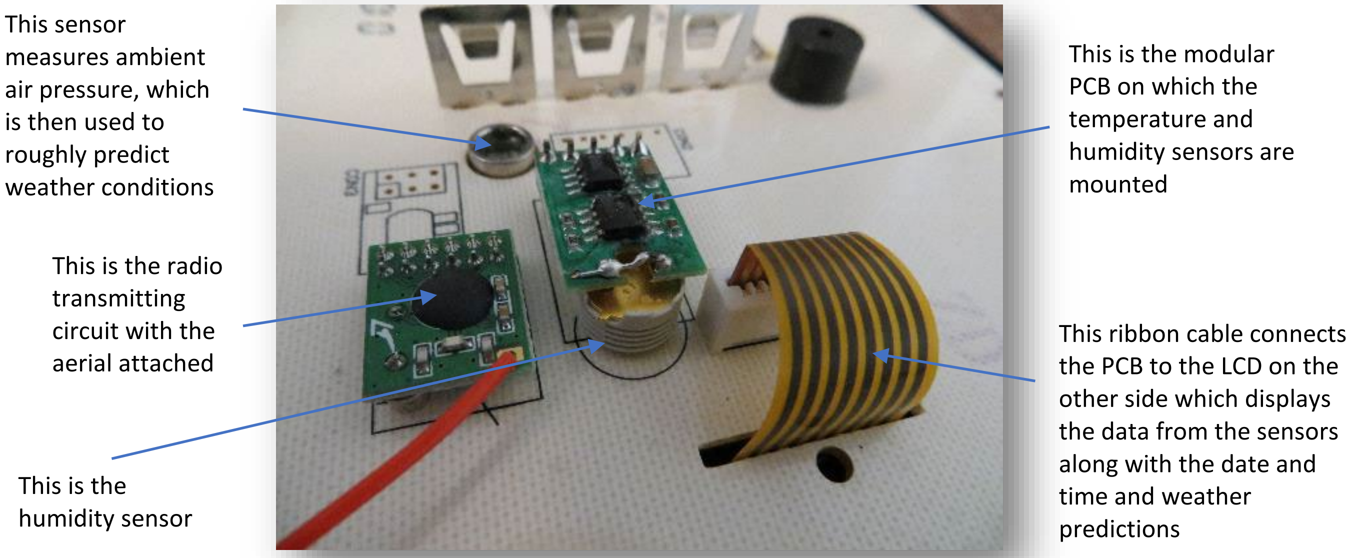


Fig.4: Components on the other side of the weather station

Research has been conducted into the technologies most likely to enable an effective and efficient solution. Research showed:

- Options for sensing temperature: analogue sensors are mostly impractical for use with microcontrollers but digital ones, such as the TMP36, will work well as they give an accurate reading
- Power sources: both primary and secondary cells would be unsuitable for the design and mains power would be far more suitable as it is reliable and would take up minimal space inside the product
- Lighting: LED strip lighting is preferable to fluorescent or filament bulb lighting due to its energy efficiency, long life, controllability and low cost
- Display: A graphical LCD display (specifically the Nokia 5110 LCD) is preferable for this project rather than a character LCD or seven-segment display because it is the correct size and can display all the data that is required
- Casing Materials: The two most appropriate casing materials are:
  - High impact polystyrene (HIPs): This is a tough thermoplastic which can be easily moulded to the desired shape using vacuum forming. While very effective when a simple casing is required, complex shapes are difficult to manufacture.
  - Acrylic: This is a shatterproof thermoplastic that is available in a variety of colours and thicknesses. The most common way to manufacture a casing out of it is to cut out shapes from sheets using a laser cutter and then layer them to form a three-dimensional object. This would be an ideal solution for my project as acrylic can be cut with precision into complex shapes.

The research phase led to the following design parameters:

Design criteria
Be simple to use and maintain
Be able to display on an LCD certain parameters, such as air temperature, humidity and remaining liquid in the reservoir
Be suitable for a range of small plants through a mode selector
Be aesthetically pleasing and able to blend in unobtrusively in the modern home
Be powered by a reliable source of electricity through a mains transformer
Be quiet when running to allow its use in a small area, for example a flat
Have a small physical profile so that it can fit in small spaces
Have an integrated RTC to control the lighting

4. Design and Build

4.1 Primary Prototype

Since the main element of my project is controlling the lighting based on a real time system, my first prototype focused solely on creating that system.

In this prototype, I included the following:

- An Arduino UNO prototyping board
- The DS1307 IC with the required crystal
- Two LEDs which indicated the state of the lighting – Green meant that the lighting would be on, and red the opposite

The code for the lighting (Figure 5) was written on the Arduino IDE and uploaded to the Arduino board via the USB interface.

```
void setup()
{
  Wire.begin();
  rtc.begin();
  rtc.adjust(DateTime(2014, 1, 21, 3, 0, 0));
}

void loop()
{
  DateTime now = rtc.now();
  hourNow = now.hour();
  if(hourNow >= 7 && hourNow <= 21)
  {
    digitalWrite(greenLedPin, HIGH);
    digitalWrite(greenLedPin, LOW);
  }
  else
  {
    digitalWrite(greenLedPin, LOW);
    digitalWrite(greenLedPin, HIGH);
  }
}
```

These lines initialise the libraries which are needed to interface the DS1307 with the Arduino

This line sets the date and time on the DS1307

If the current hour is between 7 am and 9 pm, then:

The pin attached to the green LED is set high

The pin attached to the red LED is set low

If the hour is not between 7 am and 9 pm, then the red led is set high and the green led is set low.

Fig.5: Main Section of Primary Prototype's Code

I also connected an LCD to the Arduino in order to experiment with displaying the current date and time on a screen. This LCD is a standard 16x2 character LCD. It is powered by 5 volts directly from the Arduino and is controlled by 6 data lines (Figure 6).

Like most LCDs, this one uses the Hitachi HD44780 controller and protocol to communicate with the microcontroller. The Arduino IDE has a built-in library that can be used to make interfacing the LCD easy.

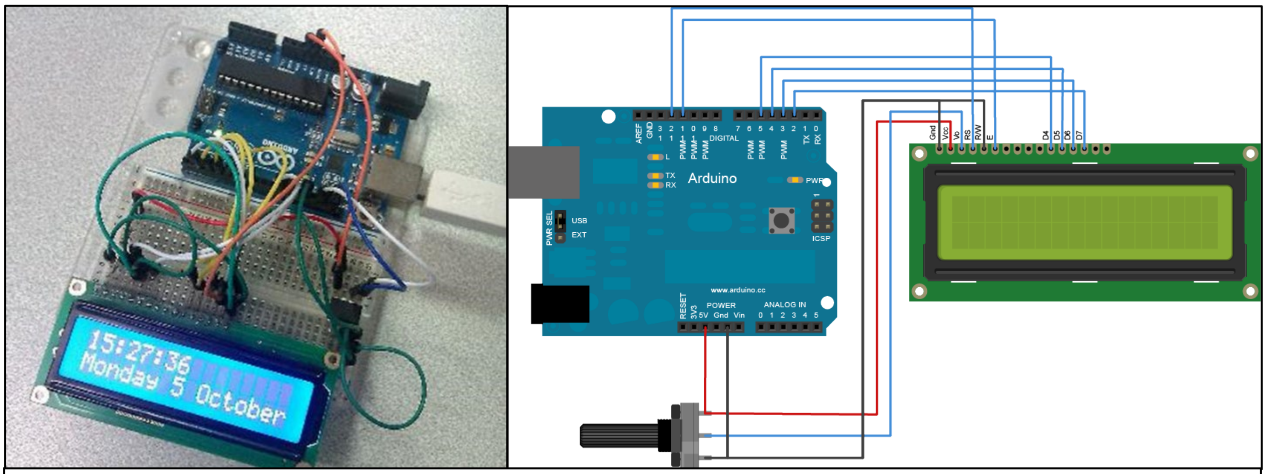


Fig.6: The Primary Prototype with LCD and the Arduino connection diagram

4.2 Secondary Prototype

In order to investigate the key components that I would be using in my circuit, I developed a second prototype on a breadboard (Figure 7). It included the following:

- The ATmega328 IC and adjoining crystal and capacitors
- The DS1307 real time clock
- A TMP36 temperature sensor, an LDR and a humidity sensor
- The Nokia 5110 LCD

This prototype incorporates all the main components, but excludes the fan, pump and LED strips, as these are simple to operate.

This time I did not use the Arduino development board as I wanted to make sure I could use the ATmega328 IC separate from the board, as I would in my project.

The code read the data from the three sensors and displayed it on the LCD, along with the time.

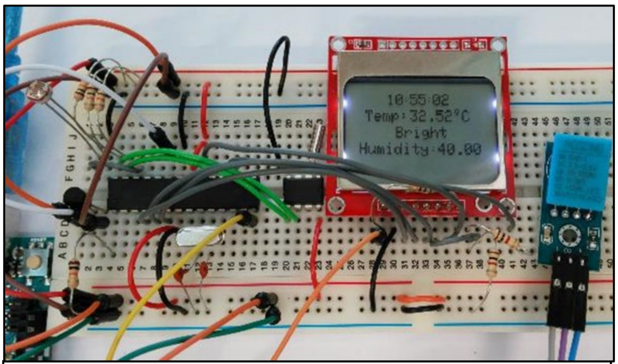
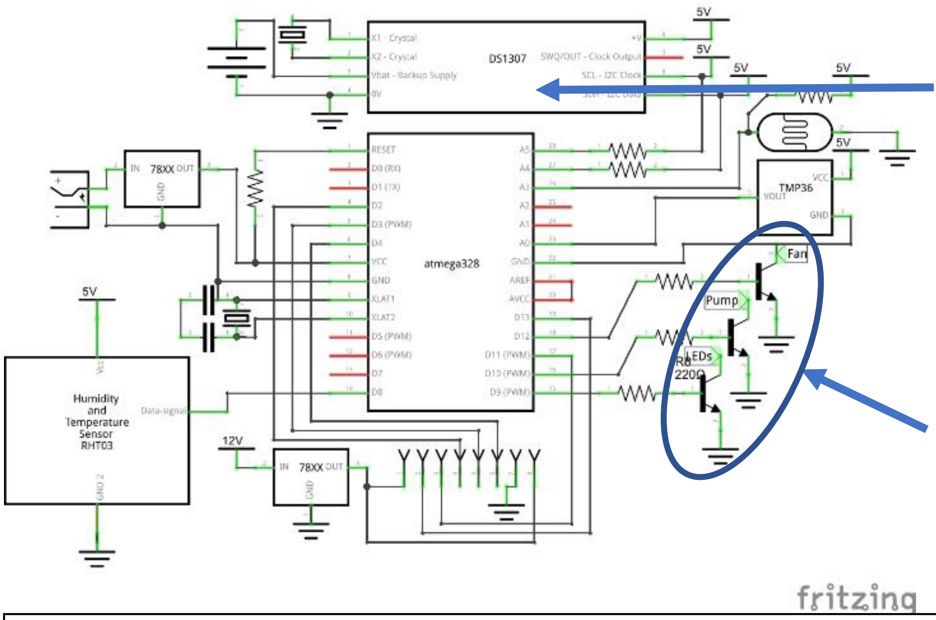


Fig.7: The Secondary Prototype

4.3 The Final Product

To design the the circuit layout, schematic and PCB a programme called Fritzing was used. It is similar to the programme RealPCB, but introduces more advanced features, such as autorouting tracks, and a much larger component library. This was necessary due to the complexity of my circuit.

The final schematic developed with Fritzing is shown in Figure 8. This schematic shows the ATmega328 microcontroller and how it is connected to the various peripherals that it is communicating with or controlling.



This is the DS1307 RTC which is connected via an I^{2}C bus to the microcontroller. It is also connected to a watch crystal and a lithium cell, which allows it to keep the time in backup mode if the main

These are the main outputs to the fan, pump and LED strip lighting. Three digital outputs (two of which support PWM) are connected, via 1k resistors, to the base of each transistor. The loads are connected to the collectors of the transistors, so the transistors are sinking current.

Fig.8: Fritzing schematic of final circuit design

In the final product, the microcontroller and the rest of the components must be mounted securely and compactly in order to reduce the chance of poor connections and easy damage that can occur easily when connecting components on breadboards, as I have done in my prototypes. The most common way of achieving this to use a printed circuit board (PCB). These are sheets of glass-reinforced epoxy laminate with a thin layer of copper on one side. Sections of the copper are removed in order to leave 'tracks' along which current may flow.

The first stage in this process is to design the layout of the PCB. This is called the mask and, during manufacture, is the template that determines the arrangement of the copper tracks.

The final PCB design, produced in Fritzing is shown in Figure 9. The process involves first selecting the footprint for each component from a library. The next step is to route tracks between the components, linking them to each other or to headers which then connect to external components, such as the LCD. As can be seen in Figure 9, the complexity of my circuit necessitated the use of thin tracks in some areas. I also attempted to keep the PCB as compact as was possible as I was aware of the limited space that would be available in the casing.

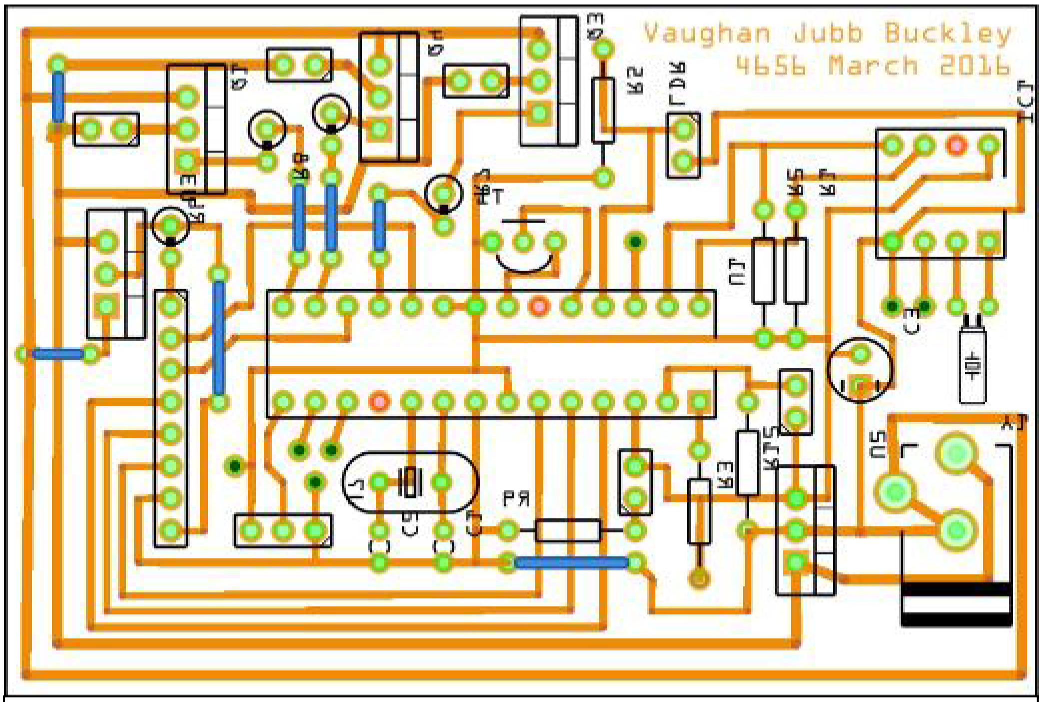


Fig.9: Final Fritzing design for the PCB

Figure 10 shows the steps by which a PCB is manufactured using the photo-etch method:

- This Fritzing 'mask' which is printed onto acetate paper
- The mask is placed, printed side up, in an ultra-violet light box and the exposed photosensitive side of the photo etch board is placed on top of it. The box is closed and left on for around three minutes.
- The board is then removed and submerged in the developer tank. This removes the exposed photoresist and leaves a positive layout of the circuit. Depending on the age of the developer, this could take between twenty seconds and a few minutes. The board is then washed.

- After this, the board is placed in the etch tank and left for about thirty minutes. The etchant is ferric chloride and the optimum temperature in the tank is around forty-five degrees Celsius.

Fig.10: Stages of PCB Manufacture

Once etched, the pads of the PCB must be drilled and the PCB is then populated with components. Figure 11 shows the finished PCB with all the components soldered on it. I used IC sockets for the two ICs as this protects them from being damaged due to the high temperature during soldering. I also needed to be able to remove the ATmega328 to download the code onto it using an Arduino board.

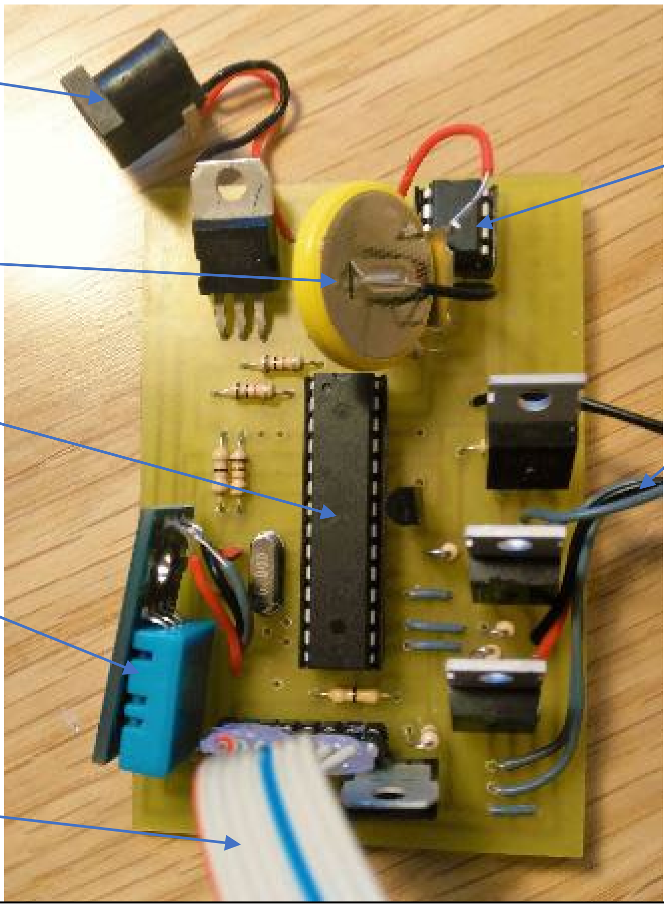


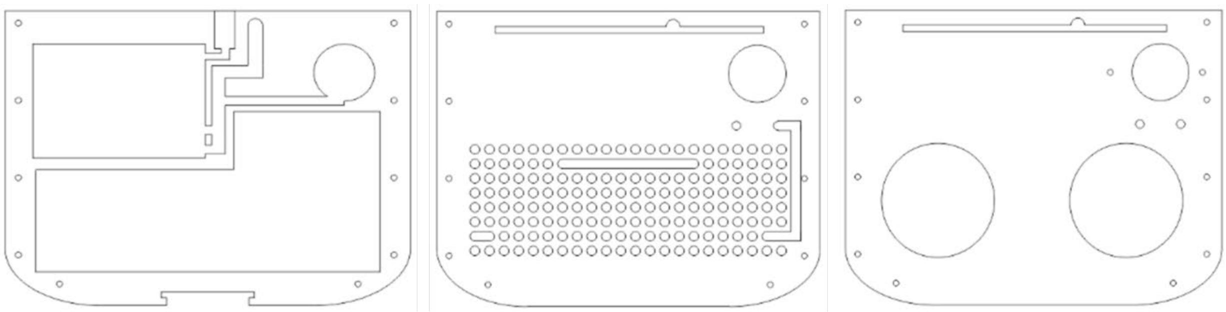
Fig.11: The PCB, drilled with populated

Throughout the manufacture of the PCB, I constantly checked that areas of potential failure were secure in both design and final functionality. I checked my PCB under a digital microscope for problems such as cracks or minor fractures in the board. I commonly used the continuity test and voltage measurement modes to check that current was flowing where it should. To ensure that the larger components such as the pump were not drawing too much current that was outside the recommended limits of the mains transformer and rectifier, I connected a multimeter in series with such components and measured current draw. In the case of the pump, a current of around 2.1 A was being drawn.

The casing is an important part of any product and was critical for mine. As stated in the final design criteria, the product must *"be aesthetically pleasing and able to blend in unobtrusively in the modern home".*

Since I intended to laser cut my casing from acrylic, 12 was necessary to design each layer on CAD software. I used CorelDRAW for my project (Figure 11). I initially cut my designs in card to ensure that the components, such as the PCB, would fit securely inside and to minimise the waste of acrylic , which is very expensive. After my design was finalised, I cut all of the layers on a laser cutter in three millimetre white acrylic sheets. There are eight different layer designs making up twenty layers in total plus one section for the lighting overhang. The layers were held together with ten threaded rods spaced around the edge of the layers.

The reservoir was sealed using common household silicone sealant which is typically used for plumbing. Silicone is ideal as it is easy to apply and has a low toxicity. A thin bead was applied around the inner edges of each layer. The layers were then sandwiched together to form a tight seal, allowing the reservoir to be filled without leakage.



This layer has cut-outs for the PCB and channels for wires going to various external components. The lower section is the reservoir. The shape at the front edge (marked X) is to allow the LCD to slot vertically through the layers.

This is a grille-shaped section is for plants to grow on and to allow roots to grow downwards. The longer channels are for silicone tubing from the peristaltic pump to run along. These spray water over the roots to keep them moist.

This is the top layer. The two large cut-outs are sections for plants to grown in. the circular hole on the top right is where the pump sits vertically. The slot at the very top is where the overhang for the lighting slides in.

Fig.12: Screenshots from CorelDRAW of the designs for some casing layers

The final code was uploaded to the ATmega328. The full code is 225 lines long, so it would not be practical to examine in its entirety here. Figure 13 examines one element of the code.

```
void updateInfo()
{
  DateTime now = rtc.now();
  display.clearDisplay();
  display.setTextSize(1);
  display.setTextColor(BLACK);

  temperature = analogRead(tempPin) * 0.004882814;
  temperature = (temperature - 0.5) * 100;

  humidity = dht.readHumidity();
  display.setCursor(0, 30);
  display.print("Humidity:");
  display.print(humidity);

  lightVal = analogRead(ldrPin);
  lightVal = map(lightVal, 0, 1023, 10, 255);
```

This line requests the current date and time from the DS1307 IC gives the object ‘rtc’ these values

This section reads the input data from the three sensors and maps it so that it is expressed in common units (e.g. temperature in °C)

The light level is read from the LDR and its value is mapped to between 10 and 255 to allow for easy manipulation of the data

Fig.13: Analysis of one section of the final code

The final product is shown in Figure 14.

Fig. 14: The final product being used in a home setting

5. Evaluation of Final Product

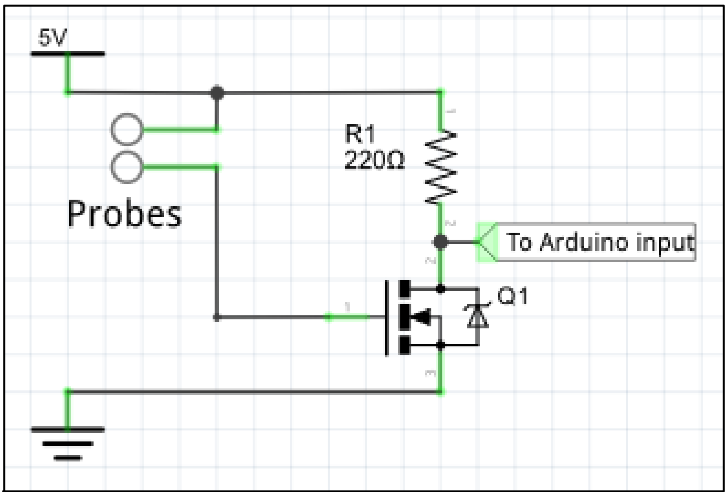
The final product was evaluated against the design criteria identified in section 4. The outcomes are shown in the table below.

Design criteria	How well does the product fulfil the criteria
Be simple to use and maintain	The final product requires minimal user intervention. Once set up, all that is required is occasional refilling of the reservoir.
Be able to display on an LCD certain parameters, such as air temperature, humidity and remaining liquid in the reservoir	The product uses a graphical LCD to display multiple parameters. However, due to the more complicated waterproofing and time constraints, I was unable to add a system for monitoring the water level.
Be suitable for a range of small plants through a mode selector	The product does not have a mode selector, but instead is programmed to be suitable for many different plants.
Be aesthetically pleasing and able to blend in unobtrusively in the modern home	In an interview with a potential consumer, they said that the product “would fit in seamlessly with my other kitchen appliances” and that it is “both stylish and practical”.
Be powered by a reliable source of electricity through a mains transformer	A twelve volt transformer is used to power the device from a mains outlet. There is also a lithium cell acting as a battery

	backup to keep the time when the unit is unplugged. This will last for around 10 years.
Be quiet when running to allow its use in a small area, for example a flat	The device is silent when running except for a few seconds each hour when the pump circulates water. However, even then it is fairly quiet and unlikely to disturb people if in a kitchen.
Have a small physical profile so that it can fit in small spaces	The product has modest dimensions that enable it to be placed in narrow places around a house.
Have an integrated RTC to control the lighting	The product accurately keeps track of the time using a DS1307 real time clock and uses this data to time lighting and other functions.

6. Recommendations for Future Work

This paper presents the design and making of a prototype. A number of improvements have been identifier that should be investigated if this product were to be taken towards commercial production:



A circuit such as this could be used to sense water level in a future modification. The MOSFET is used to maximise sensitivity.

1. Water level indication would be a useful feature in the product. This would allow a user to more accurately time their refilling of the reservoir and would reduce the chance of the reservoir drying up completely. Alternatively, or in addition, a piezo transducer could be integrated to provide an audible warning if the water level was too low.
2. A gap in the casing for the humidity sensor would allow for more accurate readings and a faster response to changes in humidity from the sensor. Currently, the only airflow is through channels in the casing for wires which, while sufficient, is far from optimal.
3. LED lighting with a greater range of wavelengths could replace the current white LEDs. This would allow for more stimulated growth of plants.
4. Time zone adjustment would be a necessity if the product was to be commercialised. A simple PTM would suffice to cycle through time zones. Daylight saving is currently software adjusted, but a separate manual adjustment would be useful.
5. Flyback diodes would provide protection from back-EMF when switching the peristaltic pump motor and fan. Although the product works well without clamping diodes, this precaution would be a wise for commercial production to reduce the chance of a product failing after being purchased.

The product would require significant modification before it could be manufactured commercially. Most notably is the conversion of the current PCB, which uses through-hole technology, to surface mount technology (SMT). SMT, as a process, is far more efficient for the mass production of PCBs. This is because the components used are smaller and are all soldered at the same time, maximising production. Much of the work done in manufacture relies on machines such as pick and place machines, which position components correctly on the PCB before they are passed through a reflow oven to melt solder paste on pads and secure the components to the board.

A second change would be to manufacture the casing using injection moulding, rather than laser cutting acrylic sheets. The latter is a hugely expensive and wasteful method. It is, however, used in schools due to the lack of more sophisticated equipment. Injection moulding is a process by which complex and simple parts alike can be formed by injecting liquid thermo(setting) plastic (or other material) into a mould.

For batch production, there are a few changes that should be made. For example, the masks would be printed in a closely packed fashion on the transparency paper to make optimal use of space. Copper fill would also be used to reduce the use of developer chemicals.

7. Acknowledgments

I would like to thanks Merchant Taylors' School, Northwood for the provision of Design and Technology Facilities and to Mr Hutchings and Ms Park for supervising the work.

8. References

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