Design and Implementation of Electronics Equipment Security Lock System

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Authors’ contributions

This work was carried out in collaboration between all authors. Author DTA designed the study and wrote the first draft of the manuscript. Author FNG wrote the protocol/proof-read the write up while author CAC perform the test/analyses of results. All authors read and approved the final manuscript.

ABSTRACT

The work presents the design and implementation of a Central Electronic Equipment Security Lock System - a security and access control system for used in public and private organisations as a means to restrict unauthorized access to valuable electronics equipment. The system interfaced the microcontroller (PIC16F877A) to the 16 x 2 Liquid Crystal Display (LCD) which is used to communicate/display the visual outputs to the user, multiplexed keypad (4 x 3) as input unit, three relays (30A, 12V) that serve as isolators and the buzzer-a warning device that gives an alarm when a wrong password is encoded. When the correct password is entered, the system grant access to the user and upon entry of a wrong code three times, the system gives a sound alarm via a buzzer showing that unauthorized person has tempered with the property being secured. By this, the user can also choose which equipment to grant access to (switch on) or not. The system is programmed using Assembly language and MPLAB compiler IDE to grant access to a single load or multiple loads either automatically or manually. The regulated power supply of the system showed a
negligible difference of (4.9 V and 11.8 V compared to the ideal values of 5.0 V and 12.0 V respectively. Also, the system operation timing tests carried out with respect to real time showed a mean variation of 0.005 min (0.30 sec). These errors are quite negligible hence the system is certified to be of optimal performance. The designed and implemented Central Electronic Equipment Security Lock System therefore finds suitable application in security and access control systems for use in public and private organisations as a means of restricting unauthorized access to valuable electronics equipment.

Keywords: Microcontroller; programming; access control and Isolators.

1. INTRODUCTION

Our society today is faced with some major problems such as insecurity and crime. The desire by people to reduce or end insecurity (unauthorised access to places or use of valuable electronic properties) has made some organisations to employ personnel who are charged with the responsibility of granting access to the use of these electronics facilities. However, this builds up expenses in addition to inability of these personnel to provide wide security coverage of these facilities especially in large laboratories. The conscious and continuous effort to end the challenge gave rise to the concept of digital locking system. An electronic or digital lock is that lock that operates using an electrical actuator instead of the mechanical system used in traditional key locks. Electronic locking systems are flexible as they enable interface to access control system and integration with security systems as well as personnel management tasks such as time and attendance [1]. The development in digital lock security system has wide areas of applications, some identified areas range from car doors locks, home doors locks, bank safe, travel bag locks etc. The common among all areas of application is related to deterring unauthorised access to places, document or entry.

A Central Electronic Security Lock System is an electronic device that controls access to many electronic facilities with less or no human interference.

The common features of any digital lock system comprises of input, output, memory and central processing units. The input unit can be single switch, multiple switches (keypad), or pattern prescription. The output unit could be display, or trigger actuator which open or lock access. The memory is used as means to save password for future reference. The central processing unit coordinates all the activities in other units. With the presence of input, output, memory and central processing units, the system could be viewed as minicomputer with low level of intelligent and low computing power.

This design interfaced digital display, multiplexed keypad, relays, and buzzer to the microcontroller unit. The multiplexed keypad serves as input device to the system, the display serves as a means to communicate visual output to the user, relay formed isolating unit between the lower voltage (5V) of the microcontroller and the high voltage (220V AC). The buzzer serves as audio output (indicator).

The system is useful in homes, offices, private/public organisations to deterred unauthorised access to facilities.

2. MATERIALS AND METHODS

2.1 Materials

The materials used for the construction of the Central Electronic Equipment Security Lock System are:

- Relays (30A, 12v), 16x2 LCD, capacitors, assorted biasing resistors, microcontroller unit (PIC 16F877A), MPLAB compiler and Integrated Development Environment (IDE), transformer (15V, 2A), assorted wires, sockets (13A) Outlets, LED (indicators), transistors, crystal oscillators, vero/Bread board. Others include: programmer (Encoder), diodes/bridge rectifier, regulator (LM7805) and (LM7812), Input switches and reset switch / multiplexed keypad buzzer, timer/watch, lead etc.

2.2 Methods

This design is divided into two parts i.e. the hardware (circuits) and software (the programme that that run the system). The hardware consists of two parts i.e. the power supply unit and the
control board (main circuit). This can be seen in system architecture in Fig. 1.

![Fig. 1. System architecture (Block diagram)](image)

2.3 Power Supply Unit

This power supply unit is built such that it gives output voltage levels (+5V and +12V). The 5V is used to power the microcontroller unit and LCD while the 12V is used to drive the relays and the buzzer. The power unit takes mains voltage (220V AC) and steps it down using 220V/15V/2A step down transformer, TR1 (chosen off the shelf). The output of the transformer is then rectified using full wave bridge rectifier (KPB-206). Two voltage regulators (LM7805 and LM7812) were employed to regulate the output of the rectifier to 5V and 12V respectively. To have effective stable 5V and 12V, pre-regulation and post-regulation filtering capacitors were incorporated to remove ripples [2]. C5 (0.1 µF) and C1 (3300 µF) are pre regulation filtering capacitors while C2 (100 µF), C3 (10 µF) and C4 (0.1 µF) are post regulation filtering capacitors. An LED (D1) as power indicator with a protecting resistor R1 (2.2 K preferred value) was then incorporated in the power unit as shown in the circuit diagram below.

![Fig. 2. Power supply circuit](image)
2.4 Control Board (Main Circuit)

The design interfaced digital display, multiplexed keypad, relays, and buzzer to the microcontroller unit. The multiplexed keypad served as input device to the system, the display served as a means to communicate visual output to the user, relays form isolating unit between the lower voltage (5V) of the microcontroller and the high voltage (220V AC). The buzzer is used as audio output (indicator) unit. Therefore, the design is divided into four stages i.e. Power supply unit, Input unit, Central processing unit and Output unit. The microcontroller unit (MCU) PIC16F877A serves as the coordinator of activities in other parts (keypad, relays, LCD and buzzer), an 8bit data bus from PIC16F family. The MCU has PORT A, B, C, D and E, with exception of PORT E which is 4bits wide, all other PORTS are 8bit wide. The MCU uses any of the PORTS to communicate with external environment; data can be written or read from the PORTS. Some of the PORTS or PIN of the microcontroller has more than one function.

2.5 PIC16F877A Configuration

The Microcontroller unit has five inputs and outputs PORTS A, B, C, D and E, a ports is the means the CPU inside the Microcontroller communicate with the external environment. With exception of PORT E which has 4bits, all others PORTS in the MCU are 8bits wide. Each PORT has configuration register which is used to the port function as output or input [3]. When logic 1 is written to the configuration register of the 16F877A, it will be set to accept input data from external environment. By writing logic 0 to the same configuration register, it function changes to serve as output. The table below illustrates the PORTS configuration used in the project.

### Table 1. Configuration of PIC16F877A pins

<table>
<thead>
<tr>
<th>S/N</th>
<th>PORT/Bits number</th>
<th>Configurations</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A (A1, A2, A3 and A4)</td>
<td>Input</td>
<td>Corresponding to Row 1, Row 2, Row 3 and Row 4 of the keypad which interfaced to the MCU using this PORTS pins.</td>
</tr>
<tr>
<td>2</td>
<td>B (B0 – B7)</td>
<td>Output</td>
<td>Used to write data to the LCD display.</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>Output</td>
<td>Outputs set to switch or control OFF and ON state of relay drivers. Bits PC0 is used to driver the buzzer.</td>
</tr>
<tr>
<td></td>
<td>Bits PC4, PC5 and PC6 Bit PC0</td>
<td></td>
<td>Used as control lines Reset(RS),Read/Write (R/W) and Enable (E) for the LCD display respectively</td>
</tr>
<tr>
<td>4</td>
<td>D (D5, D6 and D7)</td>
<td>Output</td>
<td>Used as column scan for the keypad.</td>
</tr>
<tr>
<td>5</td>
<td>E (E0, E1 and E2)</td>
<td>Input</td>
<td></td>
</tr>
</tbody>
</table>

Source: [4]

2.6 Design Analysis

2.6.1 Power supply circuit

The power supply uses a step down transformer, TR1 with the rating- 220V/15V 2A. It was chosen based on the voltage requirement of the two regulators.

Some electronic components require unidirectional flow of current or voltage. To convert the sinusoidal signal (a.c. mains) to unidirectional dc signal, BR1- a full wave bridge rectifier was used. The ripple voltage was calculated using the formula

\[ V_{ripp} = n\% \times V_{peak} = n\% \times V_{rms} \times \sqrt{2} \]

(1)

The ripple factor (percentage of noise), n% allowed in this design is 10% therefore,

\[ V_{ripp} = 2.1V \]

C₁ is a shunt capacitor that is necessary to filter the rectified voltage and hold the charges thereby preventing the circuit from destruction. Using the relationship below, the capacitance of C₁ was calculated as follows:

\[ V_{ripp} = \frac{l}{4\sqrt{3fC_1}} \]

(2)
Therefore from equation (2) above we obtain 
\[ C_1 = 0.003 \text{ F} = 3000 \mu\text{F}. \]

The capacitance with closest value (3300 \( \mu\text{F} \), preferred value) to the above capacitance was used in this circuit for the above mentioned purpose.

Since microcontroller applications are sensitive to voltage fluctuation and presence of ripples, the post regulation filters i.e. Capacitors \( C_2 \) (100 \( \mu\text{F} \)), \( C_3 \) (10 \( \mu\text{F} \)), \( C_4 \) (0.1 \( \mu\text{F} \)) were used to remove the residual ripples.

The LED used has the rating: 2V and 25mA maximum; the current coming from the transformer is a maximum of 2A which is way above the current requirement of the LED. For appropriate choice of resistance value for the LED network resistor \( R_1 \), the following calculations were considered.

The voltage entry into this resistor-LED network is the peak voltage given by the equation.
\[ V_{\text{rms}} \times \sqrt{2} = V_{\text{peak}} \quad (3) \]
since the post-rectification voltage is higher than the required 15V, then we have
\[ V_{\text{peak}} = 21\text{V} \]
21V enters the resistor-LED network but a maximum of 2V is dropped across the LED at 10mA. It therefore means that the voltage drop across the current limiting resistor = (21V-1.8V) = 19.2V.
\[ V = IR \quad (4) \]
The LED resistance is calculated using equation 4
\[ R_1 = \frac{\text{voltage across } R_1}{\text{current through } R_1} = \frac{\text{peak voltage-LED voltage}}{\text{current through } R_1} = \frac{19.2V}{10\text{mA}} = 1.92\text{K}\Omega \quad (5) \]
Hence, the resistor with value 2.2k\( \Omega \) was chosen for the design as the closest value, 2k\( \Omega \) is not common.

2.6.2 MCU

The PIC16F877A MCU selected for the work has been configured with a crystal oscillator of 4.00MHz to produce the desired clock period. Since machine cycle = Time taken for the microcontroller to execute one instruction is obtained from (5).
\[ \text{Cycle} = \frac{\text{Crystal frequency}}{\text{the number of cycles of the controller(Clock cycles)}} \quad (6) \]
In this design, the crystal frequency = 4MHz and from the PIC architecture, there are 4 clock cycles for one instruction to be executed (machine cycle).

Therefore, machine cycle = \( \frac{4\text{MHz}}{4} \) = 1MHz
Therefore applying equation 6 the processing speed is computed as:
\[ T = \frac{1}{f} = \frac{1}{1000000} = 1\mu\text{s} \]

2.6.3 MCU-buzzer

The maximum base current, \( I_B \) for BC547 is 5mA from the data sheet. However, for a current of 4.5mA to pass through the base, 1k\( \Omega \) was chosen as the base resistor.

The voltage from the microcontroller, \( V_{\text{out}} = 5\text{V} \)
The base-emitter voltage, \( V_{BE} = 0.7V \)
\[ R_B = \frac{\text{Voltage across base resistor}}{\text{base current}} = \frac{V_{\text{out}}-V_{BE}}{I_B} = 955.6\Omega \quad (7) \]
Therefore, the resistor with the value 1k\( \Omega \) was used as the base resistor. From equation 8, the buzzer current can be calculated as:
\[ I_{BUZ} = I_C = \beta I_B \]
If a minimum gain, \( \beta = 20 \) is desired, the buzzer current = 4.5mA x 20 = 0.09A = 90mA

2.6.4 MCU-relays

The coil resistance according to the rating is 180\( \Omega \) and voltage driving the relay is 12V therefore, the relay coil current was calculated as follows:
\[ I_C = \frac{\text{voltage across the coil}}{\text{coil resistance}} \approx 67\text{mA} \quad (8) \]
The collector current, $I_C$ of the transistor, Q2 is calculated using the following equation:

$$I_C = \text{Coil current} + \text{LED current} = 77\text{mA} \quad (9)$$

From the data sheet of BC547, at $I_C = 100\text{mA}$, $I_B = 5\text{mA}$

In this design, to ensure the current is enough to drive the transistor Q2 into saturation, an estimated collector current of 90mA was used at minimum gain, $\beta$ of 20. By applying (9) the base current is computed to be:

$$I_B = \frac{\text{collector current}}{\text{gain}} = 4.5\text{mA} \quad (10)$$

The same calculations applied to the remaining transistors Q3 and Q4.

### 2.7 Software Development

The microcontroller is the central coordinator, it manages all activities in the system like reading key press from the keypad, writing on LCD display, making logical decisions based on the password entered, proving the ON and OFF functionality of the buzzer and also ON and OFF control of the electronics devices. These are done with the help of a programme (software). The sequence, with which the above mentioned activities and other manipulations are repeatedly performed by the microcontroller, is called flowchart. This was developed into pseudo code and finally using MPLAB IDE, the pseudo code was developed into a firmware. The program was written in low level programming language (Assembly language), the integrated Assembler then generates the hex (binary) files based on the MCU architecture. The binary files are the machine instructions which contain 0s and 1s logic states that the MCU understands.

The hardware developed and the firmware were integrated to fully functional system using a programmer; a device that receives hex files (binary) from host system and then write them into the flash memory of the MCU.

### 2.8 System Operation

The soft touch button that forms input pins was connected to RA1 - RA4 of the PIC16F877A. With each input pin pulled up to a permanent Logic 1, the MCU continues seeing logic 1s in all inputs pins. The transitions from logic 1 to logic 0 in any of the inputs will indicate the corresponding button has been pressed which will require necessary action.

The output pins RB0 – RB7 from the MCU are connected to D0 – D7 of the LCD, these data line are used to send/read data to/from the LCD. While RD5 – RD7 are connected to E, RW and RS respectively, they are used as control lines of the LCD. RD4 is used to ON/OFF background light of the LCD. The RC0 is used for audio control [4].

### Table 2. Description of LCD pins

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSS/GND</td>
<td>Power supply ground</td>
<td>This is ground, it is a reference point to all voltages/signal lines in the LCD</td>
</tr>
<tr>
<td>VDD/VCC</td>
<td>Power supply</td>
<td>This is equivalent of Vcc, it takes maximum of 5V.</td>
</tr>
<tr>
<td>VEE</td>
<td>The pin used to supply variable voltage to the contrast control in the LCD</td>
<td>Control brightness of the LCD</td>
</tr>
<tr>
<td>RS</td>
<td>Register select.</td>
<td>Input pin to the LCD, it tells the LCD if the current data is a displayable or command.</td>
</tr>
<tr>
<td>R/W</td>
<td>Read/Write</td>
<td>This pin can be configured as input or output to the LCD. It tells the LCD to read or output data on the data bus.</td>
</tr>
<tr>
<td>E</td>
<td>Enable pin</td>
<td>This pin only functions as input to the LCD. It a strobe to the LCD.</td>
</tr>
<tr>
<td>D0 – D7</td>
<td>Data bus</td>
<td>The data bus, they carry command and RAM data in and out of the LCD</td>
</tr>
<tr>
<td>X1</td>
<td>Crystal oscillator</td>
<td>This is a crystal oscillator, it is used as clock generator, it determines the machine cycle.</td>
</tr>
<tr>
<td>RV1</td>
<td>Variable resistor</td>
<td>Used to set the contrast level of the LCD.</td>
</tr>
</tbody>
</table>

Source: [4]
Though the PIC16F877A has inbuilt RC oscillator circuit selectable using configuration fuses, an external crystal oscillator (Frequency 4MHz) is used to provide the system clock rate. The clocking rate of the crystal will determine the speed of execution in microcontroller. An instruction cycle takes 1/4 of external crystal frequency to be executed [5].

2.9 Working Principle

The system configurations and mode of operation are set by the authorised user at the initial deployment, these configurations are: setting the master password, setting number of fail trials. After final deployment, user password must match the master password for authorised access. The failed number of trials is used to set maximum number of entries a user is allowed to make. Once this number is exceeded, the system raises alarm signifying detection of a suspicious operation. In normal system operation, the user enters his/her alphanumeric password then the system compares this password with the password in the memory before access is granted. The system is sensitive to the order in which the password was entered, case type (lower/upper) in term of alphabets. The user password can be pure numeric or pure alphabet characters.

Authorised access is identified when a user’s password matches the pre-configured password. In an event a user fails on 3 consecutive trials the system secretly send alert in form of sound (audio) and light (visual) signals, this is an indication that an unauthorized access has been detected. The presence of memory enables general reset and reconfiguration of the system.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Power supply output voltage test

The power supply built in this design was intended to provide two output voltage levels i.e. 5V and 12V respectively. After the design and implementation of this unit, the two levels of output voltage were tested/measured using voltmeter. The results are as shown in the Table 3.

3.1.2 System operation timing tests

System operation timing tests were carried out on the single load at various intervals and the results presented in Table 2. Similarly the test was carried out on three different load statuses (single load, double loads and triple loads) within a 60minute interval and the result presented in Table 3.

<table>
<thead>
<tr>
<th>System time/min</th>
<th>Measured time/min</th>
<th>Time lag /min</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>9.997</td>
<td>0.003</td>
</tr>
<tr>
<td>20.0</td>
<td>19.994</td>
<td>0.006</td>
</tr>
<tr>
<td>30.0</td>
<td>29.993</td>
<td>0.007</td>
</tr>
<tr>
<td>40.0</td>
<td>39.996</td>
<td>0.004</td>
</tr>
<tr>
<td>50.0</td>
<td>49.997</td>
<td>0.003</td>
</tr>
<tr>
<td>60.0</td>
<td>59.995</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Average time lag (Table 4) = 0.005 min

Table 5 presents the results of tests carried out on different load status. From the results, the system displays optimal performance irrespective of the load status as shown by the negligible variation.

From the frequency of the micro controller (4 MHz) it takes the controller 1 micro second (ms) to execute an instruction. The timing test carried out while the system was on load was to check its stability under stress which is one of the factors that determine the longevity of the system. This system can be operated in manual
Table 5. System operation timing test results

<table>
<thead>
<tr>
<th>Load status</th>
<th>System time/min</th>
<th>Measured time/min</th>
<th>Time lag/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single load</td>
<td>60.0</td>
<td>59.995</td>
<td>0.005</td>
</tr>
<tr>
<td>Double loads</td>
<td>60.0</td>
<td>59.993</td>
<td>0.003</td>
</tr>
<tr>
<td>Triple loads</td>
<td>60.0</td>
<td>59.996</td>
<td>0.004</td>
</tr>
</tbody>
</table>

4. CONCLUSION

The need to provide security to valuable electronic gadgets is the basis of this design (Central Electronic Equipment Security Lock System). This aim has been achieved as the design has been successfully implemented. Moreover, the measurement/test carried out on the system has proven its optimal performance. One of the important feature of the system is its dual mode of operation (manual and automatic modes) giving it an added advantage over some of the previously designed systems. This system has a wide range of applications ranging from domestic electronic gadgets security to industrial electronic equipment security.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

APPENDIX

(A) Some Basic Design Equations

From Ohm’s Law, 
\[ V = IR \] [6].

The ripple voltage, \( V_{\text{ripple}} = n\% \times V_{\text{peak}} = n\% \times V_{\text{rms}} \sqrt{2} \)

Where \( V_{\text{peak}} \) is the peak voltage, \( V_{\text{rms}} \) is the root-mean square voltage and \( n \) is the ripple factor [7]

\[ V_{\text{ripple}} = \frac{1}{4\sqrt{3}fC}, \quad c = \frac{1}{4\sqrt{3}fV_{\text{ripple}}} = \frac{1}{4\sqrt{3}fV_{\text{rms}} x n\% x \sqrt{2}} \]

where \( C \) is the filtering capacitor [8]

LED resistance, \( R_1 = \frac{\text{voltage across } R_1}{\text{current through } R_1} = \frac{\text{peak voltage} - \text{LED voltage}}{\text{current through } R_1} \) [9]

Instruction period per unit execution by a microcontroller = \( \frac{\text{Crystal frequency}}{\text{the number of cycles of the controller(Clock cycles)}} \) [5]

From \( T = \frac{1}{f} \)

The collector resistance, \( R_C \) of a BJT is given by: \( R_C = \frac{\text{Voltage across } R_C}{\text{base current}} = \frac{V_{\text{out}} - V_{\text{BE}}}{I_B} \)

Where \( V_{\text{BE}} \) is the base voltage,

\( I_{\text{BUZ}} = I_C = \beta I_B \)

\( \therefore \) Base current, \( I_B = \frac{\text{collector current}}{\text{gain}} \)

Where \( I_{\text{BUZ}} \) is the buzzer current, \( I_C \) is the collector current, \( I_B \) is the base current, \( \beta \) is the desired gain [10].

The collector current, \( I_C \) of a BJT transistor is the sum of the LED current and coil current [10]

\( \therefore I_C = \text{Coil current} + \text{LED current} \)

The Relaycoil resistance, \( R \) is given related by: Relay current = \( \frac{\text{voltage across the coil}}{\text{coil resistance}} \) [11]
(B) Main circuit (control board)
(C) Program Algorithm for Electronic Equipment Security Lock System

1. Start
2. Configuration and initialization of ports
3. Initialization of LCD
4. Initialization of EEPROM
5. Store default code/value
6. Scan Power Switch (#)
   - If No, go back to 6
   - If Yes, proceed to 7
   - H
7. Display design title and name
8. Display load status
   - A
   - B
Plate 1. Cross-sectional view of the implemented electronics equipment security lock system showing the microcontroller (PIC16F877A) unit
Plate 2. Front view of implemented electronics equipment security lock system

Plate 3. Rear view of the implemented electronics equipment security lock system

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