INTEGRATED TERM PROJECT

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Group 2
Silvia Bertini
Francesco Cursi
Federico Gregori

INDEX

INTRODUCTION

Green Thumb Box is a prototype for an autonomous indoor watering system of a small potted plant. The device consists of an enclosed wooden box, inside of which sits all the necessary hardware and control equipment.

Conventional autonomous irrigation systems are mostly thought for an outdoor environment, with a connection to the tap and user programmable times.

People living in a big city can rarely count on a private outdoor space and keep most of their plants inside an apartment. Small plants, such as potted flowers and little vases, are very commonly encountered in household and do not require a great amount of water. Commercially available solutions for an indoor use lack of autonomy and also require a tap connection.

For these simple greens, the traditional programmable watering systems are unnecessarily complicated. Their irrigation and care can be easily handled by a microcontroller. The solution could be particularly useful to busy city workers and students, who enjoy a flower decorated environment in their houses or offices without having to spend too much time on it.

Finally, more than one of us personally experienced the drying out of a plant when returning from vacations and it is also for this reason that we developed a prototype that provides an easy and fast solution to the problem.

The product we designed is a box comprehensive of the plant vase, a water reservoir, a pump and drip distributor, together with multiple sensors and buttons for user control. Intelligence is imparted to the device by a microcontroller, Basic Stamp 2, embedded in the box. Batteries guarantee an autonomous power supply, but the device may also be plugged into a wall socket.

A hole in the lid, allows to sit the desired vase (within a 15 x 15 cm dimensions) and insert two moisture sensors so that, once powered up, the microcontroller continuously monitors the moisture level of the soil. Whenever it detects that the soil is too dry, it activates a pump that waters the plant for a limited amount of time, until a feedback signal from the sensors retrieves a sufficient level of moisture.

Water is pumped up from a reservoir, previously filled through a little opening of the lid. Whenever the level in the tank gets too low, the user is advised through a auditory signal and a message displayed on the LCD on the outside of the box.

Also through the LCD, one can always monitor the state of the environment through temperature and light sensors. The product may help novice gardeners to take care of small plants, checking for the more suitable levels of light and temperature for their health.

The entire apparatus is relatively small and can be easily placed around the house. An esthetically appealing add on consists of four LED stripes around the vase, that can be lighten up making the Green Thumb Box a natural and ecological table lamp.

Figure 1- Green Thumb Box

TECHNICAL BACKGROUND

Water content in soil is a fundamental parameter for irrigation management in agriculture as well in many other environmental disciplines. The many and diverse fields of interest for this type of measures lead to the development of just as many techniques to retrieve the moisture level in the soil.

Mostly thought for agricultural purposes, soil humidity control is an important index both for the state of health of the cultures and for a sustainable and efficient use of sources.

Direct gravimetric method to determine the water content in a soil sample uses the difference in weight of the soil prior and after drying. Although reliable and precise, this type of measures requires a fairly long time and does not allow for repetition in the same location.

Indirect techniques are then the most used to get a quick indication of the state of the soil. They measure a varying property of the soil and relate it to its water content. Based on different physics laws, they include measures of water volume, soil dielectric constant, soil electric resistance, potential energy of the water in a solid matrix (matric potential), thermal conductivity and relative humidity of sealed chambers.

The diverse types of soil, as well as the final use of measures, their cost and accuracy determine the more suitable moisture sensor for a specific application.

Ideal time and frequency of watering vary according to the type of plant considered. For a small, indoor flower pot, such distinctions are not so important. Light and heat conditions do not vary significantly as outside and a control over the state of the soil to ensure it is not too dry or too damp, is sufficient to the purpose of an autonomous irrigation.

A continuous feedback from the moisture sensor to the microcontroller is the main feature that marks a significant improvement with respect to the existing autonomous sprinkler systems. They are indeed open loop systems, that water the plants at determined hours and days with the risk to either overwater them or let them dry if the moisture of the soil gets too high or too low.

ELECTRICAL COMPONENTS

An accurate selection of all the components of the prototype was done, after a search for reliable and affordable sensors and actuators that guaranteed a safe use at reasonable prices. Power, durability and voltage requirements were also relevant criteria in the choice.

Basic Stamp 2 Microcontroller

The embedded microcontroller is what imparts intelligence to the box, making it smart. We chose Basic Stamp 2 as a microcontroller, because it matches the criteria of simplicity of use and programming while ensuring a control over the numerous sensors and actuators that we needed.

Its limited computational and memory capabilities with respect to other microcontrollers available in the market, does not affect the quality of the final product, since the Basic Stamp 2 is able to perform all the operations required.

Moisture sensors

A correct reading for the moisture level of the soil was critical for the purpose of the entire device. For the present case, of an autonomous watering system of a small plant, we looked for a reliable, inexpensive sensor, able to retrieve values of the superficial humidity of the soil in real time and with minimum power consumption.

Based on these criteria, the choice fell on a resistive sensor, that determines the value of moisture in the soil from the value of the electric resistance in the vase.

In order to have a differential reading, two sensors were used. Their range of measures provides readings for the soil with which they are in direct contact. For a small flower pot, soil conditions may be considered uniform throughout the vase and we considered the use of two hygrometers to ensure an accurate reading both a digital and analog.

Both sensors operate on the same physical principle, as they retrieve the value of moisture in the soil from a reading of electrical resistance between two electrodes. By letting a small DC voltage across the probes of the sensors, fully submerged in to the soil, they return an signal proportional to the soil resistance, that grows together with its water content. A damper soil allows current to flow more easily, while the conductivity decreases as the soil gets dry.

The resistance is measured simply by using a voltage divider and sending the signal to the analog pin. A digital output pin is also provided for both sensors, that outputs a high or low signal if the moisture gets above or below a certain threshold value, that can be set by a screw on the sensor.

The sensors consist of two separable parts: two probes and a printed circuit board with a LM393 comparator chip and a potentiometer to set the threshold value for the digital output.

The board module (YL-38) is the same for both sensors, while the two probes are of a different kind for the two sensors.

Although fast and very simple to use, this kind of sensors may encounter wear due to the exposure of the electrodes that, if uncoated, can get oxidized soon. Also for this reason, we used two different types of probes, one (FC-28) of covered and one (YL-69) of uncovered nickel. A surface immersion for one of the two sensors ensures a good oxidation resistance and continuity of use for the system.

In order to retrieve comparable outputs, the two sensors were calibrated with same samples of soil. The analog output varies between 0 and 4.2 V but, when the sensors were exposed to the air to calibrate the maximum output value, the digital output returned by BS2 through the AD converter AD0831 was 252 and 252, very close to the digital maximum 255.

For this reason, we did not consider to adjust a span of 4.2 V on the pin 5 of the converter but we left instead the span determined by the power source and the ground pin of 5 V. Setting the span to precisely 4.2 would have uselessly complicated the circuit, bringing no significant improvements in the sensitivity of the sensor. Since we are only interested in the threshold detection, this does not induce any error on the functionality of the device.

Technical specifications are common for both sensors: they are powered with a voltage of 5 V and connected to ground and have panel dimensions of 3 x 1.5 cm with soil probe dimensions : 6 x 2 cm.

On one sensor, both analog and digital outputs are retrieved, while the other, used to sense only as a control, outputs only a digital signal. Threshold values of the digital output were set through the potentiometer to match the watering threshold chosen for the analog signal (for a value of 85).

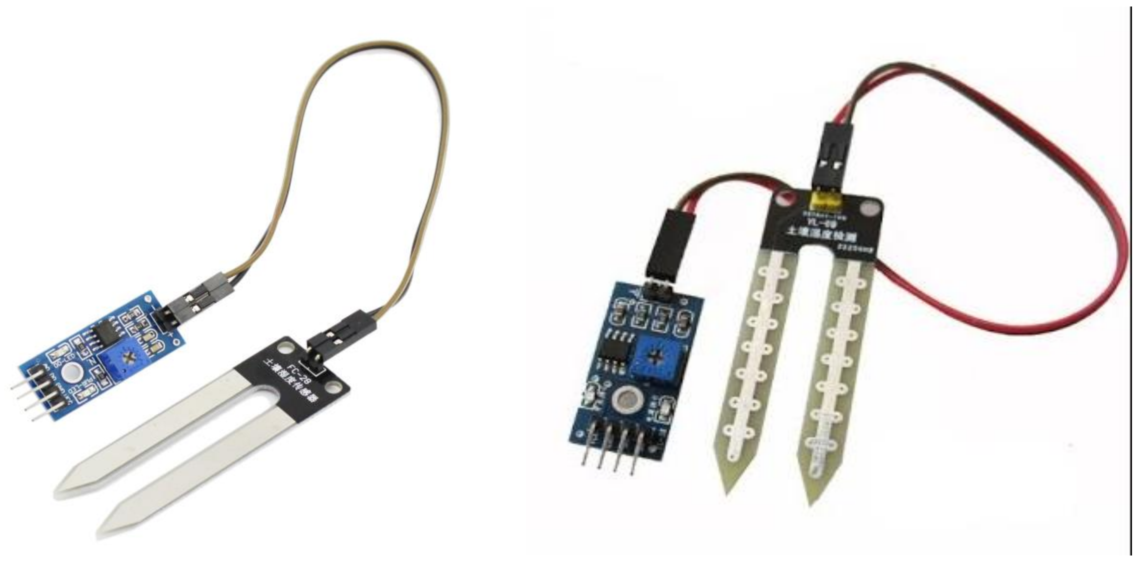


Figure 2 - YL-69 and FC-28 sensors connected to the modules

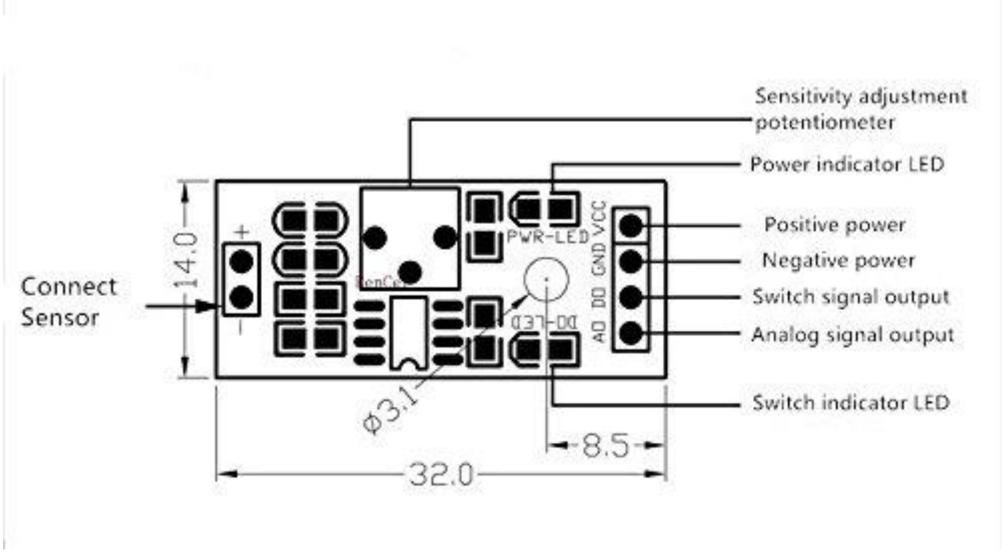


Figure 3 - YL-38 board module

Particular care was posed in the installation of the probes: in order to output a realistic value of the moisture, the probes had to be fully buried into the soil and oriented with the flat plate perpendicular to the surface, so as to minimize the influence of the sensor on water movements. The user has to ensure there is no air gaps between the probes and the soil: we observed that readings are accurate and consistent only when the soil is well pressed around the sensors' plates.

Temperature sensor

The digital thermometer DS160 was used to measure the temperature of the environment. Via a 3 wire serial interface, it sends to the microcontroller a digital, word-size signal with the value of the temperature measured in 0.5 °C units.

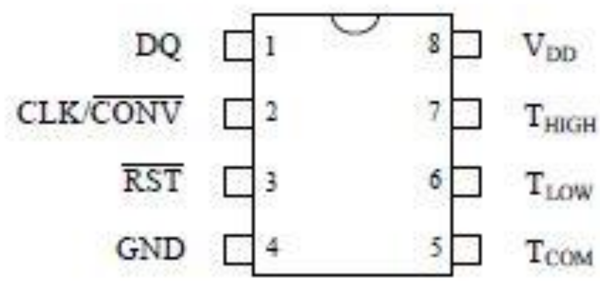


Figure 4- DS160 8 pin DIP sensor

Temperature value is transmitted serially to the Basic Stamp 2, taking the LSB first. Pin 11, 12 and 13 of the microcontroller are connected to the digital thermometer reset, clock and data transmission.

Light level sensor

In order to have information on the light level in the environment, a simple and effective low cost measurement is done through the use of a photoresistor.

This passive light sensitive sensor, varies its value of resistance according to the light condition. It consists of a Cadmium Sulfide (CdS) surface, with a decreasing value of resistance as the light gets brighter.

Other light detecting systems could have been used, such as photodiodes and phototransistors. However, thanks to their simplicity of use and low cost, CdS cells are commonly used in many indoor environments for automatic lighting or light monitoring.

The value of the resistance is of the order of hundreds of kilo ohms in the dark, dropping to tens of kilo ohms when exposed to direct bright light. For our sensor, VT935G-B, electrical characteristics at 25°C indicate a maximum resistance of 1 MΩ in the dark, getting down to 2 kΩ for a 10 lux illumination conditions.

Figure 5 - VT935G-B photoresistor

Through a command RCTime in the program run by the microcontroller, we retrieve a value of time proportional to the time constant of an RC circuit, with the resistance given by the CdS photosensitive cell and the capacitance of a 0.1 μF capacitor.

An increasing value of the resistance, in a darker ambient, returns longer time readings. Measuring the values returned in complete dark, we set an upper threshold for the time and resistance; we then evaluated the light level of the environment as a percentage of this maximum value.

Water level sensor

To have a feedback on the water level in the reservoir, a float switch was used, in a normally open configuration. With dimensions of 10.4 x 7.4 x 1.5 cm, it consists of a plastic case containing a reed switch.

Figure 6 - Float switch sensor

Its simple operation relies on a couple of electric wires, sitting next to each other at fixed positions in a sealed glass chamber. The two wires are normally not in contact but whenever a magnet, housed in a hinged float, approaches them, they become attracted in a way to touch and close the electric circuit.

When the level of the liquid rises again, the magnet floats and moves away from the wires, while the circuit gets opened.

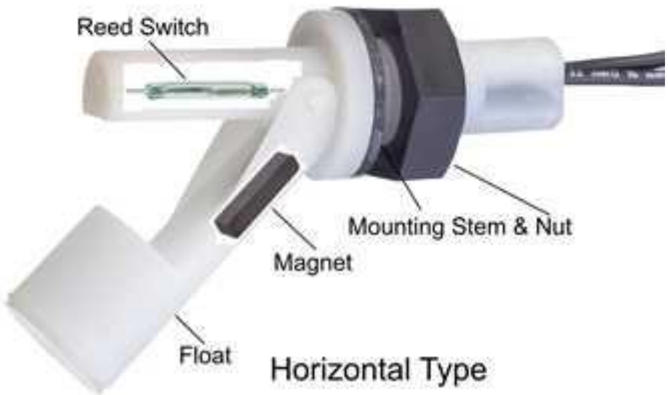


Figure 7 - Reed floating switch principle of operation

The horizontal arrangement was chosen, so the housing of the switch was fixed to a side wall of the tank through a nut and threaded stem.

Since we are dealing only with water and there are no problems such as corrosion or deposits, a polypropylene sensor was considered adequate to the purpose.

Due to its nature of reed switch, the sensor is not able to carry big amounts of electrical current. It is rated for a maximum of 0.5 A, which is, however, a value well above the current that is drawn from the Basic Stamp to which the sensor is interfaced. Source limit for a single pin of the microcontroller is of 20 mA only. Some protections such as relays or connectors should be otherwise used, to connect the sensor directly to a high current load.

Pump

We chose a small DC pump to water the plant. It runs with a RS-360SH motor, that has a nominal voltage supply of 7.2 V, but can operate in a range between 3 and 9 V. We connected the pump to a 9 V battery, to have a separate supply from the regulated 5 V that power the microcontroller and the other low power circuitry.

Watering cycles are rather short and not so frequent, so a voltage supply above the nominal value is unlikely to cause any overload on the motor.

Based on the size of the plant, we evaluated an irrigation of 40 ml of water for each cycle would be sufficient. This corresponds to a pump activation time of approximately 15 seconds.

Figure 8 - RS260SH DC Micro Pump

The pump is 5.2 cm long and has a diameter of 2.7 cm, for a total weight of 70 g. It was housed behind the tank, on a plastic support, so to avoid direct contact with wood. The pump was properly tested for leakage and heating before its installation inside the box.

Since our design is just a first prototype, we chose this low cost solution, suitable for short running cycles and hobby projects. Further improvements may use more advanced pumps, with lower noise level and power consumptions.

LCD

A user interface is provided through a LCD; for this purpose, we chose the Parallax Serial LCD, with two rows of sixteen characters each, non-backlit and with an embedded piezospeaker.

It is easily interfaced with the microcontroller, as it receives data with a single instruction and can be programmed to display text and play sounds with a great flexibility. We made use of custom designed characters to display the values of temperature and light. The screen also sends messages and play alarm sounds whenever the Green Thumb box is first turned on, water the plant or run out of water.

Figure 9 - Parallax Serial LCD

The small size of 3.6 x 8.0 cm allowed to house the display on the front face of the box, through a properly sized cut in the plywood. The small current requirement of 20 mA comes with the non-backlit model of the screen; a further improvement with a backlit LCD must take into account of greater power consumptions (up to 80 mA circa).

Through switches on the back of the screen, we selected a 19200 baud rate (i.e. the serial port receives data for a maximum of 19200 bits per second).

LED

Flexible adhesive green LED strips were applied along the sides of the box. Just used as an exterior decoration for our design, the idea can be exploited in further developments of the project to make the Green Thumb Box also an efficient table lamp or, if replaced with proper UV lights, to provide the plant with better light conditions and favor its growth.

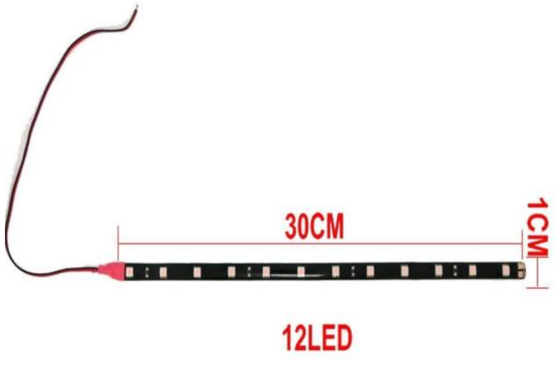


Figure 10 - Green LED strip

Transistor

Since the pump draws a current way above the Basic Stamp 2 sourcing capabilities, it was activated through a TIP120 NPN Darlington Pair transistor, leaving to the microcontroller the only duty to supply a high signal to the base of the transistor.

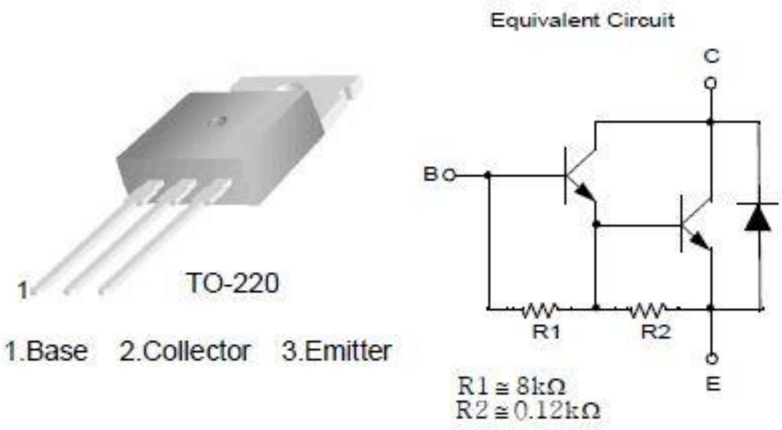


Figure 11 - TIP120 transistor

Due to the low current consumption of the pump, a Darlington pair was considered sufficient to the activation of the motor. Based on the characteristics in the datasheet, it can supply a collector current of 3 A for the base-emitter on voltage of 3 V.

RGB

One more actuator to interface the user is a round head, common cathod RGB LED light, housed through a hole in the front side of the box.

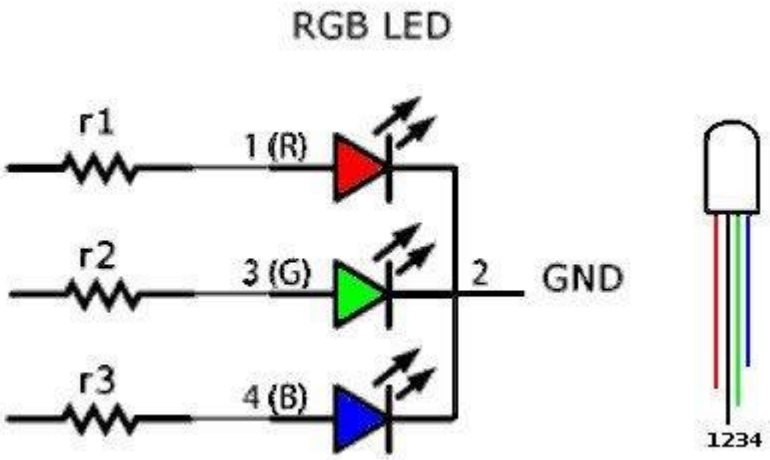


Figure 12 - RGB LED connection scheme

The LED is connected to three pins of the Basic Stamp 2 microcontroller and emits red, green or blue light when the pins provide a high output. The configuration chosen for the connection, with the microcontroller used as a source, does not pose any problem of excessive consumption, since the lights are not turned on simultaneously.

Voltage regulator

To supply the sensors with a stable voltage, a 7805 integrated circuit was used. Using a battery power supply, we could not be ensured against voltage fluctuations so we used this voltage regulator to provide the sensors with a stable positive 5 V supply.

The internal circuitry embedded in the device, protects from excessive current flow, thermal overheating and functioning inside a safe operating area. The metal element above the IC is also a sink to dissipate heat.

The 7805 integrated circuit is a three leads device, sensing the 9 V input from the battery holder and giving a stable 5 V voltage as an output. The third wire is connected to the common ground of the circuit.

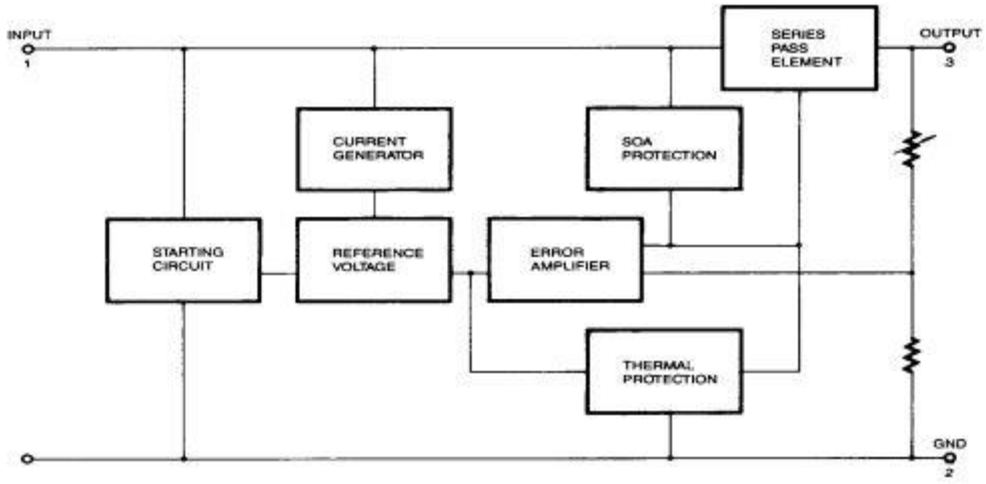


Figure 13 - TIP120 internal block diagram

Barrier strips

Four screw terminals barrier strip blocks were used in order to have a common voltage level between the elements of the circuit.

Figure 14 - Screw terminal barrier strip blocks

Since the different sensors and actuators are housed in different locations inside the box, this simple and low cost solution was used to prevent excessively long and intricate wiring. The use of one or more breadboards in place of several barrier strips was considered to be too bulky and less secure.

AD converter

The AD0831, an 8 bit analog to digital converter, with serial input and output was necessary to convert the analog reading from one of the moisture sensors and convert it into a digital format, readable by the Basic Stamp 2 microcontroller.

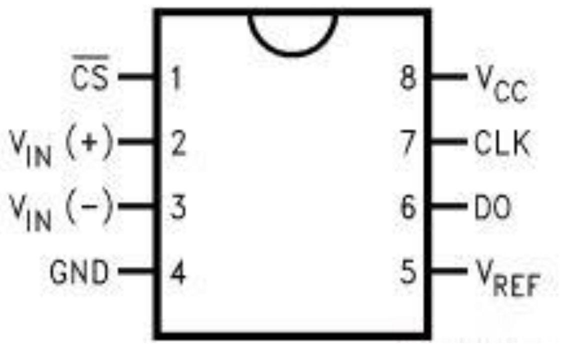


Figure 15 - ADC0831 Analog to digital converter

With 8 pins and a DIP, it is connected to the microcontroller through its chip select, clock and digital output pins for synchronous serial data communication.

ELECTRICAL DESIGN

When it comes to the circuitry of the device, all sensors and actuators are connected to the board of education and controlled by the Basic Stamp 2 microcontroller.

Power to the microcontroller and to all the elements of the circuit, apart from the pump, is normally supplied by six batteries of 1.5 V each, but a wall socket may be used too. In both cases, a voltage regulator is used so as to make sure a stable 5 V DC supply is provided. The microcontroller has its own power regulator embedded on the board of education, while a separate voltage regulator (IC7805) is used to supply the rest of the circuit.

A Single Pole Double Throw (SPDT) button is used to allow current flow in the circuit: whenever is pressed, the device turns on and the circuit is powered up.

Common poles are created through screw terminal barrier strips blocks that allow a common reference to which the potentials can be referred.

The DS1620 digital thermometer has its Pin 8 connected to the positive 5 V supply and, through a 0.1 μF capacitor, to ground; Pin 4 is also connected to ground, whereas its reset, clock and digital output pin (3, 2 and 1 respectively) are connected to Basic Stamp's pins 11, 12 and 13.

The VT935G-B photoresistor is used in an RC circuit so it is connected to ground, to the power supply of 5 V through a 0.1 μF capacitor and to Basic Stamp's Pin 14 through a 270 Ω Resistor.

The water level sensor acts like a switch, so it is connected to Pin 0 of BS2 using a normally open active low configuration, chosen for its better noise immunity. To do so, a 1 MΩ pull up resistor is used.

Both moisture sensors are powered by the regulated 5 V. One is connected directly to pin 5 of the microcontroller since it provides a digital output. The other one is connected both to Basic Stamp's pin 1, which reads the digital output of that sensor and to an ADC0831 converter which allows to evaluate the analog output produced by the sensor.

The AD converter has its Pin 4 and Pin 3 connected to ground, Pin2 to the sensor, Pin 8 and Pin 5 to the 5 V supply. Pin 1 (Chip select), Pin7(Clock) and Pin6 (Digital Output) are connected to the microcontroller's pin 2, 3 and 4 respectively.

The pump is connected to pin 10 of Basic Stamp 2 through a TIP120 Darlington pair transistor. In order to have the right voltage drop across the motor, an external power source had to be used, to supply the pump with the required current, higher than the one the controller is able to provide; indeed, the motor requires a nominal current of 360 mA to run with no load.

A 10 kΩ resistor is placed between the microcontroller and the base of the transistor, to have a suitable base current value. To prevent inductive current kickback a reverse-biased diode is placed in parallel with the pump.

The pump can be also activated manually by means of a momentary normally open button connected to pin 15 of the microcontroller. Again, to have a better noise immunity, an active low configuration is chosen, using a 1kΩ pull up resistor.

The RGB LED is connected to pin 6, 7 and 8 of Basic Stamp 2 and used to emit light signals if the level of the water is low and when the pump is actuated: when the level is too low, red light is produced, when the level is ok, green light is emitted; blue light comes out when the pump is activated.

The LCD is powered by external regulated voltage and is used to display a welcome message, the information coming from the sensors and a message telling that the pump is working. Furthermore, it plays a melody when turned on, an alarm when water is over. It is connected to pin 9 of the microcontroller.

The LED strips are connected to the power supply and manually activated by a switch.

MECHANICAL DESIGN

The prototype measures 35 x 25 x 22 cm and is built out of plywood wood of 1.27 cm thickness. The choice of the material reflects the environmentally friendly concept of the product, and it matches economical and disposal requirements.

Wood was cut and machined according to the purpose and the box was first assembled with hinges and screws according to a proper size, suitable to fit a big water reservoir and a container to sit the vase; these last two were worked out from polypropylene food containers.

Before the assembly of the box, holes and openings were made to sit the LCD, the pushbuttons, electrical wires for the moisture probes, LED, photoresistor and plastic hose for the pump.

The surface of the wood was coated with a natural wood finishing paint before the assembly. For sake of safety, the microcontroller and the barrier strips do not sit directly on the wooden floor of the box, but lay instead on an acrylic sheet 0.5 cm thick, adequately detached from the wood through long screws and spacers.

SOFTWARE DESIGN AND DEVELOPMENT

The software of the Green Thumb Box is thought to satisfy the plant needs at any time of its life. To do so, it is necessary to analyze the results given by the sensors and give the right inputs to the actuators or provide the data constantly to the user. The software behind the Green Thumb Box is built with a constant loop which receives the inputs from sensors. Mainly it deals with temperature, soil moisture, water level and environmental light parameters. Temperature is evaluated straight forward with the DS160 syntax that allows the user to see it directly on the LCD in Celsius degrees. For the Fahrenheit degrees value the conversion formula is used.

For the light value, the software adopts a percentage scale for the output displayed on the screen. To scale the output coming from the photoresistor, an empirical formula is used, observing that the maximum value returned by the RCTime function, in a very dark environment, is of about 60000 μs.

Water level sensor consists in just a switch. So it was easy to monitor its state trough a normally open active low configuration. The software lets the program run in a closed loop when the level of water reaches a critical value of about 250 ml, until the level of water goes back to a normal state.

The most challenging and important duty of the Green Thumb Box is to evaluate the soil moisture value in order to water the plant only when it is needed. The main difficulty is the delay in the answer coming from the two soil moisture sensors used. It was observed that these sensors are indeed rather slow and their output keeps changing up to 6 minutes from the starting time of measurements.

This change in values is not a problem during the standard use of the Green Thumb Box, but the software had to repair this lack of the sensors. A simple timer is used in the code that starts counting time whenever a certain threshold is passed and evaluates the output of the sensors only after 8 minutes from the first check, so to ensure the reading has reached a steady value.

The empirical duration of a loop of the cycle is 500 ms, then the seconds counter is augmented every 2 cycles and consequently the minutes timer increases of one unit every 60 seconds.

On the LCD values of moisture are returned in a percentage scale between two extreme values, evaluated at 40 and 120, chosen after several experimental trials. The pump is activated automatically when the soil gets under 45%, corresponding to a sensor reading of 85.

Another focal point considered in the software development, is the sound's duration coming from the LCD piezo. When a sound is used in a loop as an alert, like in the pump activation command, one must consider the duration of the sound played by the piezo with respect to the time that a loop takes to execute.

If one does not consider the discrepancy between the two durations, the sound would still continue playing, even after the program has gone out of the loop. To avoid this, another timer is used, so to send the signal to the LCD only when the previous sound has ended.

COST ANALYSIS

To develop an analysis of the costs of the product, it is necessary to start from the bills of materials employed and their unitary costs.

PART NAME	UNITARY COST ($)	QUANTITY	TOTAL COST ($)
Basic Stamp 2 Microcontroller	49	1	49
Board of Education	70	1	70
Photoresistor	2	1	2
Digital thermometer	8	1	8
Float switch	5	1	5
Soil moisture sensor	4	2	8
AD converter	6	1	6
Pump	5.50	1	5.50
TIP120 Transistor	2	1	2
LCD	28	1	28
Voltage regulator	2	1	2
RGB LED	1	1	1
Green LED strips	2	4	8
Pushbuttons	3	3	9
Barrier strip block	4	4	16
Capacitor	0.20	2	0.4
Plywood	5	2	10
AA Battery	0.5	6	3
9V Battery	2	1	2
Acrylic sheet	2	1	2
Additional Material			25

(Screw, Nut, Spacer, Bracket, Washer, Pipe, food container, Jumper wire, Resistor, Diode)	
TOTAL	**261.9**

Table 1 - Bills of materials with unitary and total costs

The final cost of the single prototype must not be taken as the real cost for the market in case of mass production. Indeed, with a mass manufacturing, unitary costs could be drastically cut substituting the Basic Stamp 2 and board of education with a cheaper microcontroller, such as one from Arduino series, with sufficient computational capabilities and memory. Parallax components are seen to be the most important cost items and hence their replacement is a first step to have a produce a more economic device.

The purchase of materials in bulk, rather than in unitary quantities would also significantly lower the costs. In order to build this prototype, we acquired the components in single packages: an industrial production of the product could rely on stock quantities of basic electronic components, available at rather low prices.

A first estimate for a mass produced unit is assessed around 50 $: the materials we used, wood, circuitry components, batteries, nuts and bolts, are indeed rather inexpensive and available on a large scale.

FINAL REMARKS AND FURTHER IMPROVEMENTS

We are well aware of the existence of similar electronic smart pots already available for sale on the market. Our solution, however, is thought to be truly innovative under many aspects. The main competitor we found, is called Click & Grow and is a smart garden that provides the plant with water and nutrients.

The device we developed is designed to have a better power autonomy, since it does not have to be necessarily plugged into a wall socket in order to work. Also, since the vase is not embedded in the structure of the box, the plant used for Green Thumb Box can be replaced at any time, while the competitor’s device allows the customer to grow only seeds already packaged in a special soil and sold by the firm.

Another freedom we left to the user, not available for the other solutions we found, is the choice to water the plant manually, outside the normal watering cycles. Finally, the LCD represents an efficient way to provide the user with information regarding the plant and the environment. This kind of user interface is lacking in the other smart vases.

Still far from being an ideal product, the design of the Green Thumb Box may for sure be further refined.

Replacing conventional batteries with rechargeable ones, that get automatically charged whenever the vase is plugged into the wall socket, is probably the most immediate and easy improvement to implement on the device. Apart from the immediate environmental benefit, it takes off the user the annoyance to change the batteries.

If instead the use of conventional batteries is preferred, then a system for monitoring the level of charge would be for sure useful, because it would prevent the device from shutting down unexpectedly. A feedback control on the voltage level across the battery pack could give a first, approximate measure of the level of discharge of the batteries. A voltage control of this type could have been developed using the Basic Stamp 2 microcontroller, through the use of the RCtime function. However, since the discharge curve of an battery is sharply nonlinear, especially when the level gets very low, a measure on voltage is not sufficient by itself to determine the residue life of the power supply. Also for this reason we decided not to include this functionality in our device. An amperometric measurement is for sure more advisable to detect the level of charge of a battery, but to implement it efficiently and interface it with the microcontroller we had would have been too costly and time consuming.

Other advancements can be achieved. For instance, using a suitable microcontroller, it could be adapted to work outdoor and be controlled remotely using a wi-fi network. This may allow the user to check the status of the plant at distance, simply by looking at his/her phone. The thermometer could be used to estimate the ambient temperature and evaluate whether it is the right time for watering.

Also, a motor may be attached to the base of the box so as to make it follow the sunlight. Many plants are subject to phototropism, a process which causes the plants to grow crooked, resulting in a bad appearance; allowing the plant to follow sunlight would prevent it from happening.

Furthermore, the green LED strips along the side of the box may be replaced by UV light emitters, which could be turned on in case of scarce light, allowing the plant to grow luxuriant.

APPENDICES

Appendix A - Mechanical designs

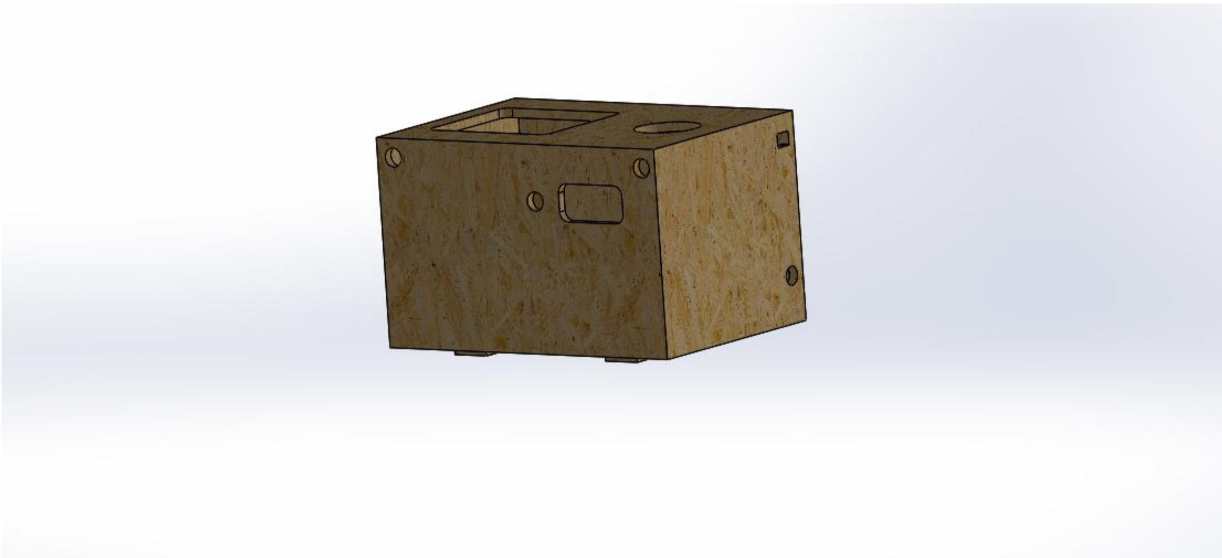


Figure 16 - Green Thumb Box 3D Solid model

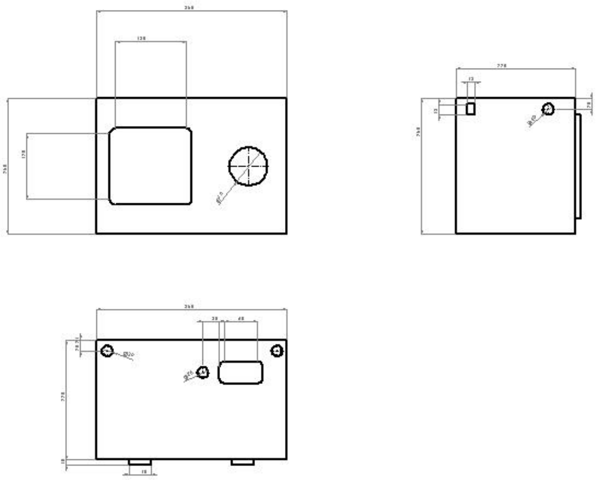
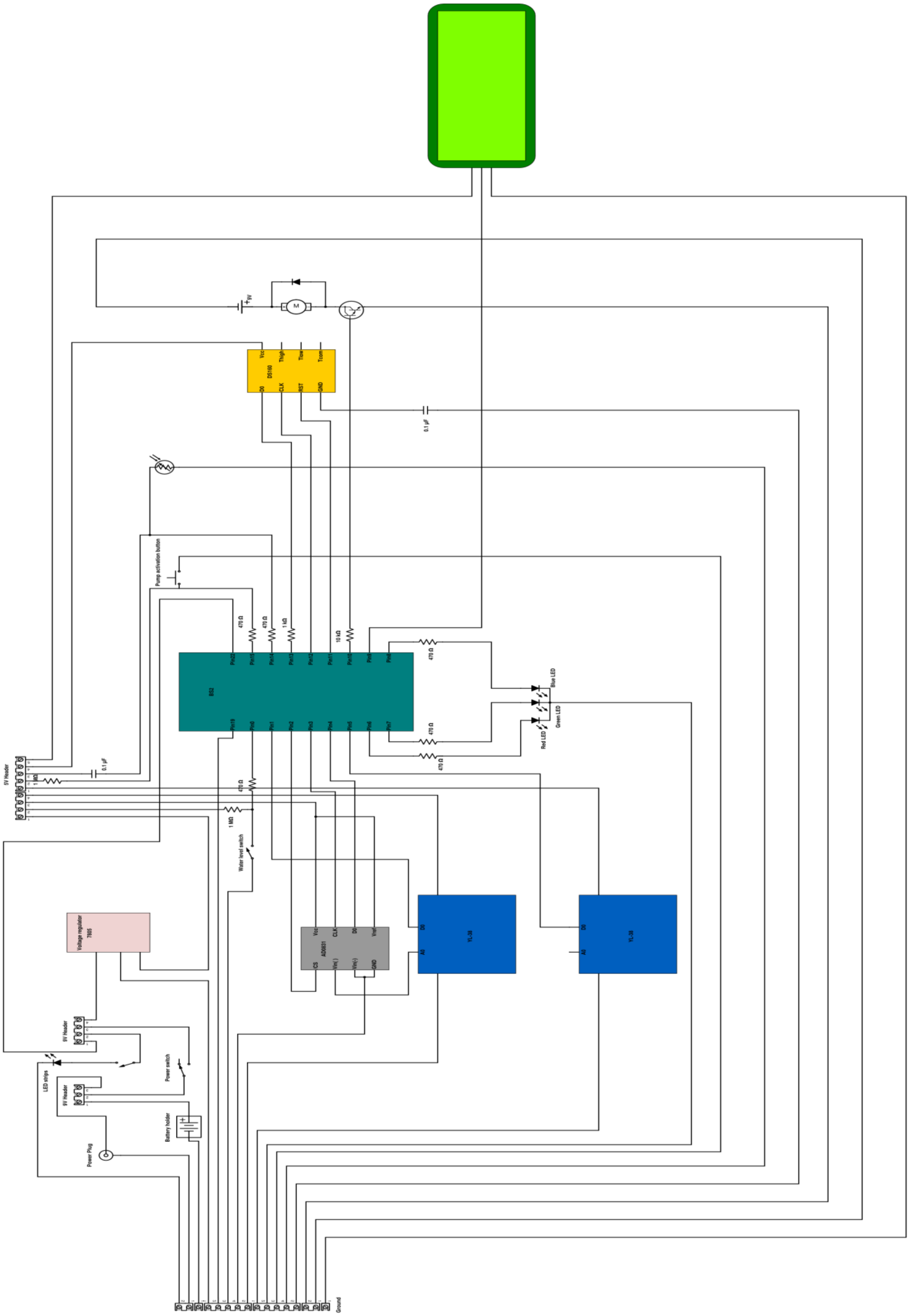


Figure 17 - Layout of the Green Thumb Box

Appendix B - Electrical circuit



Appendix C - Basic Stamp 2 program code

```
' {$STAMP BS2}
' {$PBASIC 2.5}

'GREEN THUMB BOX

'Main Program: It continously works during the GTB life.
'Monitoring the soil moisture, temperature,light AND watering the plant.

WaterLev    PIN 0
SoilDI      PIN 1
SoilAI1     PIN 2    'CS
SoilAI2     PIN 3    'CLK
SoilAI3     PIN 4    'DO
Soil2DI     PIN 5
RedLed      PIN 6
GreenLed    PIN 7
BlueLed     PIN 8
LcdPin      PIN 9
Pump        PIN 10
Temp1       PIN 11   'RST
Temp2       PIN 12   'CLK
Temp3       PIN 13   'DQ
LightDec    PIN 14
PumpBtn     PIN 15

SoilMoist   VAR Word
LightLev    VAR Word
TempOut     VAR Word
TempDegC    VAR Word
TempDegF    VAR Word

idx         VAR Nib    'variable for loop
ActiveTimer VAR Bit
TimerSound  VAR Byte
TimerMin    VAR Byte
TimerSec    VAR Byte
TimerCycle  VAR Nib

Baud19200   CON 32


Setup:

LOW RedLed
LOW BlueLed
HIGH GreenLed       '

INPUT WaterLev
INPUT LightDec
INPUT PumpBtn

idx = 0
ActiveTimer = 0
TimerSound = 0
TimerMin = 0
TimerSec = 0
TimerCycle = 0

HIGH LcdPin
PAUSE 100
```

```
SEROUT LcdPin, Baud19200, [12]                     ' Clear screen
SEROUT LcdPin, Baud19200, [21,                     ' Turn off screen
                           "   Hello from",        ' Write on screen
                           148, "Green Thumb Box",
                           22]                          ' Turn on screen so text
appears at once

SEROUT LcdPin, Baud19200, [248,    ' Define Custom Character 0
                           %00110, '     * *
                           %01001, '   *     *
                           %00110, '     * *
                           %00000, '
                           %00000, '
                           %00000, '
                           %00000, '
                           %00000] '


SEROUT LcdPin, Baud19200, [232,228,211]
PAUSE 250
SEROUT LcdPin, Baud19200, [222,213]
PAUSE 250
SEROUT LcdPin, Baud19200, [230,213]
PAUSE 1500


Main:

HIGH GreenLed


TimeControl:

DEBUG HOME,"TimerCycle = ",DEC TimerCycle,CLREOL,CR,
           "TimerSec = ",DEC TimerSec,CLREOL,CR,
           "TimerMin = ",DEC TimerMin,CLREOL,CR,CR

IF ActiveTimer = 1 THEN
 TimerCycle = TimerCycle + 1
ENDIF

IF TimerCycle = 2 THEN
 TimerSec = TimerSec + 1
 TimerCycle = 0
ENDIF

IF TimerSec = 60 THEN
 TimerMin = TimerMin + 1
 TimerSec = 0
ENDIF


WaterCheck:

IF WaterLev = 0 THEN
 LOW Pump
 SEROUT LcdPin, Baud19200, [12]                    ' Clear screen
 PAUSE 5
 SEROUT LcdPin, Baud19200, [" Tank is empty!", 13,
                            " Please refill!"]
 DO
  LOW GreenLed
  LOW BlueLed
```

```
   HIGH RedLed
   SEROUT LcdPin, Baud19200, [220,211]               ' Play a sound for 250 ms
   PAUSE 250
   LOW RedLed
   SEROUT LcdPin, Baud19200, [227,211]
   PAUSE 250
  LOOP UNTIL (WaterLev = 1)

  LOW RedLed
  HIGH GreenLed
 ENDIF


 SoilCheck:

 LOW SoilAI1
 PULSOUT SoilAI2,1

 SoilMoist = 0

 FOR  idx = 1 TO 8
  PULSOUT SoilAI2,1
  INPUT SoilAI3
  SoilMoist = SoilMoist*2
  SoilMoist = SoilMoist+SoilAI3
 NEXT
 idx = 0
 HIGH SoilAI1

 IF SoilDI = 1 OR Soil2DI = 1 OR SoilMoist > 85 AND SoilMoist < 180  THEN
  ActiveTimer = 1
  HIGH BlueLed
  IF SoilDI = 1 AND Soil2DI = 1 AND SoilMoist > 85  AND TimerMin = 8 THEN
   TimerMin = 0
   SEROUT LcdPin, Baud19200, [12]
   PAUSE 5
   SEROUT LcdPin, Baud19200, ["  Soil is dry!"]
   GOTO PumpActive
  ENDIF
 ENDIF

 IF SoilMoist < 85 OR SoilMoist > 180 THEN
  LOW BlueLed
  ActiveTimer = 0
  TimerMin = 0
  TimerSec = 0
  TimerCycle = 0
 ENDIF

 DEBUG "SoilMoist(Raw) = ",DEC SoilMoist, CLREOL,CR

 IF SoilMoist > 120 THEN
  SoilMoist = 120
 ENDIF
 IF SoilMoist < 40 THEN
  SoilMoist = 40
 ENDIF

 SoilMoist = 100 - ((SoilMoist - 40)*100/80)        'empirical formula

 DEBUG "SoilMoist = ",DEC SoilMoist, CLREOL,CR,
       "SoilDI = ",DEC SoilDI, CLREOL,CR,
       "Soil2DI = ",DEC Soil2DI,CLREOL,CR,CR
```

```
LightCheck:

HIGH LightDec
PAUSE 200
RCTIME LightDec, 1, LightLev    ' In 2 us
HIGH LightDec

DEBUG "LightLev(Raw) = ",DEC LightLev,CLREOL,CR

IF LightLev > 3000 THEN
 LightLev = 3000
ENDIF

LightLev = 100 - (LightLev/30)                  'empirical formula

DEBUG "LightLev = ",DEC LightLev,CLREOL,CR,CR


TempCheck:

LOW Temp1
LOW Temp2
LOW Temp3
HIGH Temp1
SHIFTOUT Temp3, Temp2, LSBFIRST, [238]
LOW Temp1

HIGH Temp1
SHIFTOUT Temp3, Temp2, LSBFIRST, [170]
SHIFTIN Temp3, Temp2, LSBPRE, [TempOut]
LOW Temp1

TempDegC = TempOut / 2
TempDegF = TempDegC */461 + 32

DEBUG ?TempDegC,?TempDegF,CR


LcdWrite:

SEROUT LcdPin, Baud19200, [12]
SEROUT LcdPin, Baud19200, ["T = ", DEC TempDegC, 0,"C / ", DEC TempDegF, 0,"F",
13, 'write on screen
                           148, "H%:",DEC SoilMoist,154, " Light:",DEC LightLev]
'turn on screen so text appears at once


PumpManual:

IF PumpBtn = 0 THEN
 HIGH Pump
 LOW RedLed
 LOW GreenLed
 HIGH BlueLed
 IF idx = 0 THEN
  SEROUT LcdPin, Baud19200, [12]
  PAUSE 5
  SEROUT LcdPin, Baud19200, [147," Pump active..."]
  idx = 1
 ENDIF
 IF TimerSound = 50 OR TimerSound = 0 THEN
```

```
   SEROUT LcdPin, Baud19200, [220,211,
                              222,211,
                              226,211,
                              224,211]
  TimerSound = 0
 ENDIF
 TimerSound = TimerSound + 1
ENDIF

IF PumpBtn = 1 THEN
 LOW Pump
 TimerSound = 0
 IF idx = 1 THEN
  SEROUT LcdPin, Baud19200, [12,"T = ", DEC TempDegC, 0,"C / ", DEC TempDegF,
0,"F", 13,
                             148, "H%:",DEC SoilMoist,154, " Light:",DEC
LightLev,22]
 ENDIF
idx = 0
GOTO Main
ENDIF

DEBUG CRSRXY,0,15,"TimerSound = ", DEC TimerSound,CLREOL
GOTO PumpManual


PumpActive:

LOW RedLed
LOW GreenLed
HIGH BlueLed

HIGH Pump
SEROUT LcdPin, Baud19200, [148," Pump active..."]

FOR idx = 0 TO 9
 SEROUT LcdPin, Baud19200, [220,211,
                            222,211,
                            226,211,
                            224,211]
NEXT

PAUSE 10000

GOTO Main
```

REFERENCES

Kapila Vikram, *Notes for the ME3484 - Mechatronics Course*.

Pace Scientific Data Loggers and Sensors, *Installation and Setup Instructions EC5 and EC20 Soil Moisture Sensors.*

Parallax Inc. *Applied Sensors Student Guide*, Version 2.0.

R. Munoz-Carpena. *Field devices for monitoring soil water content*. Bulletin 343, Dept. of Agricultural and Biological Engineering, Univ. of Florida, IFAS Extension.

Smith, Keith A. *Soil and environmental analysis: physical methods, Revised, and Expanded*. CRC Press, 2000.

http://www.liquidlevel.com/pages/how-does-a-liquid-level-work.

http://us.clickandgrow.com/.

http://www.cynergy3.com/blog/how-select-correct-float-switch.