Design and fabrication of an electronic door lock with external surveillance facility

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ABSTRACT: An automatic door lock was designed and fabricated using locally available semiconductor devices, such as 8051 architecture microcontroller, 1-channel type optocouplers, voltage regulators, junction diodes, light emitting diodes, comparators, timers and resistors. It operates such that, access is gained by inputting the correct Personal Identification Number (PIN). The PIN input is achieved by pressing the buttons on the keypad. The keypad is positioned outside the secured room such that access PIN is only needed on entrance. On exit, a simpler circuit is in place to allow free passage without rigorous verification. The system consists of the Electronic Logic Section and the Mechanical Section. The Electronic Logic section consists of the Power Supply Unit, the User Input Unit, the Arithmetic & Logic Unit and an Output Interface Unit. The mechanical section consists of the Rotational to Translational motion Unit and the Lock Notch Restorer Unit. All these sections were coupled together for accurate operation and efficient performance. The door lock possesses some intelligent features that give an enhanced security with an ability to monitor motion in its environment and provide necessary reaction to such motions. This door lock is designed to operate on rechargeable batteries. The door lock is interactive which makes it user friendly and easy to use. It does not require rewiring to enjoy its full benefits.

Keywords: Fabrication; Electronic; Door Lock; Security; Surveillance

INTRODUCTION

The increasing rate of crime all over the world has put virtually all human being under immense security threats. Lives are being lost; properties that are necessary for human existence are lost on daily basis due to inadequate security measures. These loses occur everywhere including homes, offices, streets and roads. Hence the need for adequate, affordable security measures in the form of security systems that ensure security of lives and properties. Residential houses, commercial houses like banks, hospitals, other institutions etc are constructed with strong materials. However, entrances and ventilations are essential. Thus, windows and doors that serve as security weak links are indispensable in our buildings. Although the windows can be secured against burglars by using steel burglary proof, the door cannot, as this serves as an entrance to residents, visitors and as well for unwanted security culprits. Since it is essential to have a door for entrance, it is also essential to have a door lock for security. In the bid to create a more reliable and intelligent security system, we will by applying electronics, logic and mechanics to create a door lock with the following features:

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- Resemblance with the conventional door lock, but with more intelligent security attributes.
- Ability to replace keys within seconds without changing the locks and at no cost.
- Possession of keys that cannot be misplaced or stolen.
- Ability to determine whether the legal occupant opened the door under duress, so as to source for external help.
- Ability to monitor its surroundings and react to motion through specific paths.

**MODE OF OPERATION**

The door lock is designed such that the key would be a Personal Identification Number (PIN). The door lock would open only when the correct PIN is entered; meaning that the user must bear in mind the PIN for its easy input on the keypad. Simply stated, the lock looks like the common jam lock where a key is needed to gain access to the interior and is not required to open the door from inside. However, in the common jam lock, whenever the key is locked inside, stolen or misplaced, the user is deprived easy access into the enclosed. This is not the case for the electronic door lock in that, the lock just needs to verify the inputted PIN for correctness.

It is worth noting that the PIN can be modified easily within seconds by following the instructions listed below:

(i) Press the star (*) button on the keypad followed by the correct PIN.
(ii) Press the star (*) button again followed by the new PIN.
(iii) Press the star (*) button the third time and re-enter the new PIN.
(iv) Complete the process by pressing the hash (#) button on the keypad.

That is [*old PIN* new PIN*new PIN#].

In order to protect the user from multiple 'trial and error' entries from intruder, the door lock will enter a more secured mode whenever a wrong PIN is entered thrice and will no longer open until the correct PIN is inputted twice consecutively.

For further protection from armed intruders that forces the right user to open their lock, the PIN is entered in reverse order. This will not only open the door, but also raise an alarm for external help and assistance. The lock also has the ability to monitor two strategic locations through infrared technology and perform some required operations such as powering the security lamps, burglar alarm etc. Pressing the ash key on the keypad automatically clears the designated keypad input memory and refreshes the device.

**THE CIRCUIT DESCRIPTION AND ANALYSIS**

The Electronic Door Lock is a security lock that operates on electronic and logic principles. Its block diagram is shown in Figure 1.

The circuit layout is such that the keypad is separated from the main board by detachable connecting wires. The electronic logic section consists of the following units: the power supply unit, user input unit, the arithmetic & logic unit and the output interface unit. The power unit supplies electricity to other units of the device. It is made up of batteries, charging circuitry, high capacitance capacitors, 7805 voltage regulator that supplies 5V to the arithmetic and logic unit. The User Input does not require any direct power from the Power Supply Unit. It takes its power from the Arithmetic & Logic Unit. (O’Malley, 1992). The User Input Unit looks like a keypad. It consists of 12 buttons that are used for makes and breaks in the circuitry of the device. It causes variation in the voltage levels of specific points in the device, thereby signalling the Arithmetic and Logic Unit (ALU). Each button on the keypad has direct connection to specific pins in the ALU (Horowitz and Hill, 1989).
The ALU is the location where user inputs are read, the surveillance inputs are analyzed, calculations are carried out then logical decisions are made. It is made up of an 8051 architecture Microcontroller, a crystal oscillator, capacitors and resistors. The Microcontroller is the major component of this unit and as well as the entire electronic door lock. The Microcontroller consists of a flash memory that stores program and a set of Random Access Memory (RAM), which helps for program execution and decision making. It is made up of 40 pins out of which 32 pins are for data input and output functions, 2 pins for power, 2 pins for clocking, 1 pin for reset and 3 pins for external memory access configuration. The complete configuration is achieved by software settings (Wharton, 1980).

The microcontroller was programmed in Assembly language. Assembly language is a low level language and was chosen because of its speed, ability to maximize memory space and capability. Assembly language programs are generally the fastest programs around, the programs are often the smallest and the hardware can be easily instructed, which are difficult or impossible in high level languages (Hyde, 2003).

The program was written with the windows editor and saved in ‘.a51’ extension file (doorlock.a51). It was debugged and converted to the 8051 machine language by an 8051 assembler, thereby creating an associated ‘.hex’ extension file (doorlock.hex). The ‘.hex’ extension file contains hexadecimal numbers, and is systematically arranged such that the microcontroller distinguishes the instruction set in the file from the data. The ‘.hex’ file is transferred from the computer to microcontroller by the use of the 8051 programmer. The 8051 programmer has a Zero Insertion Force (ZIF) socket the firmly connect to the pins of the microcontroller with low damage risk and connects to the computer through its serial port. The programmer has computer-installed software that optimizes program transfer (Wharton, 1980). Whenever any key in the User Input Unit is depressed, the microcontroller senses it and performs the required operations. The Input/Output (I/O) pins and some other parts of the microcontroller are made up of latches, thereby necessitating clocking. The clocking pins are directly connected internally to the input and output of
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an inverting amplifier. The internal inverting amplifier requires an external crystal oscillator for its clocking operation. The external crystal oscillator determines the clock frequency. A 12MHz crystal oscillator equipped with two capacitors for frequency tuning was employed in this work (Intel Application notes, 1994). The microcontroller which used here is designed to sink and source low current at its I/O pins. The Output interface Unit helps the ALU to interpret its output signals and as well as adapt to large current consumption when necessary. The output interface unit, powered by the power supply unit, powers the electric motor in the mechanical section for some seconds, whenever the correct PIN is entered on the keypad. It also helps to power the indicators used for triggering the device put in place for external surveillance. Some of the major components used in the output interface unit are transistors, optocouplers, resistors, electromagnetic relays and diodes (Atmel Application Notes, 1994). The mechanical section consists of a lock notch restorer and the electric motor. Actually mechanical energy is required to open the door whenever there is a successful PIN verification. The motor is powered ON for about 2.5 seconds within which the lock is expected to open. The lock notch is expected to return to its original state after the 2.5 seconds has elapsed. This process is achieved by the use of a restoring compression spring (Crowell, 2003).

**DESIGN, CONSTRUCTION AND TESTING**

The electronic door lock is designed to have a size similar to that of the conventional jam lock. The electronic components are arranged on component circuit board (Vero board), while the mechanical section of the lock are located on the metal casing.

An 8051 based architecture microcontroller was used. It was chosen due to its programmable memory capacity, Random Access Memory (RAM) capacity, Input/Output (I/O) pins, power consumption, availability and cost. The input/output pins are grouped in 8 to form a port. They are Port 0 consisting of pins labelled as P0.0, P0.1 – P0.7; Port 1 consists of P1.0, P1.1 – P1.7; Port 2 consists of P2.0, P2.1 – P2.7; and Port 3 consists of P3.0, P3.1 – P3.7. VCC and GND signify the supply voltage and ground pins respectively. The RST and XTAL pins signify the reset and crystal oscillator input pins respectively. EA, ALE and PSEN signify the External Access Enable, Address Latch Enable and Program Store Enable respectively. Among these three, only the EA was used for the door lock. Figures 2 and 3 show the pin configuration and the block diagram respectively for the 8051 microcontroller (Atmel Application Notes, 2004).

The crystal oscillator helps the inverting amplifier to generate clock pulses as the microcontroller cannot operate without clock pulses. The crystal oscillator determines the frequency of operation of the inverting amplifier which is internally connected to the XTAL1 pin.
Figure 2: Pin Configuration for 8051 based microcontroller (source: Atmel AT89S52 microcontroller Data Sheet)

Attached to the crystal oscillator are two loaded capacitors that help in tuning the clock frequency. The 12MHz crystal oscillator together with the 27pF capacitors was selected considering the required speed of operation. Figure 4 clearly illustrates the clocking frequency configuration used (Atmel Application Notes, 2004).
Figure 3: Block Diagram for 8051 based microcontroller (source: Atmel AT89S52 microcontroller Data Sheet)
Figure 4: Clock frequency configuration for 8051 based microcontroller

At power ON, the microcontroller takes up random values on some special purpose registers. Its I/O pins might also have randomly chosen values; hence the need to reset the microcontroller. In order to reset the microcontroller, the logic 1 voltage level on the reset pin for a minimum time of two machine cycles. (1 machine cycle = 12 clock cycles: 12MHz clock frequency = 1MHz machine frequency). Therefore logic 1 voltage would be required on the reset pin for at least 2 microseconds so as to avoid routine resetting the microcontroller after power ON; a 10μF capacitor and 10kΩ resistor in series were placed to serve as a reset circuit (Intel Application Notes, 1994).

The keypad input buttons are small switches that cause circuits to be made when depressed and re-breaks the circuit when released (Bates, 2006). Their operations are optimised by the aid of 10kΩ pull-up resistors. Current flows through the pull-up resistors only when the button is depressed. The pull-up resistors make the current flowing through the input buttons to be about 0.5mA whenever the buttons are depressed (as shown in Figure 5). Due to the low current flow, current rating was not a problem during component selection. Size and durability were the main factors for selection (Malvino, 1993).
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The maximum current recommended to flow through the output of the microcontroller is put at 15mA (Atmel Application Notes, 2005). In the implementation of the design, transistors and optocouplers were employed due to their circuit isolation and current control capability. Interfacing the microcontroller directly with the electromagnetic relays is not suitable because the electromagnetic relay requires a minimum current of 30mA to operate. The transistors and optocouplers help in receiving 5mA from the microcontroller and simultaneously give 35mA to the relays.

![Optocoupler Diagram](image)

**Figure 6: Schematic Diagram of an Optocoupler (source: Fairchild semiconductor Data Sheet)**

The light sensitive transistor of the optocoupler is turned “ON” only when incident light photons fall on its base. Incident photons can only fall on the light-sensitive base of the transistor when substantial current flows through the Light Emitting Diode. The current flow through the optocoupler's light emitting diode is controlled by 1kΩ resistors. Since the current flow through the optocoupler’s light emitting diode is equal to the current flowing out of the microcontroller's output pins, the microcontroller was carefully considered in deciding the amount of current that will flow through the optocoupler’s light emitting diode (Fairchild Application Notes, 2007).

After the successful interfacing of the optocoupler with microcontroller, about 18mA current will flow into the Light Sensitive Transistor's collector. Since the electromagnetic relay coils serve as the collector load resistance, they would not be energized due to the insufficient current flow. This led to the integration of the bipolar NPN transistors, which is a unique integration because, optocoupler darlington pair ICs are not locally available. The bipolar NPN transistors were connected to the Light Sensitive Transistors of the optocouplers to form a darlington pair. This would cause a greater amplification of the output current from microcontroller, thereby conveniently powering the electromagnetic relays (Kuphaldt, 2004). The coil of the electromagnetic relays, serve as the collector load resistors of the newly introduced bipolar NPN transistors as shown in Figure 7.

Despite the roles the transistors and optocouplers have played so far, there is still a limit to their current carrying abilities. An electromagnetic relay which works with the principle of electromagnetic induction must be put in place to provide a reliable platform to make and break high current carrying channels within the circuits. The schematic diagram is as shown in Figure 8.
Figure 7: The formation of darlington pairs between Light Sensitive and Bipolar NPN Transistors

Figure 8: Electromagnetic Relay interfacing with Transistor

The electromagnetic relays are made of coils, soft iron, restoring spring and switches. When significant current flows through the coil, it induces electromagnetism on the soft iron causing them to attract. In the process of attraction, a switch (normally close switch) is opened while another (normally open switch) is closed. When the current stops flowing through the coil, the restoring spring makes the currently closed and opened switches (normally open & normally close switches) to become opened and closed respectively. This makes the electromagnetic relays versatile in switching operations. Using the electromagnetic relays, the output current from
the microcontroller is enabled to trigger external circuits operating up to 2000 times its value. The diode 1N4001 helps to suppress back EMF generated by the coils of the electromagnetic relays, this prolongs the life of the transistor (Horowitz and Hill, 1989).

A Direct Current Motor was also employed in this work to play the role of converting electrical energy to mechanical energy. It is preferred because:
- the entire device operates on direct current
- direct current motor speeds are easier to regulate
- The motor produces rotational motion, which is easily converted to other forms of motion.

The DC motor is powered by 18V power supply and it directly interfaces the Electronic Logic Section to the Mechanical Section (Lovine, 2000).

The electronic door lock was also equipped with a charging circuit to charge the rechargeable batteries used to power it. The charging circuit consists of a transformer, power diodes and capacitors as shown in Figure 9.0. Every form of ripples in the circuit is eliminated by the capacitor (Malvino, 1993).

![Diagram of Charging Circuit]

**Figure 9: Schematic diagram for charging circuitry**

Further work on this design includes the surveillance adapter that works with electromagnetic waves in the Infrared spectrum. The infrared is preferred because of its invisibility. This ensures adequate surveillance even in the dark.

The surveillance adapter is made of two main sections which are the transmitter and receiver sections. The output of the transmitter is an Infrared Light Emitting Diode (IRLED). (See Figure 10)

The transmitter section is made up of timing ICs, infrared light emitting diodes (IRLEDs), resistors and capacitors. The major components are the timing ICs, while other circuit elements are required to appropriately configure the timing ICs. The timing ICs used was LMC555 timer. The first timing IC (Timer1) was configured as a 50% duty cycle astable multivibrator with an output frequency of 40 kHz which is the carrier frequency. The output pin is connected to the IRLED through a 220Ω resistor. The second timing IC (Timer2) was also configured as a 50% duty cycle multivibrator, but it has an output frequency of 250Hz which is the signal frequency. The output pin of Timer2 is connected to the reset pin of Timer1, thereby making the signal from Timer2 to modulate the carrier from Timer1 (National Semiconductor Application Notes, 1997).
Figure 10: Schematic diagram for Infrared transmitter

The IRLED is powered with the modulated 40kHz source. The infrared receiver continuously demodulates the infrared waves, which gives it the ability to detect obstruction on its reception path.

Figure 11: Schematic diagram for Infrared receiver
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Figure 11 shows the infrared receiver consisting of the infrared detector (TSOP 1738), voltage regulators, capacitors, etc. The infrared detector is often designed for specific frequency bands. When infrared ray is detected, the $V_{\text{out}}$ pin of the detector drops from 5V to about 3.2V and it maintains this value until there is a blockage of signal that will cause. When infrared rays are being detected and $V_{\text{out}}$ is maintained at 4.5 V, obstruction of rays would cause the $V_{\text{out}}$ to return to 5V and the microcontroller is then signalled. Signals sent to the microcontroller are digitized by the use of a comparator (Paton, 1998).

The transmitter and receiver circuit pair were placed beside each other but shielded from direct communication. A plane mirror was placed on the end across the monitored path such that, incident modulated rays from the transmitter is sent to the plane mirror which reflects the ray to the receiver module as shown in figure 12. Whenever there is an obstacle in the ray path, the microcontroller is alerted for further action. The schematic diagram of the electronic and logic section of the electronic door lock is as shown in figure 13.

![Diagram of Electronic Door Lock with Infrared Receiver](https://via.placeholder.com/150)

**Figure 12: Infrared Transmitter and Receiver installation chart**

Successful authentication opens the door automatically via the mechanical section. The mechanical section of the work is designed to pull back the lock notch for the time stipulated by the Arithmetic and Logic section. The interior view of the mechanical section is as shown in figure 14. It is powered by the direct current motor which brings in rotational motion. The rotational motion is converted to the required translational motion for the control of the lock notch. The DC Motor has a pulley (pulley 1) of diameter 8 mm. This is connected to a bigger pulley (pulley 2) of diameter 85 mm with an elastic belt, thus making the velocity ratio equal to 10.625 (see equation (2)). ‘Pulley 2’ is directly connected to a smaller pulley (pulley 3) to form a ‘wheel & axle’ system making the pulleys (‘Pulley 2’ and ‘Pulley 3’) have the same angular velocity. From equation (3), the velocity ratio of the directly connected pulley is 2.125. According to equation (4), the total velocity ratio of the rotational motion is equal to 22.58 (Anyakoha, 2007).

\[
\text{Velocity Ratio (V.R)} = \frac{\text{Distance moved by the effort}}{\text{Distance moved by the load}}
\]

\[
V.R: \text{Pulley (1:2)} = \frac{\pi \times \text{Diameter of Pulley 2}}{\pi \times \text{Diameter of Pulley 1}} = \frac{85}{9} = 10.63
\]

\[
V.R: \text{Pulley (2:3)} = \frac{\pi \times \text{Diameter of Pulley 2}}{\pi \times \text{Diameter of Pulley 3}} = \frac{85}{40} = 2.13
\]

\[
\text{Total Velocity Ratio} = V.R: \text{Pulley (1:2)} \times V.R: \text{Pulley (2:3)} = 10.63 \times 2.13 = 22.58
\]
Figure 13: Schematic Diagram for Arithmetic and Logic Section of the Electronic Door Lock
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Whenever the DC motor is powered on, 'pulley 3' is responsible for pulling back the lock notch by the aid of an elastic string. When the DC Motor is off, the lock notch is returned by the aid of a restoring spring. The pulley arrangement enables the DC motor to pull back the lock notch against the restoring spring easily (Anyakoh, 2007). All the sections extensively described above were effectively coupled together to achieve electronic door lock with the external surveillance. Figure 15 shows the 3 - Dimensional view of the Door lock; Figure 16 shows the pictorial view of the main board of the Door lock (Electronic and Logic section); while Figure 17 shows the pictorial view of all sectioned interconnected together.

The door lock was step-wise tested in the electronics laboratory by effectively checking all the security features. Various scenarios were created and the door lock was seen as reliable, and as an improvement on the conventional locks. It was later installed on a domestic panel door for final testing which was successful.

![Diagram](image)

**Figure 14:** Dimensional Interior view of the mechanical section of the Lock
Figure 15: 3-Dimensional view of the Door lock

Figure 16: Pictorial view of the main board of the Door lock (Electronic & Logic section)
CONCLUSION

The ability of the electronic door lock to observe and make decision makes it a better security system than the existing conventional locks. The fact that it is based on electronic principles makes it difficult for invaders to easily penetrate. The door lock has solved problems such as misplacement of keys, unauthorized accesses by the use of master keys, unauthorized accesses by compelling residents to input their PIN, unwarranted movements around the door surroundings and inputting PIN on trial and error basis. The electronic door lock is subjected to improvement that might involve migration data logging, network operations, wireless controls, biometric’ authentication and lots more.

REFERENCES


