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Automatic Control System Trainer with Multiple Experiments

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Abstract- Engineering and Technology is a field that requires practical experience for better understanding of its operations and for effective implementation. There is no system without any form of control if a predefined outcome is anticipated; therefore an in-depth knowledge of control system is a must for every engineer. The indigenous Real Time Automatic Control System Training kit proposed in this research is intended for use in Electrical/Electronic Engineering control laboratory. It comprises of seven modules: the power unit that supplies power to the system; the LCD (Liquid Crystal Display) unit that displays the state of the system at any particular time; the Traffic Light Unit for experiments in traffic light monitoring and control; the Temperature Control Unit For temperature monitoring and control; the Automatic Security Light Unit for trainings in Security light design; the Intruder Detection and Alert Unit for experiments on the design of security management systems using intruder detection system and alarm and the Controller which is the central control unit for the system. There is also an extension for the connection of bread board if the students want to develop other microprocessor based control systems. The microprocessor is detachable so that the student can reprogram the chip to suit his or her application. This system if implemented will greatly enhance engineering training in Nigeria and can also be a great revenue source for the country.

Keywords*-Automatic, Control, Practical, Engineering Training*

I. INTRODUCTION

Automatic Control systems are implemented to increase dynamical performance or precision of scientific and industrial equipment. The basic principle of such system is to take into account actual measurements in order to compute appropriate actuations that adjust the operational conditions to meet given requirements (Salzmann et al, 1999). Due to this broad application field and its interdisciplinary nature, Automatic Control is a fundamental subject usually taught in many engineering disciplines, such as electrical, mechanical and chemical engineering. Practical experimentations are made during laboratory sessions where students can try out on real processes the material they learn during the class (Gillet et al, 1994). As a matter of fact, implementing a complete control solution from scratch requires knowledge not only of the matter studied but also of the different technologies needed to interface the real process, such as sensors and actuators, to the computers or hardware used to conduct the experiment. Knowledge of hardware interfacing and real-time programming are also needed to carry out the experiment. Fundamentals of all these aspects should be taught to students in automatic control. Acquisition of measurements and modification of actuations are the usual tasks carried out by automatic control systems.

II. BASIC CONCEPTS OF AUTOMATIC CONTROL SYSTEM

Automatic control in engineering and technology is a wide generic term covering the application of mechanisms to the operation and regulation of processes without continuous direct human intervention (Wikipedia, 2016). It covers the range of application from a household thermostat controlling a boiler, to a large industrial control system with tens of thousands of input measurements and output control signals

In the simplest type of an automatic control loop, a controller compares a measured value of a process with a desired set value, and processes the resulting error signal to change some input to the process, in such a way that the process stays at its set point despite disturbances.

A. Types of Control Systems

Fundamentally, there are two types of control loop; open loop control, and closed loop (feedback) control. In open loop control, the control action from the controller is independent of the "process output" (or "controlled process variable"). A good example of this is a central heating boiler controlled only by a timer, so that heat is applied for a constant time, regardless of the temperature of the building. The control action is the switching on/off of the boiler. The process output is the building temperature.

In closed loop control, the control action from the controller is dependent on the process output. In the case of the boiler analogy this would include a thermostat to monitor the building temperature, and thereby feedback a signal to ensure the controller maintains the building at the temperature set on the thermostat. A closed loop controller therefore has a feedback loop which ensures the controller exerts a control action to give a process output the same as the "Reference input" or "set point". For this reason, closed loop controllers are also called feedback controllers (Steffano et al, 1967). The definition of a closed loop control system according to the British Standard

Institution is 'a control system possessing monitoring feedback, the deviation signal formed as a result of this feedback being used to control the action of a final control element in such a way as to tend to reduce the deviation to zero (Mayr, 1970). Likewise; a Feedback Control System is a system which tends to maintain a prescribed relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control. (Mayr, 1969). It is the advanced type of automation that revolutionized manufacturing, aircraft, communications and other industries. It is usually continuous and involves taking measurements using a sensor and making calculated adjustments to keep the measured variable within a set range (Bennett, 1992).

B. Typical Manual Control

An understanding of a typical manual control system is helpful in studying automatic process control. This is illustrated in Figure 1, which shows a process with one controlled quantity.

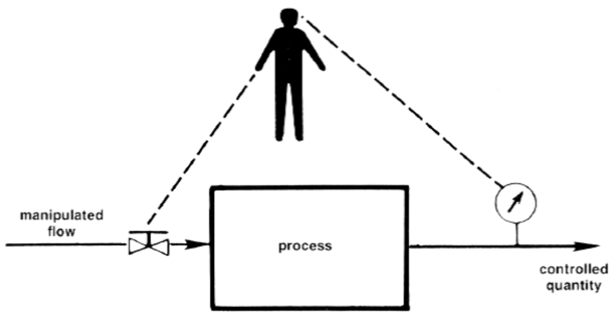

Figure 1. Manual Control System

On the stream leaving the process, there is an indicator to provide the operator with information on the current actual value of the controlled variable. The operator is able to inspect this indicator visually and, as a result, to manipulate a flow into the process to achieve some desired value or set point of the controlled variable. The set point is, of course, in the operator's mind, and the operator makes all of the control decisions. The problems inherent in such a simple manual operation are obvious.

C. Feedback Control

The simplest way to automate the control of a process is through conventional feedback control. This widely used concept is illustrated in Figure 2.

Sensors or measuring devices are installed to measure the actual values of the controlled variables. These actual values are then transmitted to feedback control hardware, and this hardware makes an automatic comparison between the set points (or desired values) of the controlled variables and the measured (or actual) values of these same variables. Based on the differences ("errors") between the actual values and the desired values of the controlled variables, the feedback control hardware calculates signals that reflect the needed values of the manipulated variables. These are then transmitted automatically to adjusting devices (typically control valves) that manipulate inputs to the process.

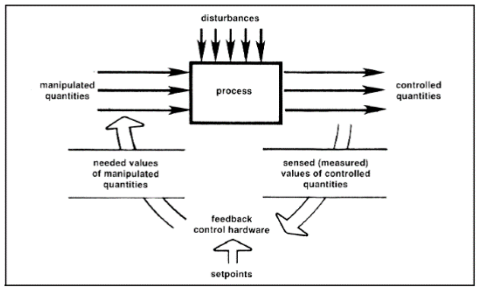

Figure 2. Feedback Control System

D. Manual Feedforward Control

Feedforward control is much different in conception from feedback control. As a disturbance enters the process the operator observes an indication of the nature of the disturbance, and based on that entering disturbance the operator adjusts the manipulated variable so as to prevent any ultimate change or variation in the controlled variable caused by the disturbance. The conceptual improvement offered by feedforward control is apparent. Feedback control worked to eliminate errors, but feedforward control operates to prevent errors from occurring in the first place. The appeal of feedforward control is obvious. Feedforward control does escalate tremendously the requirements of the practitioner, however. The practitioner must know in advance what disturbances will be entering the process, and he or she must make adequate provision to measure these disturbances.

E. Automatic Feedforward

In automatic feedforward control, disturbances enter the process and are measured by sensors. Based on these sensed or measured values of the disturbances, the feedforward controllers then calculate the needed values of the manipulated variables. Set points that represent the desired values of the controlled variables are provided to the feedforward controllers. It is clear that the feedforward controllers must make very sophisticated calculations. These calculations must reflect an awareness and understanding of the exact effects that the disturbances will have on the controlled variables. With such an understanding, the feedforward controllers are able then to calculate the exact amount of manipulated quantities required to compensate for the disturbances. These computations also imply a specific understanding of the exact effects that the manipulated variables will have on the controlled variables. If all of these mathematical relationships are readily available, then the feedforward controllers can automatically compute the variation in manipulated flows that is needed to compensate for variation in disturbances.

F. Control Variables

The three important variables involved in the understanding of control systems are controlled quantities, manipulated quantities, and disturbances as shown in figure 3.

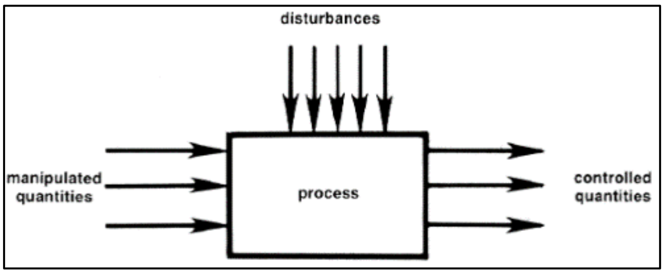

Figure 3. Control Variables

The controlled quantities (or controlled variables) are those streams or conditions that the practitioner wishes to control or to maintain at some desired level. These may be flow rates, levels, pressures, temperatures, compositions, or other such process variables. For each of these controlled variables, the practitioner also establishes some desired value, also known as the set point or reference input. The Variables Involved For each controlled quantity, there is an associated manipulated quantity or manipulated variable. In process control this is usually a flowing stream, and in such cases the flow rate of the stream is often manipulated through the use of a control valve. Disturbances enter the process and tend to drive the controlled quantities or controlled variables away from their desired, reference, or set point conditions.

G. *Real Time Automatic Control Systems*

A Real-Time System (RTS) is defined as a system in which the time where the outputs are produced is significant. The outputs must be produced within specified time bounds referred to as deadlines. The correctness of a RTS depends not only on the logical results produced, but also on the times at which such results were produced. The system may enter an incorrect state if a correct result is produced too early or too late with respect to the specified time bounds or deadlines. Figure 4 shows a block diagram representation of an example of a RTS.

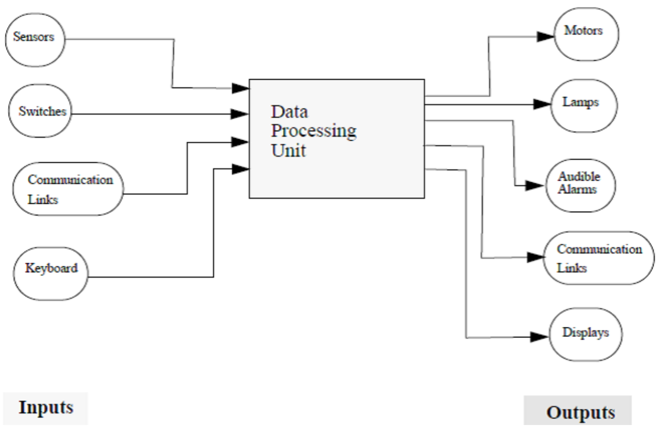

Figure 4. Example of Real Time Control System

III. DESIGN METHODOLOGY AND ANALYSIS

This section explains the methodologies used in this dissertation while presenting the reasons behind the choice of these methodologies for different aspects of the work. This dissertation used top-down design approach and prototyping methodology in its design and implementation.

A. *System Design*

In order to successfully implement the Real Time Automatic Control System Trainer, several electronic components were considered. The choice of any component depends on their characteristic which is considered relevant to the design of the project. Other factors which include cost, efficiency and reliability were also considered in the use of various components. The design of this project will be done under two headings namely hardware and software design.

B. *Hardware Design*

The Real Time AUTOMATIC Control system Trainer is made up of seven sub-systems. They are: the power unit, the intruder detection unit, the traffic light control unit, the temperature control unit, the Display unit, the automatic security light unit and the controller. Figure 5 shows the block diagram of the system showing the different units.

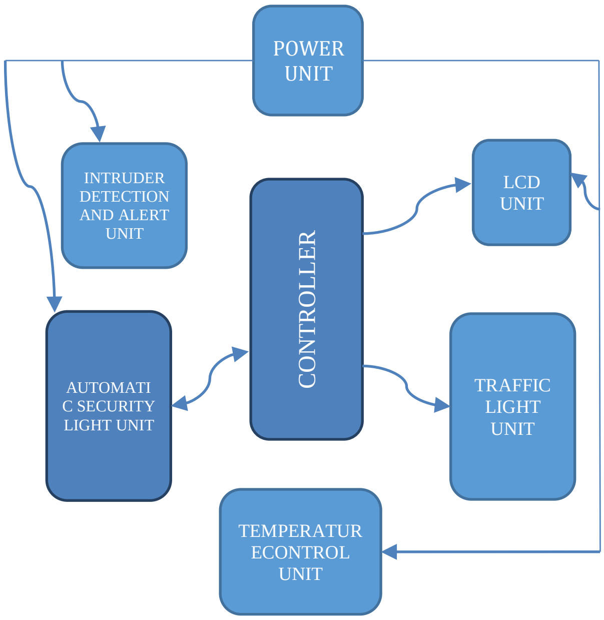

Figure 5. Block diagram of the prototype Real Time Automatic Control System Trainer

C. *Power unit*

The power supply is the source of constant and efficient electric energy needed to power the system. This is supplied by a 5V, 2A power supply adapter through a power jack, and then the output is then further smoothened by a 10uf capacitor. Additionally, it has a LED indicator which helps indicate when the power is available. The block diagram describing the functionality of the power supply is shown in figure 6.

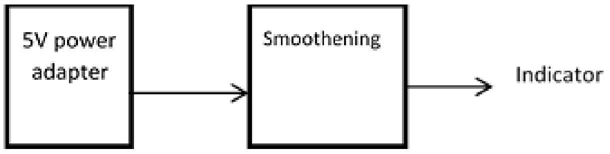

Figure 6. Block diagram of the Power supply unit

D. Intruder Detection and Alert Unit

This unit is for performing experiments on intruder detection and alert systems. It consists of an infrared module for intruder detection and an arrangement of resistor, transistor, diode, LED and a buzzer for alarm activation. IR LED is used in this circuit to transmit infrared light. An Infrared light-emitting diode (IR LED) is a type of electronic device that emits infrared light not visible to the naked eye. Photo diode is used to capture reflected light of IR LED. It is semiconductor diode that, when exposed to light, generates a potential difference or changes its electrical resistance.

The infrared module mainly consists of an infrared-transmitter, an infrared-receiver and a potentiometer. According to the reflecting characteristics of an object, if there is no obstacle, emitted infrared ray will weaken with the propagation distance and finally disappear. If there is an obstacle, when infrared ray encounters an obstacle, it will be reflected back to the infrared-receiver. Then the infrared-receiver detects this signal and confirms that there is an obstacle. Figure 7 is the diagram showing the basic operation of the infrared sensor module.

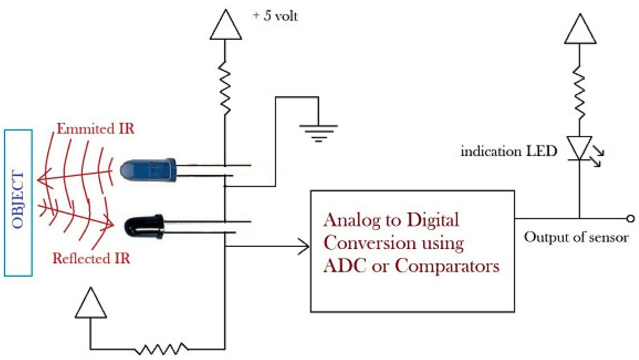

Figure 7. Basic operations of the Infrared Sensor

The circuit diagram for the intruder detection and alert unit is shown in figure 8.

From the circuit above on detection of an intruder, a signal is sent to the p1.4 of the control unit which interprets it and sends a corresponding signal to the alarm sub unit through the p0.3 of the control unit for necessary action.

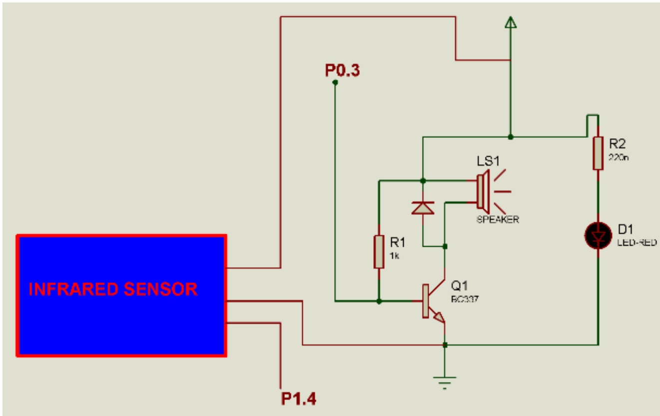

Figure 8. Circuit Diagram for the Intruder Detection and Alarm unit

E. Alarm Sub Circuit Calculation

As shown in figure 8 the system sounds an alarm when an intruder is detected. The alarm unit is connected to the microcontroller and the basic design here is achieved by the use of resistors and transistor. This transistor is configured as a switch. It functions as a switch if it is properly biased.

For proper biasing, the base current (I_b) must be ten times smaller than the

Collector current (I_c).

But $I_c = LEDcurrent + buzzercurrent$

$LEDcurrent = \frac{5}{220} = 22.7mA$

Remember

Buzzer current(BZ) $= 5\text{mA}$

$I_c = 22.7mA + 5mA = 27.7mA$

$$R_c = \frac{V_c}{I_c} \quad (1)$$

Since $V_c = 5\text{v}$

Therefore

$$R_c = \frac{25}{27.7\text{mA}}$$

$$R_c = \frac{25 \text{ x } 10^3}{27.7}$$

$R_c = 0.90\text{k}\Omega$

Approximately $R_c = 1\text{k}\Omega$

Therefore, for approximately 27.7mA current to flow through the collector, a buzzer with resistance of 780Ω and 220Ω were used at the collector of the transistor.

Hence, considering the base resistor

$I_c = I_b\beta,$

$$therefore\ I_b = \frac{I_c}{\beta} \quad (2)$$

B > 5 x load current

$$\beta > 5 \times \frac{Loadcurrent}{\text{Max.chip current}}$$

But, load current = 27.7mA, Max. Chip current = 20mA

$$\beta > \frac{5 \times 27.7 \times 10^{-3}}{20 \times 10^{-3}}$$

β>6.93

Therefore, let β = 7

From equation 2:

$$I_b = \frac{27.7 \times 10^{-3}}{7}$$

$$I_b = 3.96\ mA$$

But, $R_b = \frac{V_b}{I_b}$

$V_b = 5$v

$$R_b = \frac{5}{3.96x\ 10^{-3}}$$

$$R_b = 1.26\ k\Omega$$

Hence a 1K Ω is used to ensure the transistor is driven to saturation.

F. Automatic Security Light Unit

This unit is used to perform experiment as regards automatic security light, which comes on at night or when it is dark and goes off during the breaking of the day. This unit is made up of the darkness detection sub-unit (light dependent resistor) and the security light switch as shown in figure 9. The LDR (Light Dependent Resistor) uses the intensity of the light rays it receives to determine when it is dark. It also consists of a resistor, and a transistor interfaced to the control unit. While the security light switch consist of a transistor, security light and a resistors.

On detection of darkness (i.e. very low light intensity) by the darkness detector sub unit, a signal is sent to the control unit which interprets it and then activates the security light by biasing the transistor in the security switch sub unit. When the light intensity increases the security lights are automatically switched off.

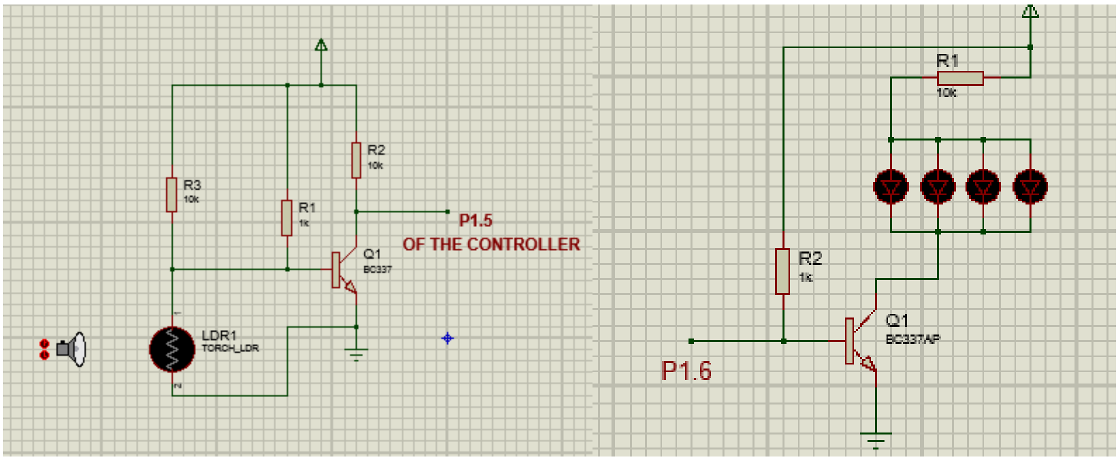

Figure 9. Circuit diagram for Automatic Security Light Unit

G. Temperature Control Unit

This unit allows one to perform an experiment that has to do with temperature monitoring and device control. This unit is made up of LM35, resistor, LED and an Analog to Digital Converter (ADC). The output of LM35 gives analog reading which is converted from Analog to Digital through the ADC and its output fed into the port 3 of the control unit, LED is used to indicate when the temperature limit (in this case 29°C) is exceeded, while all its activities are displayed on the central Liquid Crystal Display. The output voltage from theLM35 is linearly proportional to the measured temperature. The network of resistors and zener diodes seen in the ADC configuration supply 1.28V to the $V_{ref/2}$ pin of ADC0804 as its reference voltage as shown in figure 10. This is the voltage by which the step size of the ADC0804 will be set to 10mV. LM35 output voltage varies by 10mV per °C change in temperature. Hence both the LM35 and ADC0804 are now working at 10mV change. So for a range of 0 to 100°C, LM35 outputs 10mV per °C and ADC0804 processes 0V to 1V.The state of the module and the ambient temperature as sensed by the LM35. The system sends a signal to the actuator triggering a predefined action when the redefined maximum temperature is exceeded. In this work the maximum temperature is 29°C and the actuator puts on an LED. In real life application it can be to put on a cooling system if it is an industry it can be a cooling system or it can be a fan in the home.

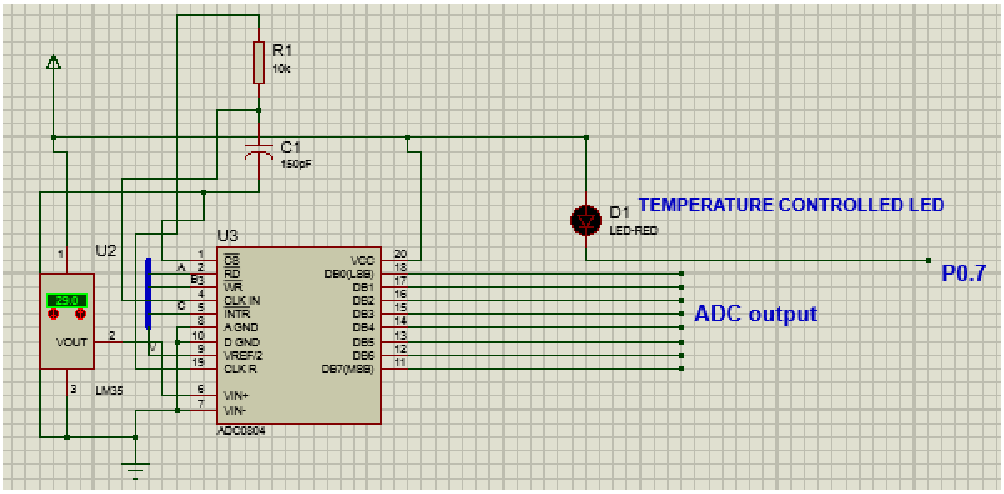

Figure 10. circuit diagram for the Temperature Control unit

H. Traffic Light Unit

This unit allows one to perform an experiment that has to do with traffic light demonstration, but this is limited to T-junction. For the purpose of the demonstration nine LEDs were used. The LEDs are configured as common Anode, while the cathodes of the individual LEDs were interfaced to the port 2 of the control unit.

1) Limiting resistor for all led used in this work

From database, LED allowable current is taking as 23 mA, and 5v across it.

But $R = V/I$

$R = 5/23\text{x } 10^{-3}$, $R = 217\Omega$

But for this work, 220 Ω Resistor was used since it is readily available in the market.

I. Liquid Cristal Display (LCD) Unit

This unit is responsible for displaying all the activities of the system, making it user friendly.

Liquid crystal displays (LCD) are widely used in recent years as compares to LEDs. This is due to the ability to display numbers, characters and graphics, incorporation of a refreshing controller into the LCD, thereby relieving the CPU of the task of refreshing the LCD and also the ease of programming for characters and graphics. HD 44780 based LCDs are most commonly used.

Figure 11. A general purpose alphanumeric LCD with two lines and 16 characters

1) LCD Pin Description

The LCD discussed in this section has the most common connector used for the Hitatchi44780 based LCD. It has 14 pins with additional two pins for back light. A picture of a generic alphanumeric LCD is shown in Figure 11. The pin description, modes of operation and how to program and interface with microcontroller are describes in the following section.

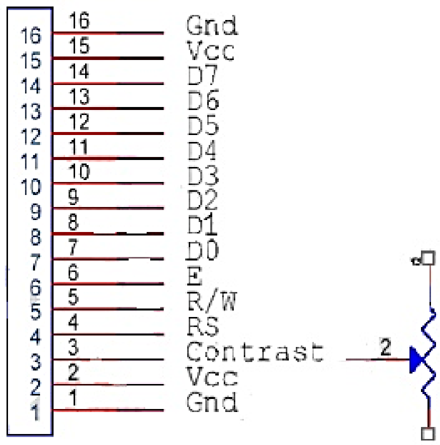

Figure 12. The Pin Labeling of Hitachi 44780 based LCD

- VCC, VSS, VEE: The voltage VCC and VSS provided by +5V and ground respectively while VEE is used for controlling LCD contrast. Variable voltage between Ground and Vcc is used to specify the contrast (or "darkness") of the characters on the LCD screen.
- RS (register select): There are two important registers inside the LCD. The RS pin is used for their selection as follows. If RS=0, the instruction command code register is selected, then allowing to user to send a command such as

clear display, cursor at home etc.. If RS=1, the data register is selected, allowing the user to send data to be displayed on the LCD.

- R/W (read/write): The R/W (read/write) input allowing the user to write information from it. R/W=1, when it read and R/W=0, when it writing.
- EN (enable): The enable pin is used by the LCD to latch information presented to its data pins. When data is supplied to data pins, a high power, a high-to-low pulse must be applied to this pin in order to for the LCD to latch in the data presented at the data pins.
- D0-D7 (data lines): The 8-bit data pins, D0-D7, are used to send information to the LCD or read the contents of the LCD's internal registers. To displays the letters and numbers, we send ASCII codes for the letters A-Z, a-z, and numbers 0-9 to these pins while making RS =1. There are also command codes that can be sent to clear the display or force the cursor to the home position or blink the cursor. We also use RS = 0 to check the busy flag bit to see if the LCD is ready to receive the information. The busy flag is D7 and can be read when R/W = 1 and RS = 0, as follows: if R/W = 1 and RS = 0, when D7 = 1(busy flag = 1), the LCD is busy taking care of internal operations and will not accept any information. When D7 = 0, the LCD is ready to receive new information.The circuit diagram for the LCD connection is shown in figure 13.

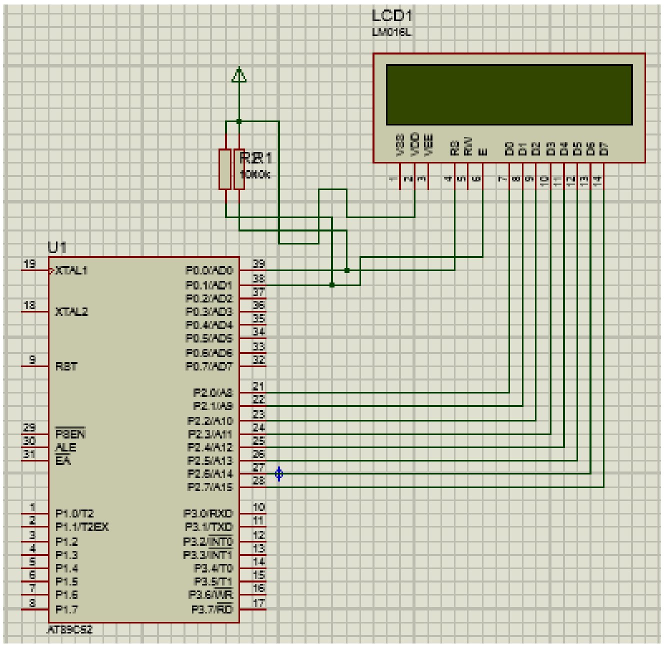

Figure 13. LCD connection to the microcontroller

J. The Control Unit

This unit does the entire processing of all the input signals to the system and as well as take the necessary action in response to the input (s). It consists of four control buttons and an Atmel microcontroller (AT89C52). The circuit diagram for the controller and its input pins are shown if figure 14.

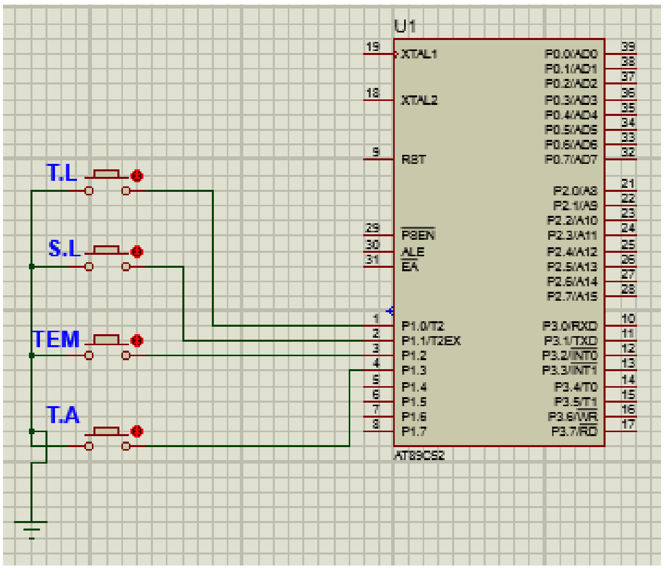

Figure 14. The control Unit

The AT89C52 has on-chip oscillator but requires an external clock to run it. A quartz crystal oscillator is connected to inputs XTAL 1 which is pin 19 and XTAL 2 which is pin 18. Also two 33pf capacitors were also connected to the crystal while the other side of the capacitor is connected to the ground. The essence of the crystal oscillator is to control the speed of the micro controller. The speed of the microcontroller refers to the maximum oscillator frequency connected to XTAL pins. The frequency can be observed on the XTAL 2 pin using the oscilloscope. RESET pin is the Pin 9. It is an input pin and is active high (normally low).Upon applying a high pulse to this pin, the microcontroller will reset and terminate all activities. This is often referred to as "power on reset". Activating a power on reset will cause all values in the register to be lost. Normally the value of the program counter (PC) is "0"upon reset, forcing the CPU to fetch the first up code from ROM memory location 0000.this means that we place the first line of source code in ROM location "0" because that is where the CPU wakes up and expects to find the first instruction. A 10uf/16V capacitor and 10KΩ resistor was connected to pin 9 to complete the reset of the microcontroller. To perform traffic light experiment the control button T.L is pressed, to perform security light experiment S.L control button should be pressed, on performing temperature experiment TEM control button should be pressed and to perform experiment regarding intruder alert then T.A control button should be pressed.

K. The Software Design

The software design involves the design of the flowchart for the AT89C52 control program. Software has become the most critical element in the design and implementation of a computer based system of whatever size. Because of the critical nature of software, structured programming and top-down software development methodologies are usually used by many microprocessor system application designers.

In structured programming, each software component is first described in terms of a few fairly abstract statements, and then they are iteratively refined until they could be expressed in the algorithm. The application program, that is, the set of instructions directing the microprocessor's execution of a specific task must first be developed and then loaded into the memory unit.

IV. RESULTS AND DISCUSSION

This section involves the testing of the system, final implementation and discussion of the results obtained. This will involve integration of the different components of the design to achieve a complete working device. The complete circuit diagram was tested on a bread board, patterned and etched on a printed circuit board. The components were mounted following the design as shown in figure 15. The system functions in such a way that any student performing an experiment will select the module he or she wants to work on by pressing the button for that experiment. To perform traffic light experiment the control button T.L is pressed, to perform security light experiment S.L control button should be pressed, on performing temperature experiment TEM control button should be pressed and to perform experiment regarding intruder alert then T.A control button should be pressed. There is also an expansion slot for students that wish to perform other microcontroller based experiments that are not part of the original design.

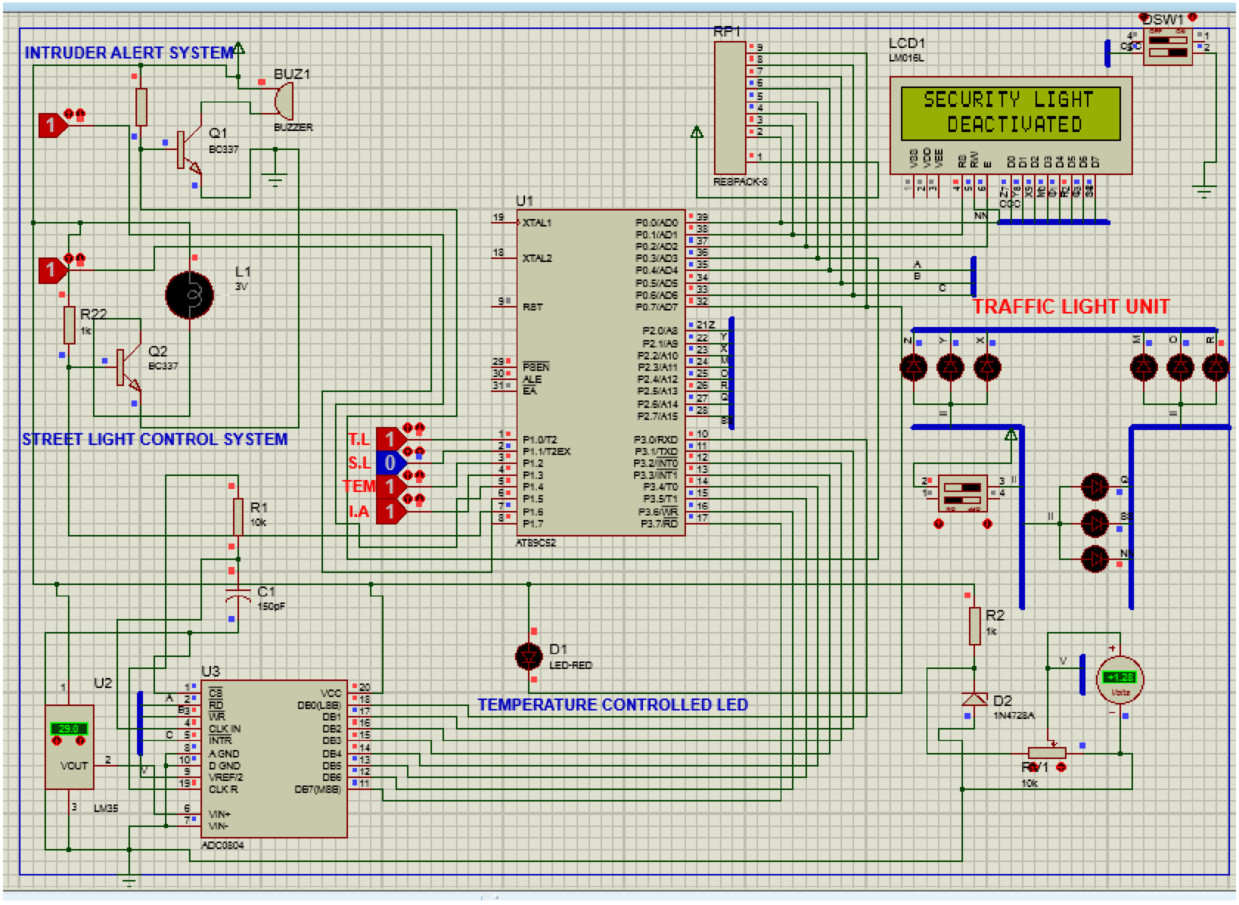

Figure 15. The complete circuit diagram of the Real Time Automatic Control System Trainer

A. *System testing*

The Automatic Load Shedding system essentially comprises two basic parts, namely: the hardware and the software parts. This section involves testing each part separately. When the desired result is obtained, the two parts are then integrated and the overall system test is carried out with the aim of getting the desired result.

B. *Hardware Subsystem Testing*

The output of the 5V/2A power adapter was tested to ensure that the power supply to the system is 5V/2A. To do this the adapter was powered by a 220V AC and the output was measured using multimeter. It gave an output VOLTAGE of 5V and current of 2A. The electronics components were tested and found to be functional. The microcontroller was tested by measuring the crystal terminals of pin 18 and 19; the crystal pins read a voltage of 2 volts showing that it is functional. This shows the crystal pins are oscillating. The whole circuit was then mounted on a bread board and tested for continuity. The program was then burnt into the controller and the system was test run. It performed satisfactorily. The circuit pattern made on the printed circuit board was tested for continuity and it was found to be okay. The components were mounted and test run. It functioned satisfactorily.

C. *Software Subsystem Testing*

The software program was tested and debugged using the MIDE compiler program. Afterward the hex file generated by the compiler was downloaded into the microcontroller and the operation of the microcontroller while executing the hex file was tested and observation of any malfunction noted for correction. The corrections were made and the system performed satisfactorily. The different parts of the research work were found to function as required. The complete circuit diagram was traced, patterned and etched on a printed circuit board. The components were mounted and they functioned satisfactorily. The whole system was packaged using Perspex for protection and good aesthetic value. The LEDs indicating the roundabout at the T-junction came up (it is meant to be on when the system is powered by defaut), the LCD initialised and displayed the introductory messages. The keys responded as expected when pressed and all the subsections performed satisfactorily.

V. CONCLUSION

This research work is on the design and implementation of Real Time Automatic Control System Trainer. This system comes as a solution to the challenges being faced by engineering students in Nigeria by providing a training kit for practical understanding of the theoretical knowledge taught in class. It is a very good tool for electrical and electronic engineering students in that it provides the platform for them to experience a practical approach to the learning of Real Time Automatic Control System. The system is also economical in that it houses minimum of four different experiments in automatic control covering both industrial and home automation and can be extended to other microcontroller based automatic control system experiments through the expansion slots connected to the controller. The use of this system in school laboratories will greatly enhance the training of engineering students in these fields.

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