An Automatic Control System Design with Practical Implications

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Abstract

The automatic control system design course requires students to design and build a closed loop control system. In the design presented here, students are to design, build and troubleshoot a humidity control system which is used to manage soil moisture levels in a green house. Maintenance of proper soil moisture levels for different plants is crucial to farming. The idea is to water the plants when the soil becomes dry beyond a certain level. Students are expected to select, design and build each component based on required specifications. Students are encouraged to take initiative in examining all the available options. This works to incite curiosity and inquisitiveness in students. To monitor the moisture levels of the soil, students are to investigate the conductivity of electrodes constructed from different metals and then choose the one with the widest range of variations in resistance reflecting changes in soil wetness. A signal conditioning circuit is then designed to change output resistance of the sensor to voltage, which is then amplified and fed into the controller to be compared to a preset moisture level. A simple switching circuit with hysteresis can be designed using an LM139 operational amplifier. A transistor circuit is used to energize the relay switch, which in turn controls the water flow. An LCD display is used to display moisture levels. Students must investigate and compensate for the effect of noise on the sensing probe. Junior and senior students with basic knowledge of electronics and automatic control should be capable of performing this experiment. It has been implemented in my automatic control course and has proved to be a very successful learning and teaching experience.

Introduction

The primary function of any valuable experiment is to solidify the learning experience by demonstrating realistic applications. Through it, students can investigate the validity of concepts learned in the classroom. It should also enhance the student's ability to troubleshoot systems to ensure optimum performance. In class, students learn how to apply theory in the design of selected projects. This experiment enables them not only to develop their design, but also to build it and troubleshoot for best performance.

The ideal subject matter for an experiment must be an interesting and exciting simulation of a real life application. The mission is to capture the student's attention and imagination and sustain his interest throughout the project. Students should be excited enough to complete the experiment in order to witness the outcome, not simply because they are required to do so by the teacher. The proposed experiment is an application which accomplishes this objective. The most significant value of this simple experiment is in the potential to spark interest in learning.

Soil moisture control is a topic interesting and appealing enough that students will discuss it with their family, friends and colleagues. The cultivation and care of plants is of relevance to nearly everyone. Gardening and agriculture are household issues which also have commercial applicability. The experience and know-how gained from this experiment can be readily used and shared. One appealing aspect of this project is its ease of implementation. Having completed this experiment, students can witness the results of their work which gives them a good sense of accomplishment. Students can put the project into practice in their homes, jobs or any place where they are capable of cultivating plants.

A good experiment must be a general application incorporating as much information as possible. The objective is to inspire self-confidence as well as to help develop essential career skills. The proposed experiment brings into play the knowledge learned in automatic control systems[1], electronics[2] and analog and digital systems[3] classes and could easily be adapted to any of the advanced course labs. To complete this project, junior or senior students must be capable of utilizing their accrued knowledge to design and construct this moisture control system. Additionally, the proposed experiment exposes the students to as many devices as possible. During this experiment, students must learn how to connect and interface digital and analog devices and DC and AC circuitry as well as sharpening their research skills through the utilization of data sheets.

The proposed project can be used in parts, as in class experiments, or in its entirety as a class project where students assume full responsibility for design and implementation of all aspects of the system. In this case, students are required to acquire all necessary components through local dealers or the internet. Although these components are readily available and inexpensive, this requirement adds the dimension of responsibility to the project as well as familiarizing the student with the cost of building such a system. It also emphasizes the need to be cost effective.

This experiment, which started as a capstone project, is now used regularly in the automatic control class due to the overwhelmingly positive response from students. It has proven to be both a very successful learning and teaching experience. As seemingly abstract ideas become practical solutions and skills, students begin to trust their knowledge of the subject matter. After completion of this project many students have commented positively about their involvement and the knowledge and experience they have gained. From the teacher's perspective, this experiment has proven to be a very effective way of relaying the material to the students and ensuring that they understand it and use it properly.

Moisture Control System

The objective of this experiment is to design and build a moisture control system to maintain the moisture of the soil in a green house to within desired levels. Watering plants is imperative for their survival and different plants require different degrees of soil moisture. Over-watering or under-watering can result in damage or death of the plant. The proposed system is designed to prevent such a mishap by constantly monitoring and adjusting moisture level as needed. It is the student's responsibility to select, design and construct each of system parts and then put them together to form the complete moisture control system.

Since the idea is to control the soil moisture in a green house, the first step would be to build a prototype of the green house. A suitable choice for this purpose would be to use a small fish tank. Through the glass, one can observe the plants and monitor their progress. The tank is filled a quarter of the way up with good potting soil. Herb plants are then planted to test the system. A small fluorescent fixture can be added to provide the plants with needed light. The plants are watered though holes punched in a hose placed in the top of the tank and connected to a water pump. The holes in the hose would allow for even watering of the plants. The pump is connected to 100 V ac source. Glass walls will allow verification of system function.

To measure the moisture of the soil, students are required to select or design and build a moisture sensor. Students must first understand that this sensor is based on the concept of conductivity. Conductivity is one of the first and main subjects covered in the field of electricity. The relationship between moisture and conductivity is very simple, the higher the moisture level, the higher the conductivity and the lower the resistance. Conductivity also varies from metal to metal. Another factor is the soil itself. Different soils dissipate moisture differently and therefore conduct electricity differently. Atmospheric temperature and humidity can also affect moisture levels in soil. Using conductivity and related factors, students are encouraged to investigate the use of various materials to come up with the best design of a moisture sensor to use with the system at hand under given conditions.

One simple solution to the sensor problem is to buy a moisture sensor through a local dealer or on the internet. Once the sensor is acquired, students must test its efficiency with the available soil in their particular systems. Different soils absorb moisture differently under varying conditions which is reflected in the conductivity of the soil. Therefore, some sensors are more suitable than others under different soil conditions. A good sensor is one with the widest range of variation of the output voltage with moisture level. The validity of the sensor is tested by adding tablespoons of water to the soil and monitoring the output voltage of the sensor. When the store bought sensor was tested, results were very unsatisfactory. The output voltage of the sensor did not identify and reflect a range of different moisture levels. After adding two tablespoons of water, the output voltage went from a low level to a high level indicating the soil was wet. This sensor was not a good reflector of different moisture levels because it monitored only two levels: dry and wet. It would be better used in applications where it is required to test if the soil is dry or wet but not at different degrees of moisture. The sensor test results are presented in Figure 1.

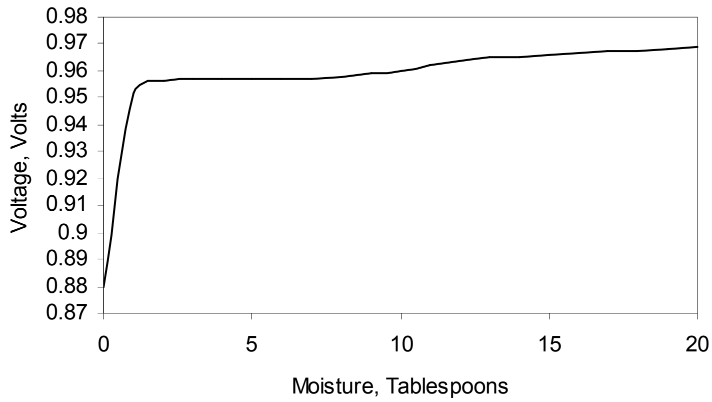

Figure 1. Moisture response of commercial sensor

A possible next step would be to go and buy another sensor and test its performance under the same conditions, but this process of trial and error could become expensive. A cheaper approach would be to use the concept of conductivity to design and build sensors using different metals. A moisture sensor can be simply constructed using two electrodes which are placed about an inch apart in the soil and monitoring the resistance between them[4]. The soil between the electrodes acts as a conductor whose resistance changes with moisture variance. As the moisture level rises, the conductivity between the electrodes rises and therefore the resistance drops. To convert changes in resistance to changes in voltage as required by the system, a simple voltage divider circuit is added. As the resistance of the sensor changes, the base current of the sensor transistor will change. This will result in changing the collector current and therefore the voltage across the output resistor. Students can experiment with electrodes made from different metals and choose the one which best reflects moisture level variation in its response. The complete sensor circuit is shown in Figure 2.

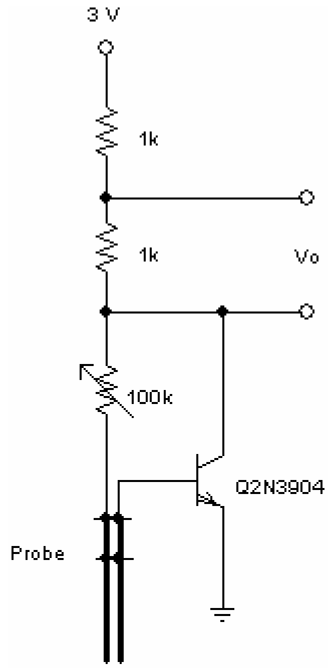

Figure 2. Sensor Circuit

Using two nails as electrodes, the response was erratic and unreliable. The output voltage changed up and down in no specific order as tablespoons of water are added to the soil. Test results are shown in Figure 3.

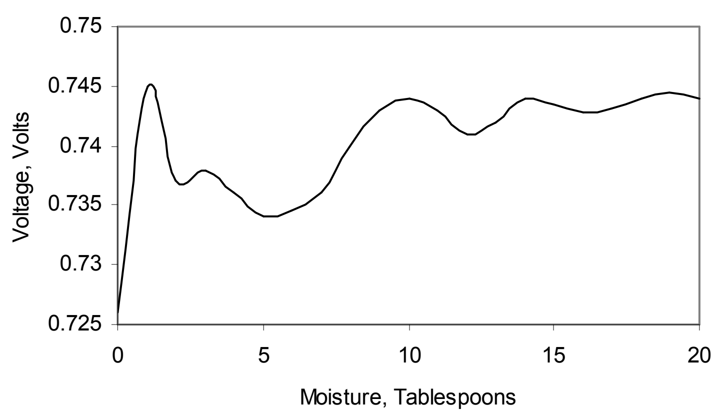

Figure 3. Moisture response of nails sensor

When two copper strips were used as electrodes, the response was much more reliable. The output voltage increased steadily as tablespoons of water are added reflecting a wide range of moisture level. Test results are shown in Figure 4.

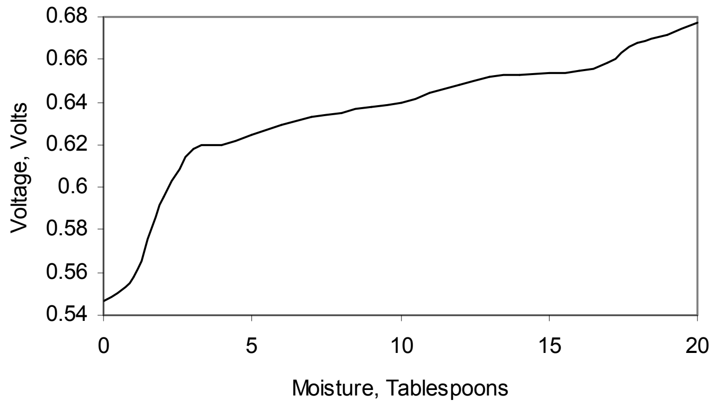

Figure 4. Moisture response of copper sensor

To ensure repeatability of performance, these three sensors are tested under the same conditions few more times and results are recorded. A study of the results indicates that the homemade copper strip electrodes sensor outperformed the other two sensors by a vast margin and is then selected as the sensor of choice to be used to complete the project.

After this stage is completed, students are very pleased because they can actually see the results of their work. Using a sensor of their own design, they can see the output voltage changing in reaction to the moisture added. This gives them confidence in their knowledge and in their ability to apply it properly.

Once the sensor is selected, the next step is then to use its output voltage reflecting the moisture level in the controller design. Since the actual voltage readings are small in value and to prevent noise distortion, an amplifier is needed to raise these values to a reasonable, measurable range. This amplification will also allow the build up of hysteresis around the desired voltage in the next stage. For that purpose, the instrumentation amplifier INA122 [5] was used to amplify the voltage range by 8 from 0.54V-0.68V to 4.3V-5.5V. The INA122 is a precision amplifier with very low power consumption which is ideal for portable battery operated systems. It can also provide an excellent common mode noise rejection. An external resistance is added to set the gain of the amplifier. The amplifier circuit is given in Figure 5. The resistance can be selected using the following equation[5]:

$$R_G = \frac{200k\Omega}{G-5}$$

Where G is the gain of the amplifier. For the proposed system, the gain G was selected to be 8 and R_G was calculated to be 67kΩ.

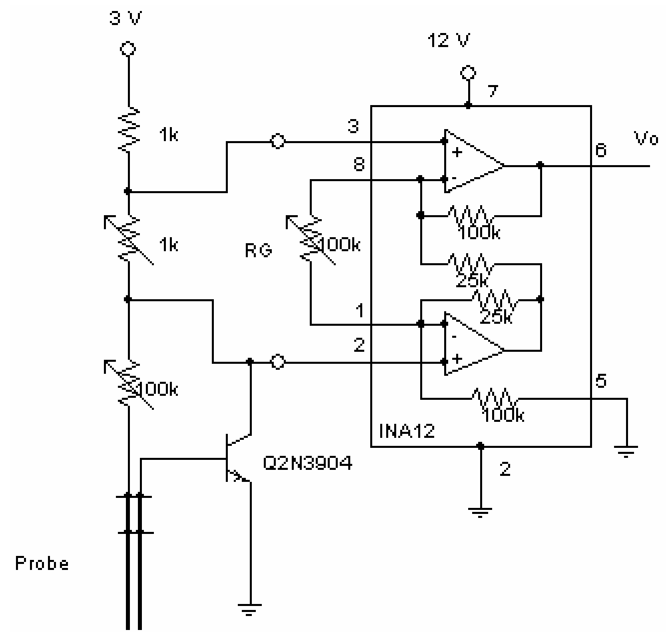

Figure 5. Differential amplifier

After the voltage is amplified to a sensible value, the next step is to compare it to a preset voltage value representing the desired moisture level. If the actual voltage is below the reference value, then soil is too dry and water needs to be added and if the voltage is above the reference, then soil is too wet and watering must stop. A single ended operational amplifier comparator such as the LM139 can be used to compare the actual voltage to a reference voltage. However, using the basic comparator for the comparison will cause chattering resulting in continuous switching between on and off. When the actual voltage is just below the set voltage, the comparator output is low where as when the actual voltage is just above the set voltage the comparator output is high. Essentially, a basic comparator does not allow for a neutral zone where there is no switching. To avoid that, the students must use a comparator with hysteresis. This design will allow for a pre selected neutral zone around the reference value within which there will be no switching. The resistors in the comparator circuit are calculated based on the width of the neutral zone using the following equations[6] :

$$R_2 = R_1(1+\frac{Vsat}{V_H})$$

$$V_{UT} = V_{REF}(1+\frac{R_1}{R_2})$$

$$V_{LT} = V_{REF}(1+\frac{R_1}{R_2}) - \frac{Vsat * R_1}{R_2}$$

Where Vsat is the DC supply, V_H is the hysteresis voltage and V_{LT} and V_{UT} are the desired range limits.

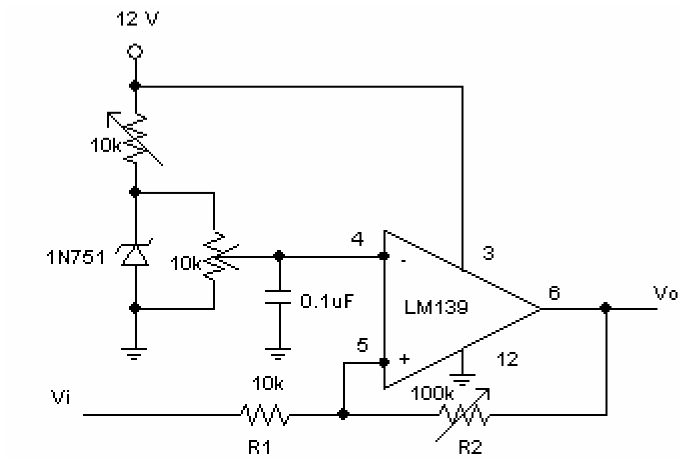

Figure 6. Comparator Circuit

The desired moisture level, the corresponding voltage reference and the neutral zone are dictated by the type of plants and soil used. They can be different from one system to another. Once they are selected for the system at hand, they are used to calculate the controller resistors R_1 and R_2 which can then be easily adjusted. A water pump, powered by a 110V, 60 Hz AC source, can be used to provide water to the plants.

Now, if the actual voltage drops below the neutral zone, then the output of the controller is low and water pump is turned on. As water is added, the soil moisture increases, causing the resistance to drop which in turns increases the current and therefore the voltage output of the sensor. When the voltage reaches the high end of the neutral zone, the output of the controller switches to high causing the pump to turn off and stop watering.

To interface the AC powered pump with the DC controller, a magnetic relay switch can be used. The relay consists of a coil and a switch. When DC current flows through the coil, a magnetic field is created closing the switch which is normally open. When the DC current is ceased, so is the magnetic field, reopening the switch. The output of the controller is connected to the coil whereas the pump is connected to the AC source through the relay switch. If the current supplied by the operational amplifier in the controller is insufficient to energize the relay, a 2N3906 pnp transistor can be added to amplify the current. The relay coil is connected at the collector of the transistor, while the base is connected at the output of the controller. When the sensor voltage is below the desired range, the output of the comparator is low, which turns on the transistor and activates the relay turning the pump on. Inversely, when the sensor voltage is above the desired range, the output of the comparator is high, which turns off the transistor and deactivates the relay turning the pump off. A 1N4002 diode can be added across the relay to protect the operational amplifier and transistor against transients developed by the relay's collapsing magnetic field.

Students must design the input resistance of the transistor based on the relay current requirements.

A visual reading of the moisture level is needed for accuracy and peace of mind. People need to see how moisture is changing to best fit the plant. A set of LEDs can be used to represent the moisture level. The output of the sensor can be connected through a set of voltage dividing resistors to the LEDs. The number of LEDs lit will be proportional to the voltage output of the sensor and therefore the moisture of the soil. A preferable display would use an LCD to show the level either numerically or alphabetically. There exists a wide variety of LCDs on the market. Students must research their options to select the best fit for their system. One of these choices is a 31/2 digit display made by AND[7]. Using an LCD, students need an analog to digital converter to interface analog output of the sensor with digital display. An ICL7136 ADC can be used for this purpose[8]. The ICL7136 is a low power A/D converter which includes a 31/2 digit LCD driver, a clock, a voltage reference and seven segment decoders. Students must consult the data sheets for pin configuration and calculation of external elements to ensure proper operation. The LCD display can be calibrated to read from 000 to 100 percent. The interface circuit is given in Figure 7.

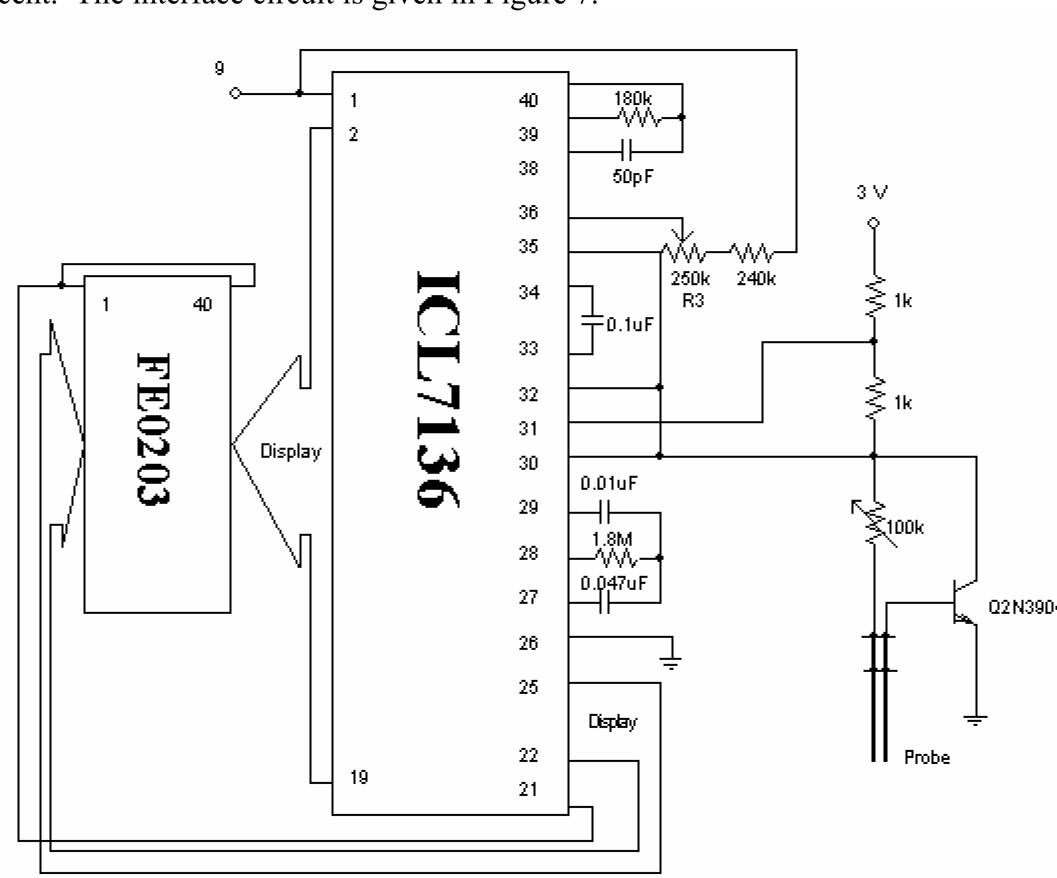

Figure 7. LCD display circuit

The power consumed by all the different components in this system is low enough to allow the use of battery power for an extended length of time. The exercise of designing and building a power supply to run the system could be part of the project if the teacher sees fit.

System Test

To test the validity of the proposed control system design, the fish tank green house was used. All the system parts were connected together on a breadboard and the board was bolted to the top of the tank. The output of the sensor was connected to the instrumentation amplifier which in turn was connected to the operational amplifier comparator. The output of the comparator was connected to the transistor relay circuit. The water pump was connected to the AC source through the relay switch. The LCD was connected to the sensor through the ADC. A 12 V, 9V and 3V batteries were used to provide the DC power. The complete system is shown in Figure 8.

To begin with, the soil was dry and the system was off. When the power was turned on, the sensor acted erratically causing the continuous switching of the relay. Students then had to troubleshoot the system to determine the cause of the malfunction and correct it. First a digital multimeter was used to recheck for the correct components and connections by measuring the voltage at different testing points in the system. When the problem was not found, an oscilloscope was used to check the output of the sensor. Surprisingly, the students found that the sensor probe was picking up a 60 Hz noise possibly caused by the fluorescent lighting in the room.

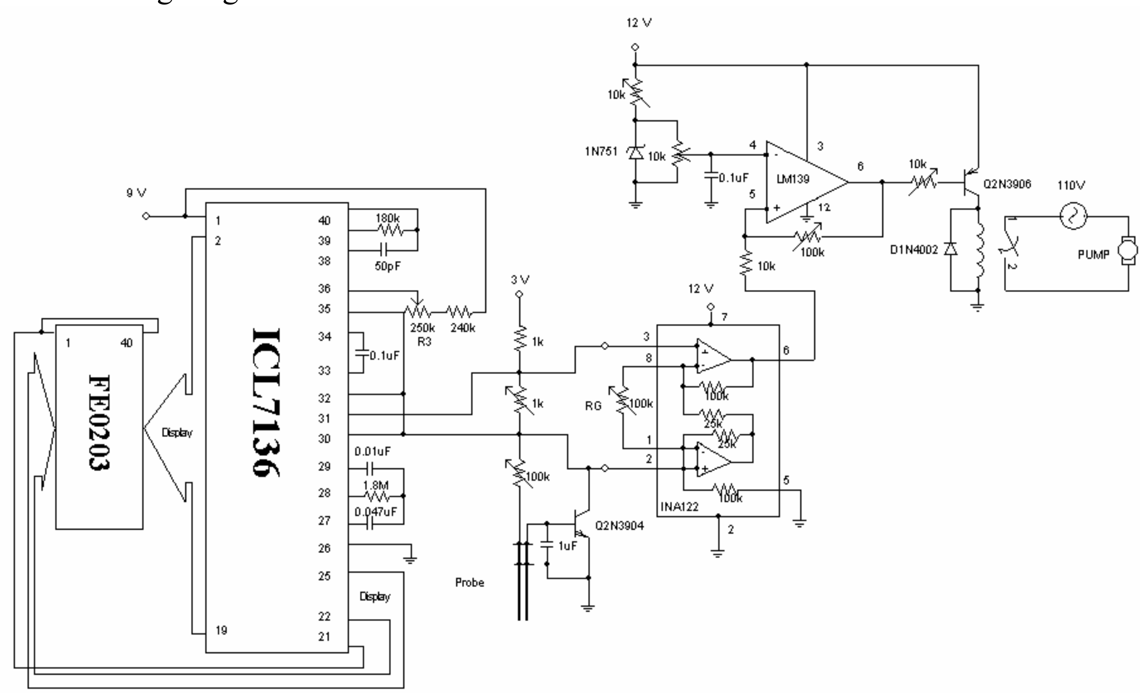

Figure 8. Soil moisture system

To eliminate the noise, a 1μF capacitor was connected from the sensor to ground. Using the capacitor, the sensor was more reliable and could be used successfully in the circuit to amplify the DC signal without interference from the AC noise.

With the system functioning properly, a reference point representing the desired moisture level was selected. A reference of 5V, which is within the dry-wet range, was used. Controller resistors were adjusted to allow a hysteresis voltage of 0.5V around the reference value. When the power was turned on, the sensor voltage was 4.3V, which is lower than the lower limit of the desired range of 4.7V to 5.2 V. The relay was energized, turning the pump on, to water the plants. As the moisture level in the soil increased, the sensor voltage was increased. Watering was continued until the voltage reached the high end of the desired range. At that point, the output of the comparator switched to high, turning off first the transistor, then the relay and then the pump to stop the water flow. With the water off, the soil moisture dropped due to evaporation and absorption by plants. As the moisture dropped, so did the output voltage of the sensor. When the voltage reached 4.7V, which is the lower end of the desired level, the pump was again turned on to allow watering. This operation would continue, ensuring that the moisture level remained within the desired range for a healthier plant.

Conclusion

A simple experiment with a practical application is presented. Students are required to design and build a functioning soil moisture control system. Soil moisture control is an appealing topic because of its impact on many people and businesses alike. Farmers, greenhouse owners, and even homeowners are all faced with the problem of maintaining the proper level of moisture for various types of plant life. Another appealing aspect of this project is its ease and flexibility of implementation using inexpensive components. Using the knowledge they have acquired in various courses, students would be responsible for selecting or designing and building all of the different components of the system. Through this project students learn to use seemingly abstract information in a practical and business-like manner.

Because it involves the use of information and skills learned in basic electronics and automatic control courses, this experiment could be a very useful and valuable tool when used as part of any junior or senior level electronics, automatic control, digital systems or capstone courses. This experiment has actually been put into practice in my automatic control course and has proven to be a very positive learning experience for student and teacher alike. Students involved with this project have given a very positive feedback on course evaluations and exit interviews.

Acknowledgement

The work done by Laura Stininger, Mary Grassley, Tim Krieger, Shem Ringenberg and Boyd Watts is acknowledged.

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Biography

AHMAD M. FARHOUD is currently an assistant professor in the Engineering Technology Department at the University of Toledo. He received his B.S., M.S., and Ph.D. degrees in electrical engineering from the University of Toledo in 1985, 1987 and 1991 respectively. His research and teaching interests cover the areas of Adaptive Control of Power Systems, Automatic Control Systems, Electronics, Analog and Digital Systems Design and Electric Machines.