

**DESIGN AND CONSTRUCTION OF A TWO-WAY SECURITY
AUTHENTICATION ELECTRONIC SAFE LOCKS USING
ARDUINO MICROCONTROLLER**Tertsegha J. Anande¹, Mbayer Abunku², Yilwatda M. Morkat³^{1,2,3}(Department of Electrical and Electronics Engineering/University of Agriculture, P.M.B. 2373, Makurdi, Benue State, Nigeria).

Abstract—The most common challenged in today's world is security of lives and properties. This has necessitate the need to concentrate effort towards improving the security frame work currently in existence and the need to build new ones were applicable. In this research a comprehensive literature study and implementation related to the various door locks and gate security systems in areas such as home, vehicles, banks and industries where possibilities of incursion are increasing day by day is realized. The input of the system in this design has two stages of authentication, stage 1 is the screen pattern inputted via the TFT touch screen and stage 2, is the knock pattern inputted via the piezoelectric sensor. The TFT touch screen and piezo sensor are connected directly to the microcontroller and both stages have to be verified before the Arduino microcontroller sends an electric signal to the DC motor which turns the deadbolt and unlocks the safe. The user first inputs his recorded screen pattern, and if correctly entered, he next enters the knock pattern. The green LED which is normally on blinks to indicate normal system functionality. Both the screen pattern and knock pattern have to be correctly inputted before the safe is unlocked. If the wrong screen pattern is entered, the user is told to try again and if the wrong knock pattern is entered, a red LED blinks and the user told to try again. As a means of backup and extra security measure an android application is incorporated in the design to enable reset and easy access by the rightful individual of the security architecture. The application installed on an android device which is then connected to the microcontroller in case of a failure or system lock down due to wrong patterns being inputted more than three times. If more than 3 wrong patterns are inputted, the system locks down permanently until the pattern entries are reset with the user's android application and PIN. To record a new pattern, the user first resets the pattern entry by inputting a PIN on his android device after which he records a new screen pattern, presses and holds the push button switch to record a new knock pattern. The recorded knock pattern is played back to the user after recording by rhythmic blinking of both the red and green LEDs.

Keywords— Piezo sensor, TFT touch screen, Arduino microcontroller, Safe Lock, GSM, DC motor, Password.

1. INTRODUCTION

Authentication by definition is the use of one or more mechanisms to prove a claim. Two-way authentication as the name implies, is simply a user authentication method that requires two independent input information provided by a user to establish his/her identity before access is granted [1]. These independent inputs may be something the user knows (a PIN or password), something the user possesses (a bank card or key), or something that is inseparable from the user (biometrics). The use of two-way authentication is based on the premise that an un-authorized user is unlikely to have both factors required for access, if in an authentication attempt and at least one of the access granting factors is supplied incorrectly or missing, the user's identity is not established and access to the asset being protected by two-factor authentication then remains blocked [1]. An electronic lock is basically a locking device that operates by means of electric acurrent. The movement (opening and closing) of the locking mechanism which can be magnets, solenoids or motors is controlled by supplying or removing electric power input. This lock may be in the form of a standalone lock with an electronic control assembly mounted directly to the lock, or connected to an access control system [2]. The use of an access control system by electronic locks is what allows the technology of two-way authentication to work seamlessly with electronic locks. In this work, the electronic lock is used with the two-way authentication technology as access control via an Arduino microcontroller.

2. RELATED WORK

Over the years, the role of security guard has evolved to take into account personal safety and safety of one's surroundings. The industrial revolution sparked an uptick in security guard services as more people owned property. Today, many

businesses such as banks and schools employ security guards for protection. Though moats and armed guards have been in place to protect homes for centuries, with the invention of electricity, the art of home protection was greatly improved. In 1853, the first patent on electro-magnetic alarms meant that businesses and wealthy residents could secure valuables [3]. Magnetic contacts were installed on the windows and doors that, when tripped, would send a signal through the electromagnetic wiring and sound an alarm. These groundbreaking security systems were effective in deterring break-ins from occurring.

Cryptography was a common form of code making and code breaking during the American Civil War. Although cryptography has a long and complex history dating back to hieroglyphics in 1900 BC, it wasn't until the 19th century that it developed into the more modern encryption techniques that we use today [4].

The earliest lock in existence is the Egyptian lock, made of wood, found with its key in the palace ruins of Nineveh, in ancient Assyria. In the 19th century, level locks, cylinder locks and keyless locks were invented and improved upon [4].

Before the steel and modern metallurgy techniques popularized vaults, reinforced rooms were used for the highest level of security. As steel became a more popular element for manufacturing, vaults started to appear in banks, casinos, schools and military buildings to store intellectual property, money, or even dangerous objects. Modern vaults feature walls more than a foot thick, encased with strengthened concrete. Well-constructed vaults include some of the most complicated locking mechanisms known to man.

In 1949, the notion of video surveillance became an eerie concept. While the technology was developed in 1940 it wasn't until the 1970s that it was used in homes as security measure [5].

The security system has developed by leaps and bounds in the last century and new technology is emerging each day ranging from different types of alarm systems, different forms of biometrics to combination of two types of security systems to give a two-way security system.

The first successful metal key changeable combination lock was invented by James Sargent in 1857. This lock was the prototype of those being used in contemporary bank vaults. In 1958, the first electronic combination lock was invented [5]. As subsequent developments were along the lines, the locks were improved upon by improvement of materials and increasing complexity of the working mechanisms including the use of different forms of electronic locks to which the two-way authentication security electronic safe lock using an Arduino microcontroller is one.

3. HARDWARE DESCRIPTION

The input of the system has two stages of authentication, stage 1 which is the screen pattern inputted via the stage 2, the knock pattern inputted via the piezoelectric sensor. The TFT touch screen and piezo sensor are connected directly to the microcontroller and both stages have to be verified before the Arduino microcontroller sends an electric signal to the which turns the deadbolt and unlocks the safe. The user first inputs his recorded screen pattern, and if correctly entered told enter his knock pattern. Next the user knocks in the right pattern and sequence as recorded and the green LED which is normally on to indicate normal system functionality blinks. Both the screen pattern and knock pattern have to be correctly inputted before the safe is unlocked. If the wrong screen pattern is entered, the user is told to try again and if the wrong knock pattern is entered, a red LED blinks and the user told to try again. This process is shown in the block diagram in fig 3.1. As a means of backup and extra security measure, an android application is designed which is to be installed on an android device and connected to the microcontroller in case of a failure or system lock down due to wrong patterns being inputted more than three times. If more than 3 wrong patterns are inputted, the system locks down permanently until the pattern entries are reset with the user's android application and PIN. To record a new pattern, the user first resets the pattern entry by inputting a PIN on his android device after which he records a new screen pattern, presses and holds the push button switch to record a new knock pattern. The recorded knock pattern is played back to the user after recording by rhythmic blinking of both the red and green LEDs.

The design and implementation of the two-way authentication electronic safe lock comprises of the hardware design and software design.

3.1. Hardware Design for Two-Way Authentication Electronic Safe Lock

The hardware design consists of all physical components required and their operation for the implementation of the two-way authentication electronic safe lock.

Fig 3.1 shows the block diagram of the two-way authentication electronic safe lock.

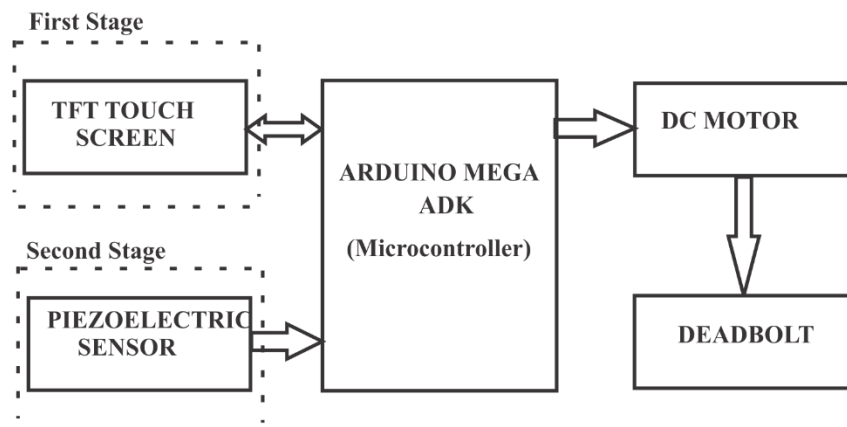


Fig 3.1: Block Diagram of the two-way authentication electronic safe lock

The hardware design for the two-way authentication electronic safe lock comprises of three categories:

1. Input and indicator unit.
2. Microcontroller unit.
3. Output unit.

3.1.1. Input and Indicator Unit

The input unit consists of an Arduino compatible Nextion 3.2" TFT Touch screen and a DT series MEAS-SPEC piezoelectric sensor. The screen pattern is entered via the 3.2" TFT Touch screen, which is followed by the knock pattern. The indicator unit consists of Light emitting diodes (RED and GREEN).

3.1.1.1. Nextion 3.2" Touch Screen

The Nextion 3.2" TFT Touch screen v2.0 displays a welcome message which welcomes the user followed by which the user now enters his recorded screen pattern which if correctly entered turns on a green LED. The voltage range of the touch shield is between 4.5-5.5 VDC but operates typically at 5V.

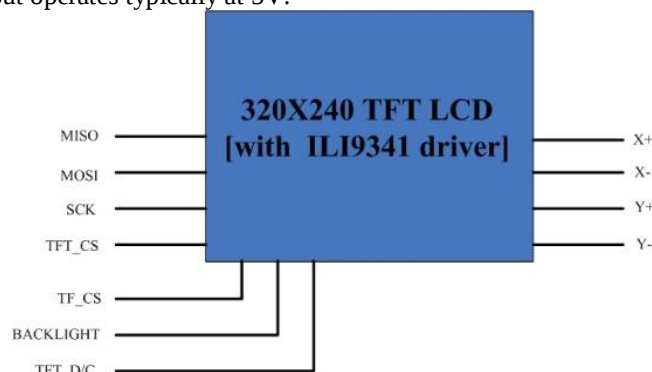


Fig 3.1.1: TFT touch shield V2.0 Pin mapping

3.1.1.2. DT series MEAS-SPEC Piezoelectric Sensor

The piezo electric sensor records the knock pattern by means of piezoelectric effect. After the user inputs the correct screen pattern, he knocks on the safe. If the correct knock pattern is inputted, the safe is unlocked else the red LED comes on to indicate that the knock pattern is wrong. The DT series of piezo film sensors elements are rectangular elements of piezo film with silver ink screen printed electrodes. DT film element produces more than 10 millivolts per microstrain, about 60 dB higher than the voltage output of a foil strain gauge. Has an output voltage of 1mV to 100's of volts and operating temperature of -40 to 140 °F (-40 to 60 °C). The capacitance is proportional to the area and inversely proportional to the thickness of the element. One leg of the sensor is connected to analog pin 0 on the Arduino board and the other leg to the DGND. A pull down resistor of 1MΩ is connected in parallel with the sensor between the input and ground to close the circuit and drop the voltage on the inputs to less than 0.8V but not negative, or a logical low value as shown in fig 3.1.2. The pull-down resistor must have a larger resistance than the impedance of the logic circuit. 3.3MΩ is large enough and used with piezoelectric sensor. This particular sensor was chosen based on its applications, voltage and current ratings specified by the manufacturer.

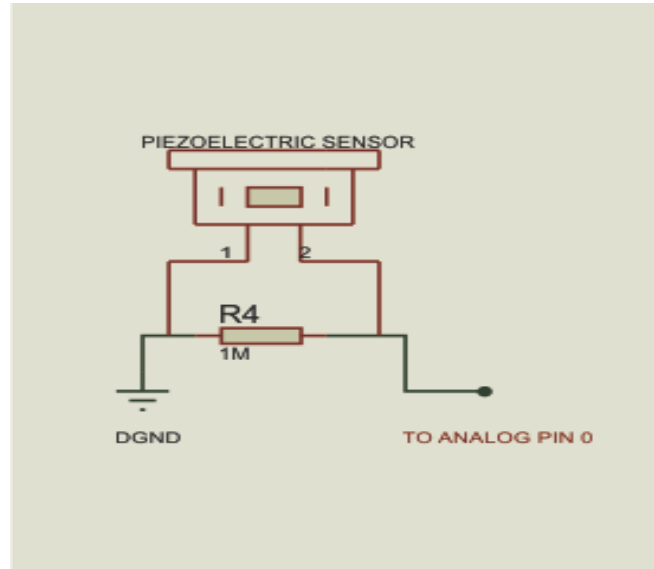


Fig 3.1.2: Piezo sensor in parallel with a pull down resistor

3.1.1.3. Light Emitting Diode (LED)

A green and red LED are connected in series with limiting resistors of value 180Ω each. The green LED is normally on indicating normal system functionality and also flashes to the rhythm of the knock pattern when the user is programming a new lock pattern. Then red LED indicates if either the knock or screen pattern was entered incorrectly. From the manufacturers datasheet the green LED operates at a voltage of $2.1V$ and a current of $17mA$ while the red LED operates at a voltage of $2V$ and a current of $18mA$. The 180Ω value of the resistors as shown in fig 3.1.3a and fig 3.1.3b were thus obtained as follows:

For the Green LED

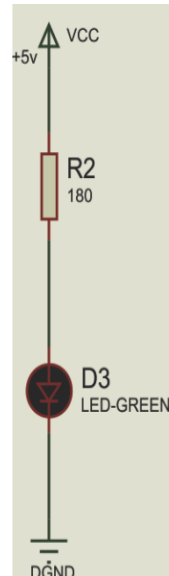


Fig 3.1.3.a: LED D_3 in series with resistor R_2

$$V_{CC} = 5V, I_L = 17mA, V_{LED} = 2.1V$$

Taking KVL,

$$V_{CC} - R_2 I_L - V_{LED} = 0$$

$$\frac{V_{CC} - V_{LED}}{I_L} = R_2$$

$$R_2 = \frac{5 - 2.1}{17 \times 10^{-3}} = 170.6\Omega$$

180Ω was chosen for R_2 as the close standard value of resistor to 170.6Ω

For the Red LED

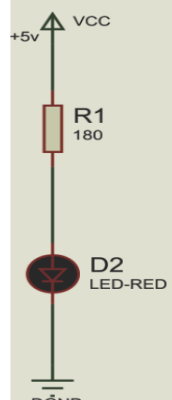


Fig 3.1.3.b: LED D_2 in series with resistor R_1

$$V_{CC} = 5V, I_L = 18mA, V_{LED} = 2V$$

Taking KVL,

$$V_{CC} - R_1 I_L - V_{LED} = 0$$

$$\frac{V_{CC} - V_{LED}}{I_L} = R_1$$

$$R_1 = \frac{5-2}{18 \times 10^{-3}} = 166.66\Omega$$

180 Ω was chosen for R_2 as the close standard value of resistor to 166.66 Ω

3.1.2. Microcontroller Unit

This unit as shown in fig 3.1.4 consists of the Arduino Mega ADK which is a microcontroller board based on the ATmega2560 with a momentary push button switch connected to it for programming the lock patterns. The Arduino Mega ADK can be powered via the USB connection or with an external power supply. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

Power: Power is supplied to the Arduino Mega ADK by a 12V DC battery.

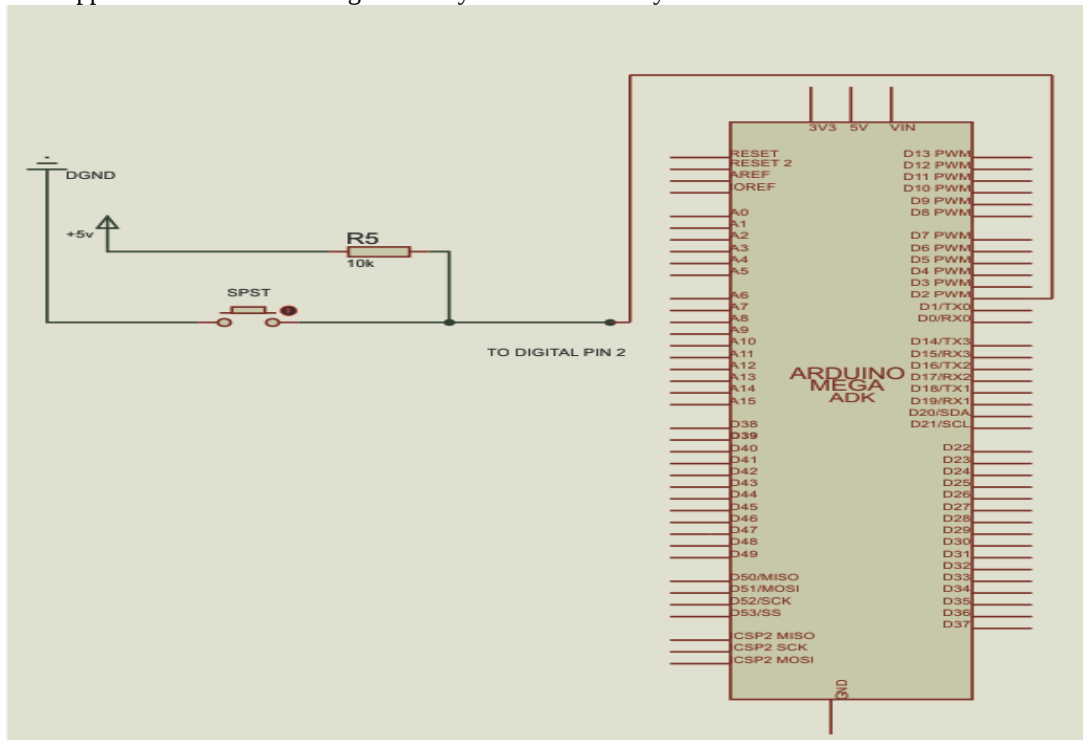


Fig 3.1.4: Microcontroller Unit

3.1.2.1. Momentary Push Button Switch

This switch is used to program knock pattern. When the user is required to or wants to program new lock patterns, the switch is held down and the new knock pattern is recorded. The switch is released when the new pattern has been entered. This switch has one end connected to a 5V source and the other end connected to the digital pin 2 of the microcontroller and a 10K Ω pull up resistor. Pull-up resistors are resistors used in logic circuits to ensure a well-defined logical level at a pin under all conditions i.e. a logical high value of 2V-5V.

With a pull-up resistor, the input pin will read a high state when the button is not pressed. In other words, a small amount of current is flowing between VCC and the input pin (not to ground), thus the input pin reads close to VCC.

The value of the pull-up resistor needs to be chosen to satisfy two conditions:

1. When the button is pressed, the input pin is pulled low. The value of resistor R1 controls how much current you want to flow from VCC, through the button, and then to ground.
2. When the button is not pressed, the input pin is pulled high. The value of the pull-up resistor controls the voltage on the input pin.

In bipolar logic families with an operating voltage of 5V, the typical pull-up resistor value is 1-5K Ω but typical resistor values of 1-10K Ω for switch applications.

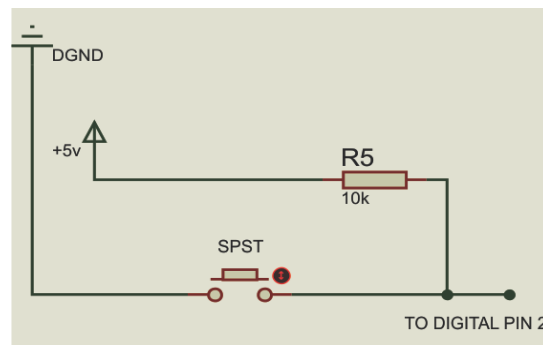


Fig 3.1.5: Push button switch connection

It is important to note that digital logic circuits have three logic states: high, low and floating (or high impedance). The high-impedance state occurs when the pin is not pulled to a high or low logic level, but is left “floating” instead.

3.1.3. Output Unit

This unit consists of a GM22 mini metal sealed DC gear motor which turns the dead bolt to lock the safe. This motor operates between 9-12V. As shown in fig 3.1.6 the motor is powered by a 12V supply through a relay. Its coil is driven by a 2N2222 NPN transistor which has a 1N4007 diode connected to it. The 1N4007 diode in this circuit prevents the flow of backward e.m.f to the transistor which can damage the transistor. A 100ohm resistor is connected to the base of transistor and is connected to pin 22 of the microcontroller.

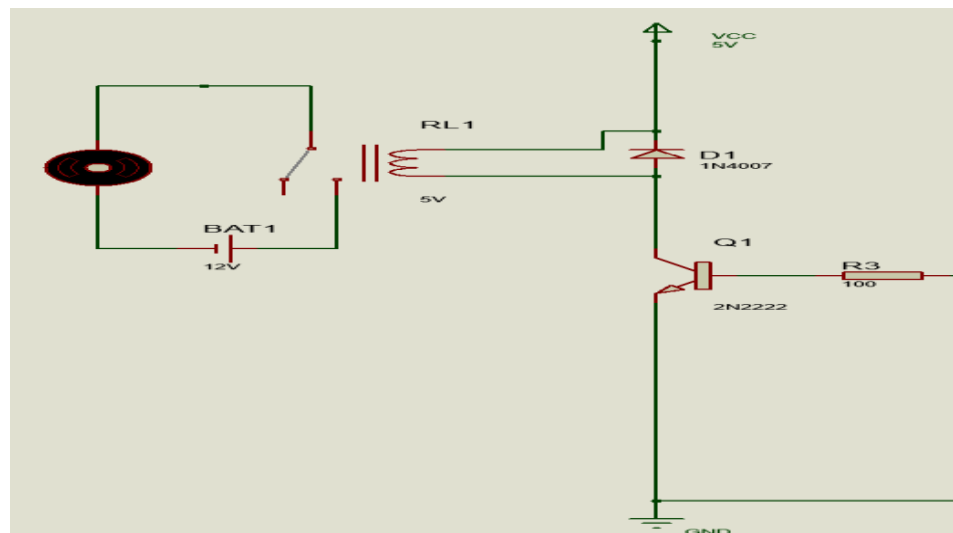


Fig 3.1.6: Output Unit

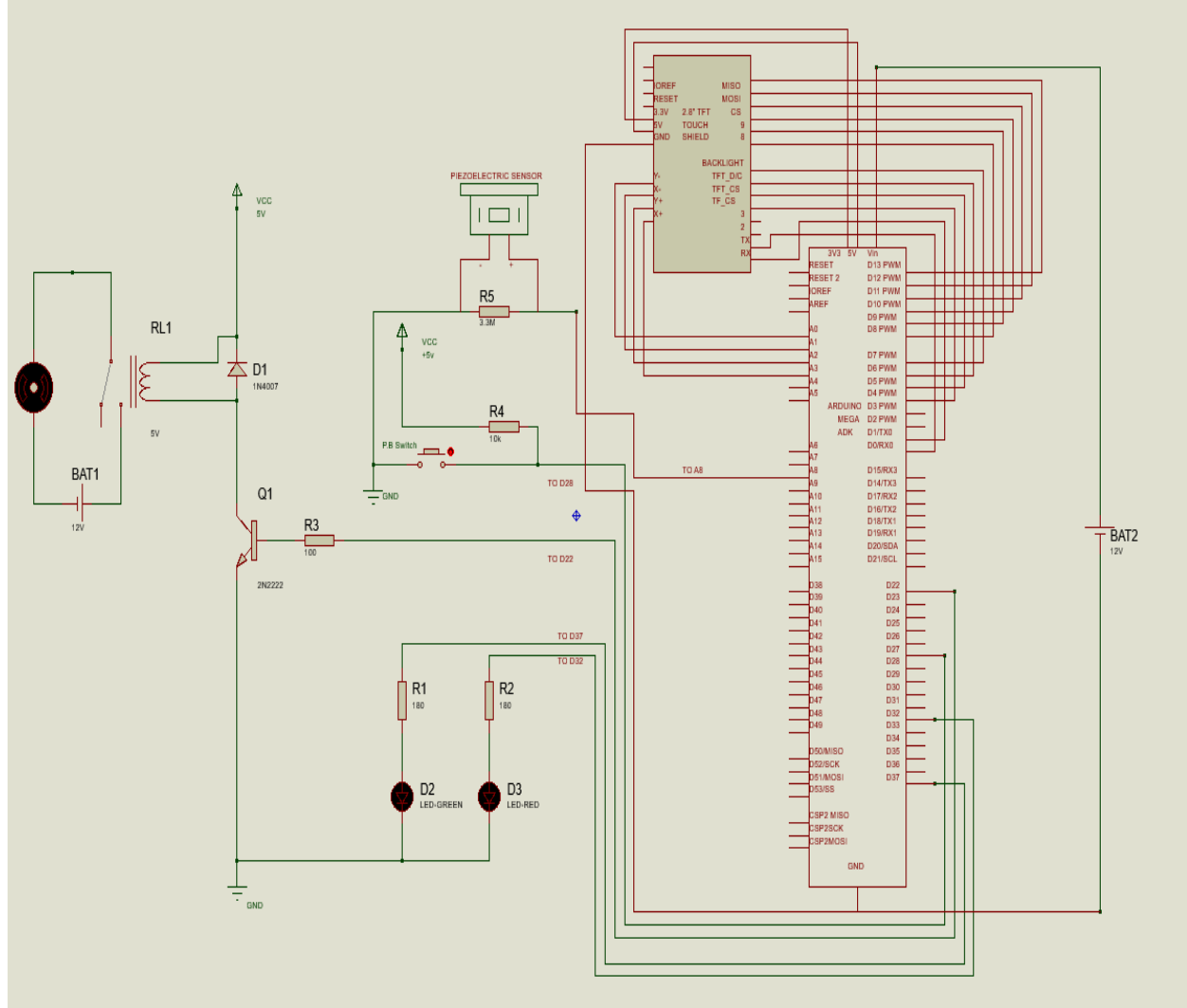
For Resistor 3 at the Base of Transistor 2N2222

$V = 5V$, $I = 40mA$, $V_{BE} = 0.7$

$$R = \frac{5 - 0.7}{40mA} = 107.5\Omega$$

A 100Ω resistor was selected.

The circuit diagram of the two-way authentication electronic safe lock is shown in fig 3.1.7.



4.0. SOFTWARE DESCRIPTION

The microcontroller is programmed using the C++ which is the Arduino programming language on a computer using the Arduino Integrated Development Environment (IDE). The way the system is programmed is shown in the flow chart in fig 4.1. The system is programmed to display a “WELCOME” and “ENTER” message on the screen. If the correct screen pattern is entered, the user is required to enter his knock pattern which opens the lock. If any of the authentication fails, the system displays an “INCORRECT PATTERN” message and the user is required to re-enter the pattern. The user has a maximum of 3 wrong trials before he is shut out of the system completely. When this happens, the user is required to reset the patterns by entering the code on his android device.

Fig 4.1.1 is the flowchart of the reset process. When the number trials limit is exceeded the system displays an “AUTHORIZATION FAILED” and “CONNECT ANDROID DEVICE”. The user is required to connect his android device the user required to enter his pin from his android device and this resets the pattern entries.

Fig 4.1.2 is the flowchart of the new pattern recording. After the user has reset the pattern entries, the device displays an “ENTER PATTERN” message which if a screen pattern is entered the pattern is saved. An “SECRET KNOCK REQUIRED” message is displayed and the user required to enter a knock pattern which when he does is saved.

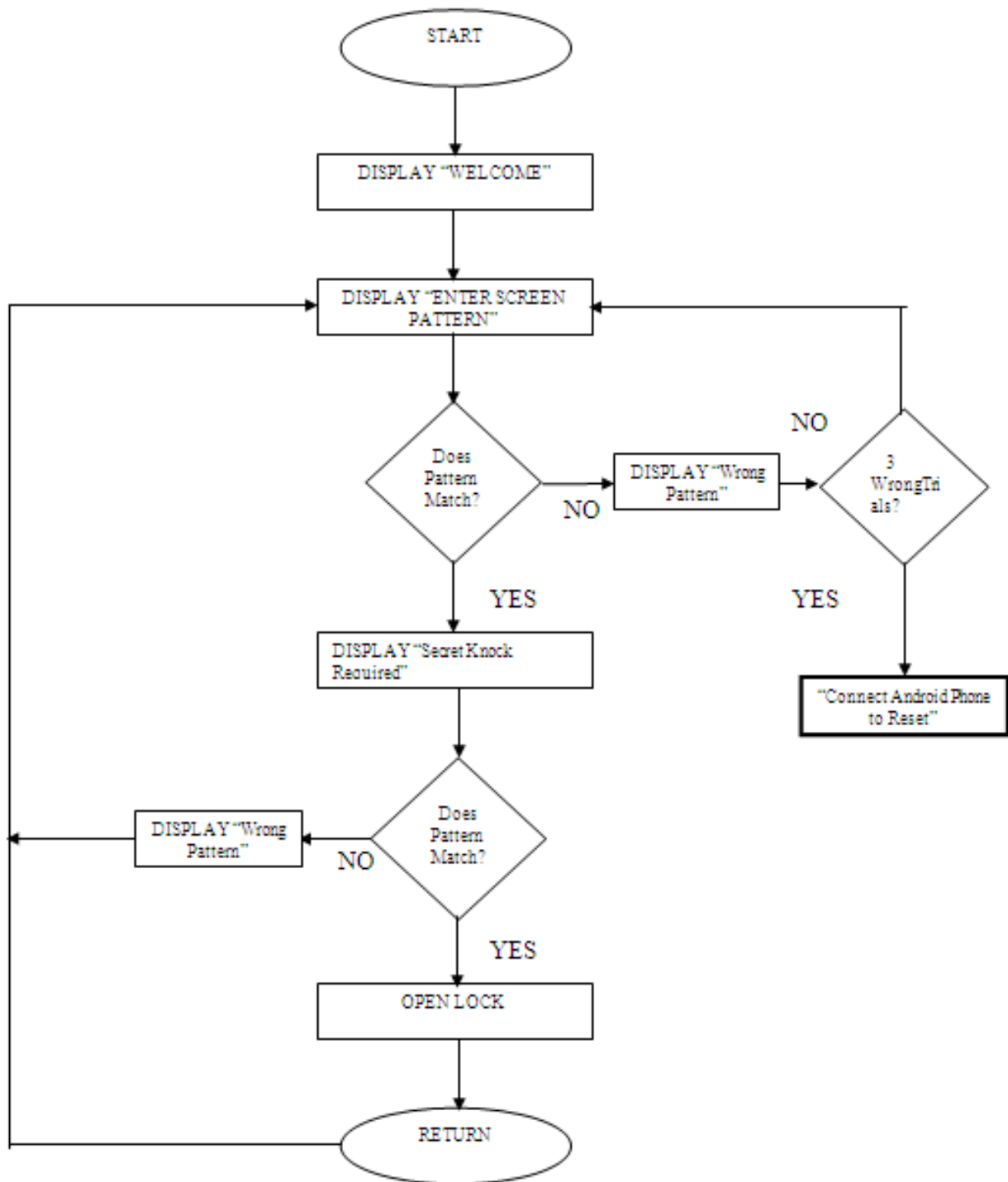


Fig 4.1: Flowchart of the System

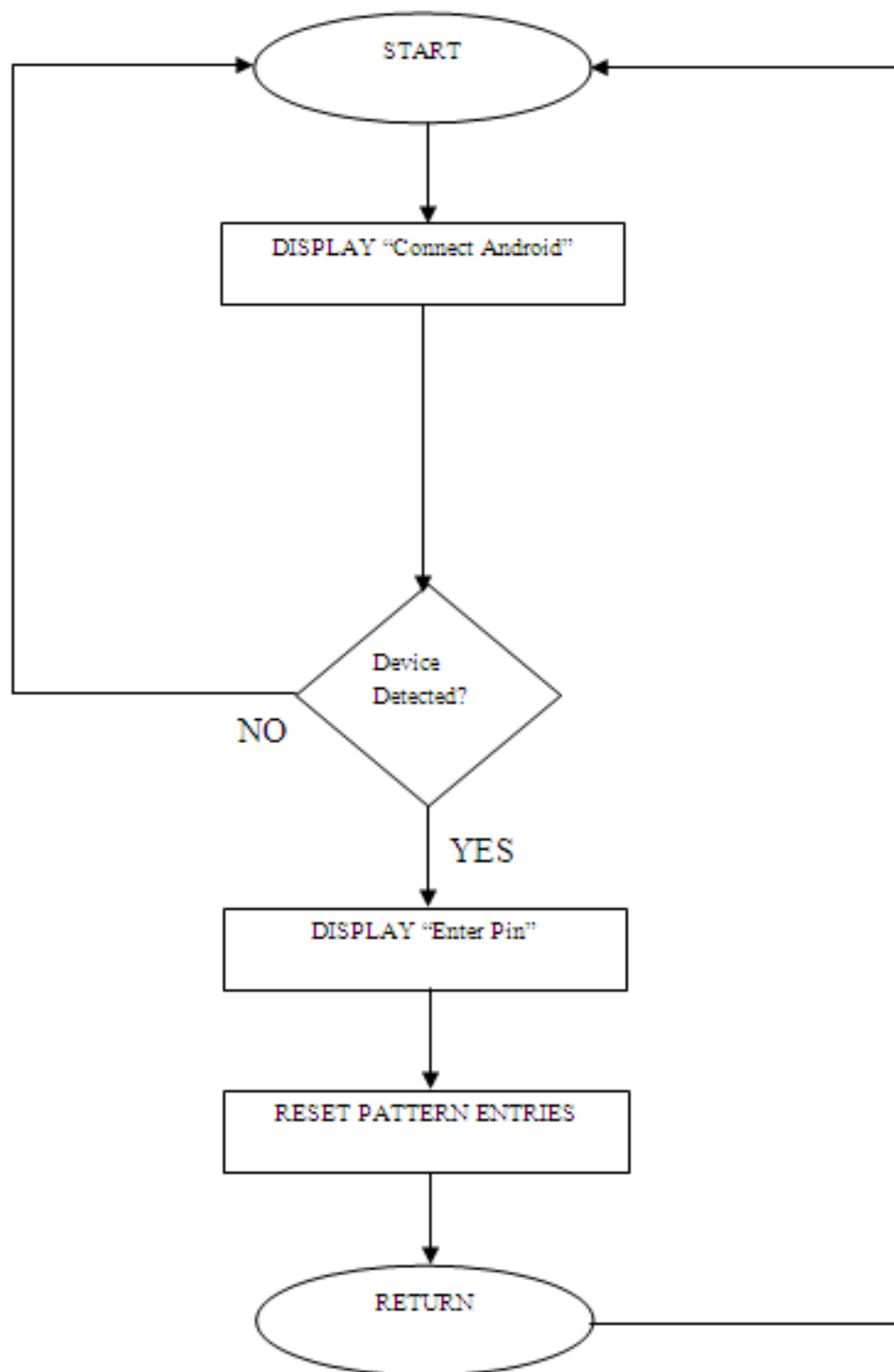


Fig 4.1.1: Flowchart of Reset Process

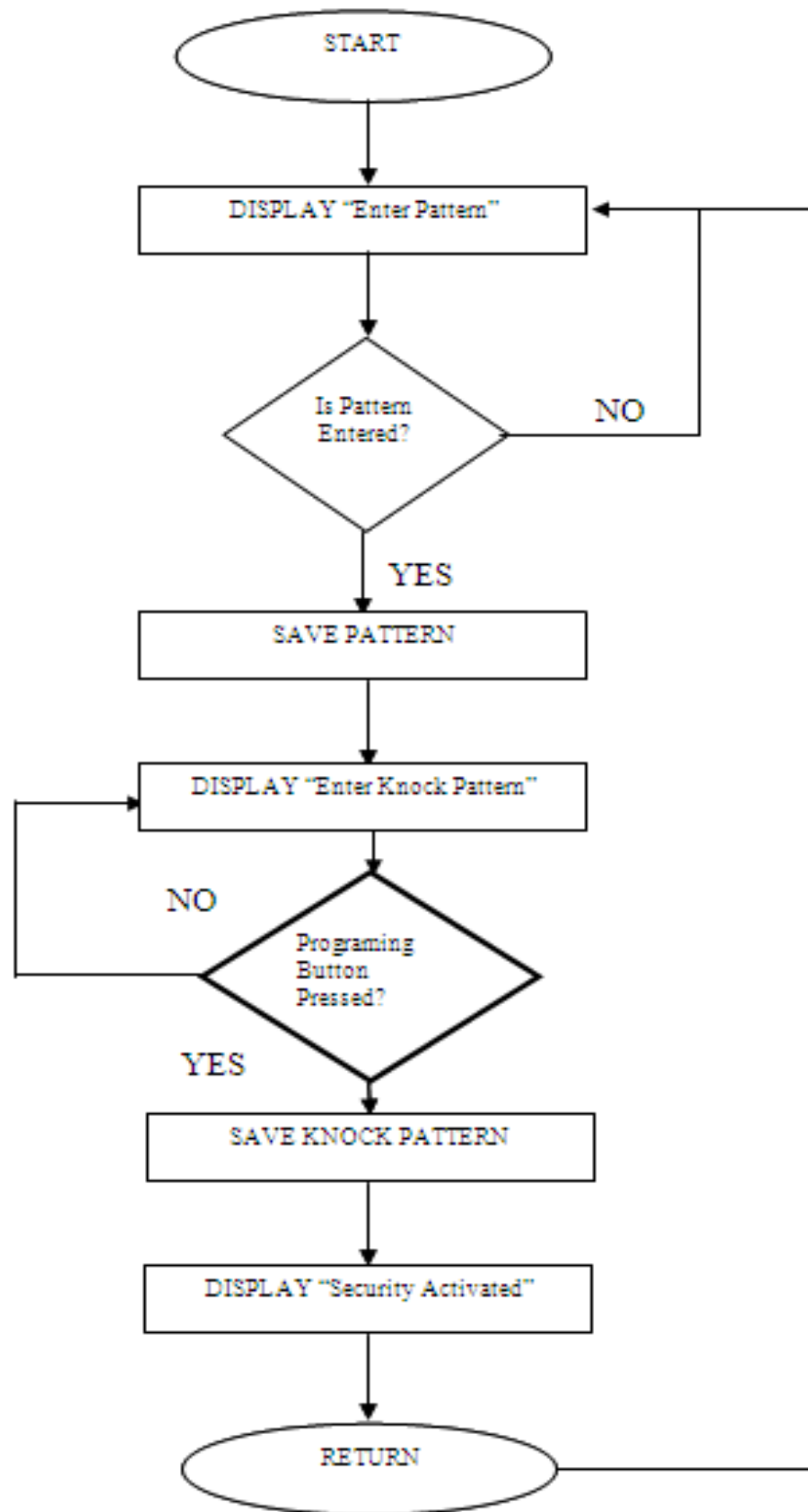


Fig 4.1.2: Flowchart of New Pattern Recording

4.2. Software Implementation

The Design for the display on the screen was done on Nextion Editor which is a development software used for visual building of graphic interface for embedded GUI-intensive devices with various types of TFT displays and Touch Panels [**]. This is a GUI provided by the touch screen manufacturer and uploaded to the screen via an SD card. An overview of the GUI is shown in *fig 4.2.1*.



Fig. 4.2.1. Overview of The Nextion Editor.

Two separate programs were written, for the programming of the microcontroller and the android support application. The sketches (program) for the Arduino microcontroller was written, compiled and uploaded using the Arduino IDE (integrated development environment) while the codes for android support applications were written and compiled using eclipse studio.

4.2.1. Arduino Integrated Development Environment (IDE)

Sketches which define what the board will do were created here. Before writing the sketches or programs, the relevant header files were included from the library as shown in *fig 4.2.1*. A header (.h) file, is a file containing definitions for variables and functions, which are shared between several sketches. This helps split the code instead of having everything in a huge .ino (extension for Arduino compiled sketches) file, and allows you to re-use the same code across projects in the form of a Library. Each particular header files are stored in their separate libraries. At least two files are needed for a library: a header file (with the extension .h) and the source file (with the extension .cpp). The header file has definitions for the library: basically a listing of everything that's inside; while the source file has the actual code.

4.2.2. Proteus Design Suite V8.0

The circuit diagram was designed using Proteus Design Suite V8.0 but only the switching section of the circuit was simulated using this software as the circuit in its entirety could not be simulated using the Proteus Design Suite V8.0 because not all components used for the project were contained in the Proteus Design Suite V8.0. The entire circuit was transferred to Fritzing; an [open-source hardware initiative](#) for simulating, testing and developing electronic prototypes and systems.

4.2.2.1. Fritzing

The complete circuit was implemented with this software. Fritzing was also used in the breadboard and Vero-board designs along with the initial code development *Fig 4.2.2.1 Shows an overview of the Fritzing software.*

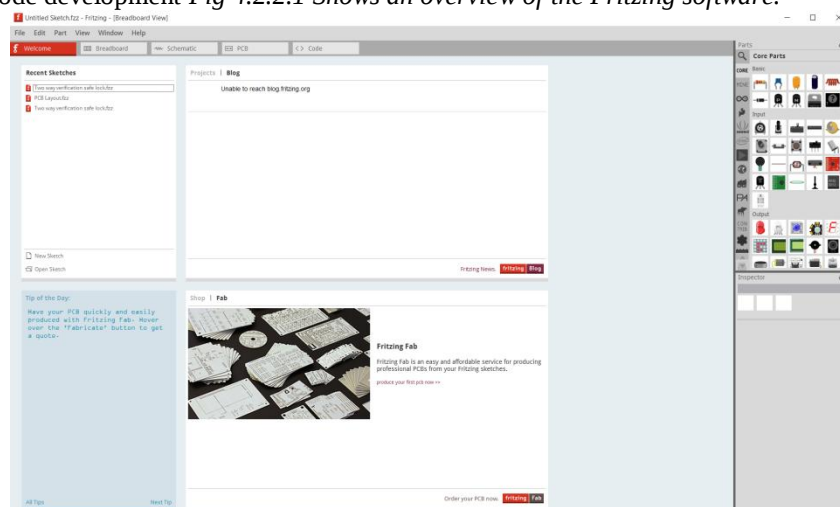


Fig 4.2.2.1: Overview of the Fritzing software

A breadboard and Vero-board were initially designed on this software before they were physically implemented. Fig 4.2.2.3 shows the vero board design.

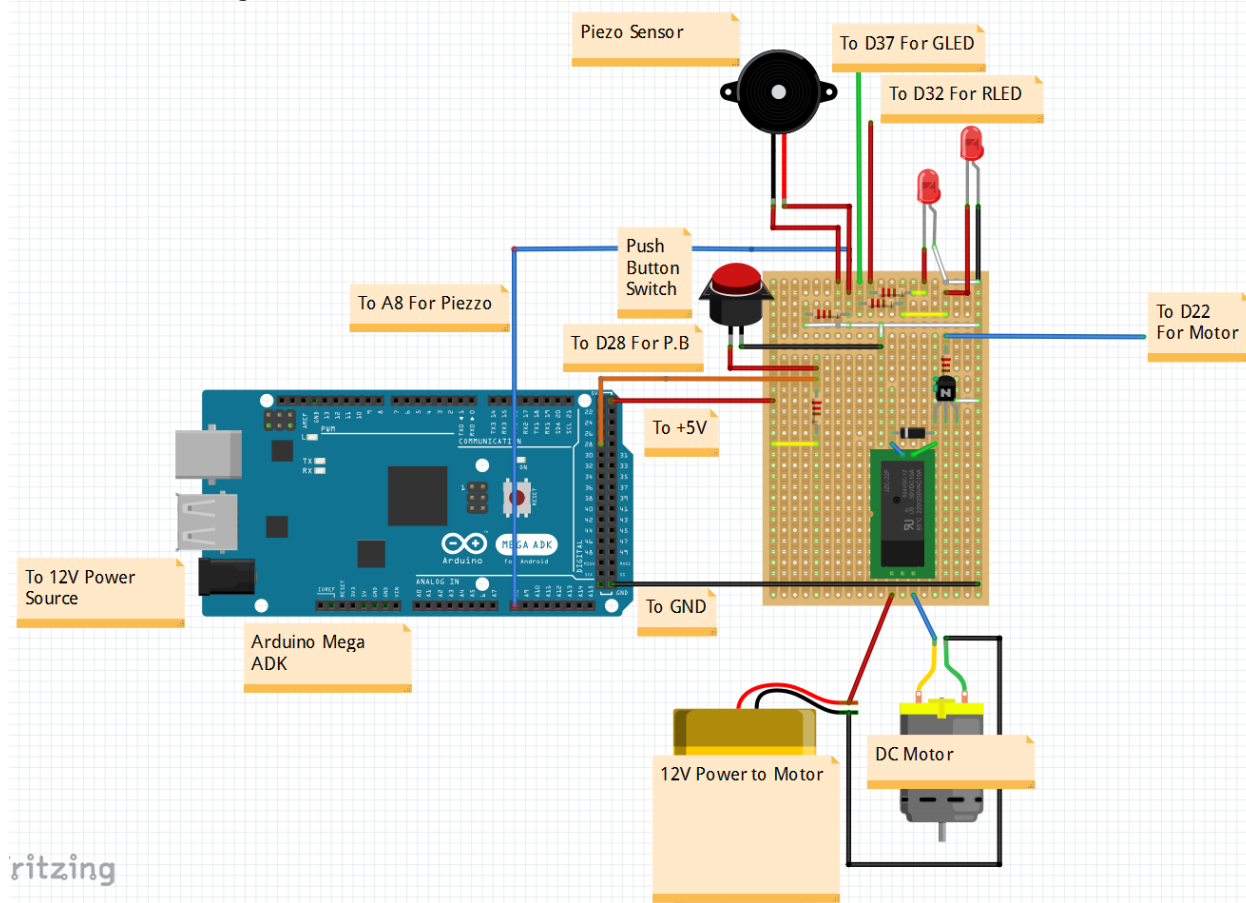


Fig 4.2.2.3: shows the vero board design without the TFT touch shield mounted.

RESULT

After implementing the circuit on bread board, the system worked and all necessary corrections made. The circuit was then transferred onto a Vero board as shown in fig 4.2.2.3. A Vero board is a version of the breadboard where circuits that are confirmed working are permanently soldered in the exact configuration as on the bread board. To ensure that the components are held firmly onto the board, soldering is carried out. A soldering iron and a soldering lead are needed to solder the component to the Vero board. Manual soldering process was used to solder components and connecting wires into the board. Continuity test was conducted with a multi meter to ensure there was no bridging and enhance firm contact.

CONCLUSION

The two-way verification electronic safe lock is a reliable electronic lock. The screen and knock patterns make the safe easier to access by the user as the complexity and stress of carrying key cards or keys is eliminated. The android support application increases the security of the system and ensures the user still has access to the safe if he forgets his patterns. The ATmega2560 chip makes the response of the system considerably fast and very responsive. C ++ programming language which is the programming language for programming Arduino microcontroller was used.

REFERENCES

- [1.] Alan G. Smith, "Introduction to Arduino A Piece of Cake!" (2011) Cake Made by Lisa Smith and Family, Inc., Pennsylvania 2011.
- [2.] Arduino, "Arduino MEGA ADK", <https://www.arduino.cc/en/Main/ArduinoBoardMegaADK>, [Accessed Oct. 2015].
- [3.] Arduino, "Lily-Pad Arduino Main Board", <https://www.arduino.cc/en/Main/ArduinoBoardLilyPad>, [Accessed Oct. 2015].
- [4.] Arduino, "What is Arduino?", <https://www.arduino.cc/en/Guide/Introduction>, [Accessed Oct. 2015].

- [5.] Atmel, "ATmega2560", <http://www.atmel.com/devices/atmega2560.aspx>, [Accessed Oct. 2015].
- [6.] Blue Coat, (2012), "The history of security", <https://www.bluecoat.com/history-of-security/> [Accessed Oct. 2015]
- [7.] Chris Woodford, "Piezoelectricity", (2009) <http://www.explainthatstuff.com/piezoelectricity.html>, [Accessed Oct. 2015].
- [8.] Di Marzio J.F, "[Android. A Programmers Guide](#)", (2008), The McGraw-Hill Companies, Inc., New York 2008.
- [9.] Durfee W, "Arduino Microcontroller Guide", University of Minnesota, (Oct. 2011)
- [10.] Electronicstutorials.com, "RELAY SWITCH CIRCUIT", (2016), <http://www.electronics-tutorials.ws/blog/relay-switch-circuit.html>, [Accessed Mar. 2016]
- [11.] Fadi Aloul et al, "Two Factor Authentication Using Mobile Phones", (2009), Department of Computer Science & Engineering, American University of Sharjah, UAE 2009.
- [12.] Future Electronics, "[Push Button Switches](#)", (2015), <https://www.futureelectronics.com/en/switches/push-button-switches.aspx>, [Accessed Oct. 2015].
- [13.] Index of Assets, <https://cdn.sparkfun.com/assets/> [Accessed Oct. 2015].
- [14.] Instructables, "The Arduino Microcontroller", (2014), <https://instructables.com/arduino-projects>. [Accessed Oct. 2015].
- [15.] Instructables, (2014), "Types of Arduino Boards", <http://www.instructables.com/id/intro-to-Arduino/step1/Different-types-of-Arduinos/> [Accessed Oct. 2015].
- [16.] Itead.cc, "Nextion Display", (2016), <https://www.itead.cc/display/nextion/nextion-nx4024t032.html> [Accessed Mar. 2016].
- [17.] Jiao Tong University, Shanghai, (June 17 –29, 2012) "Introduction to the Arduino Microcontroller", (2012), Hands-on Research in Complex Systems,.
- [18.] Ken Leung, "History of Arduino Microcontrollers", (2010) <http://www.kenleung.ca/portfolio/arduino-a-brief-history.3/>, [Accessed Oct. 2015].
- [19.] Liane Casavoy, "What is TFT-LCD?", (2014) <http://cellphones.about.com/od/phoneglossary/g/What-Is-Tft-Lcd.htm>, [Accessed Oct. 2015].
- [20.] Maina Gladys Mambui, "Final Year Projects, Abstracts", (2014) Department of Electrical and Electronic Engineering, Jomo Kenyatta University of Agriculture and Technology, 2014/2015 Academic Year.
- [21.] Mario Böhmer, "Beginning Android ADK with Arduino", (2012), Apress, Inc., New York 2012.
- [22.] Martin Devine, "Locksmith career", (2009), <http://www.pdfdrive.net/introduction-to-locks-and-keys-e798636.html>, [Accessed Oct. 2015].
- [23.] Mason, C. R. , "[Art & Science of Protective Relaying, Chapter 2, GE Consumer & Electrical](#)", (2011), <http://www.gedigitalenergy.com/multilin/notes/artsci/>, [Accessed Oct. 2015].
- [24.] Megatronics, (2015), "Product Description of Arduino Uno", <http://www.megatronics-eg.com/product/org-arduino-uno/>, [Accessed Oct. 2015].
- [25.] Nanomotion.com, "The Piezoelectric Effect". <http://www.nanomotion.com/piezo-ceramic-motor-technology/piezoelectric-effect/>, [Accessed Oct. 2015]
- [26.] Perspecsys, "History of Security Systems", (2012), <http://www.perspecsys.com/history/>, [Accessed Oct. 2015].
- [27.] Robokits, <http://robokits.co.in/motors/high-torque-dc-geared-motor-300rpm>.
- [28.] Seedstudio, (2013), "Arduino : What is Arduino", <http://seedstudio.weebly.com/>, [Accessed Oct. 2015]
- [29.] Simon Monk, "30 Projects for Evil Genius", (2010), The McGraw Hill Companies, Inc., New York © 2010.
- [30.] The Swide, (2010), "History of Keys and Locks", <http://www.swide.com/art-culture/history-of-keys-and-locks-from-ancient-egypt-to-modern-days/2014/11/02> [Accessed Oct. 2015].
- [31.] UkEssays.com, (2015), "The History of the Arduino Microcontrollers", <http://www.ukessays.com/essays/information-technology/the-history-of-the-arduino-microcontroller-information-technology-essay.php>, [Accessed 5 Oct. 2015].
- [32.] Wamukaya K. Brian, "Final Year Projects, Abstracts", (2014) Department of Electrical and Electronic Engineering, Jomo Kenyatta University of Agriculture and Technology, 2014/2015 Academic Year.
- [33.] Wikipedia, "DC Motors", (2015) https://en.wikipedia.org/wiki/DC_motor [Accessed Oct. 2015].
- [34.] Wikipedia, "History of Locks", (2015) https://en.wikipedia.org/wiki/Key_%28lock%29, [Accessed Oct. 2015].
- [35.] Wikipedia, "The Piezo-Sensor", (2015), https://en.wikipedia.org/wiki/Piezoelectric_sensor. [Accessed Oct. 2015].
- [36.] WileyIndia, (2013), "Introduction to Android Open Accessory", www.wileyindia.com/media/pdf/1118454766-66.pdf, [Accessed 2015].