# SMART DOOR LOCK USING RHYTHMIC KNOCKS

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**BACHELOR IN MECHATRONIC ENGINEERING WITH HONOURS**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2024**

**SMART DOOR LOCK USING RHYTHMIC KNOCKS**

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**A report submitted**
**in partial fulfilment of the requirements for the degree of**
**Bachelor in Mechatronic Engineering with Honours**

**Faculty of Electrical Technology and Engineering**



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2024**

**DECLARATION**

I declare that this thesis entitled "SMART DOOR LOCK USING RHYTHMIC KNOCKS is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

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Name : Nurul Natasha Binti Irfan

Date : 10 / 1 / 2024

**APPROVAL**

I hereby declare that I have checked this report entitled "SMART DOOR LOCK USING RHYTHMIC KNOCKS", and in my opinion, this thesis fulfils the partial requirement to be awarded the degree of Bachelor of Mechatronics Engineering with Honours

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Date : 10/1/2024

# DEDICATIONS

To my beloved mother, father and younger brother. The reason of what I become today. Thank you for your endless love, sacrifices, prayers, supports and advices.

**ACKNOWLEDGEMENTS**

All praise be too might ALLAH S.W.T Merciful and Beneficent for the strength and blessing throughout the entire research and completion of this Final Year Project (FYP1). First and foremost, all praise is due to Allah, Lord of the worlds for giving us wellness, intellect and strength to do this project and also the following individuals. Without them, it would not be possible for me to complete this project. In particular, I owe a debt of gratitude to my project supervisor Dr Hairol Nizam Bin Mohd Shah for encouragement, guide, advices, motivation and ideas to complete my project. Without his continued support and interest, this project would not have been same as presented here.

Next, I would like to say a million thanks to my parent for their support and understanding in allowing me to focus on my attention to this project. They have always been the driving force in pushing me to excel in everything that I do. To our friends, all of you have been an inspiration to the both of us. My fellow postgraduate students should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space.

Finally, I would also like to extend our utmost gratitude to all the lecturers of University Technical Malaysia Malacca (UTeM) for their guidance and patience. Their teachings have thought me that education and knowledge are vital in life if we wish to succeed.

Thank you very much.

# ABSTRACT

The advancement of technology has introduced innovative methods for unlocking doors, aiming to provide enhanced security and convenience. This project focuses on a smart door lock system that uses rhythmic knocks as a unique biometric authentication method. Traditional methods like key-based or card-based systems have limitations in terms of security and convenience. Biometric solutions such as fingerprint recognition and face recognition have gained popularity, but their widespread adoption is hindered by infrastructure requirements. In this project, the feasibility and effectiveness of using rhythmic knocks as a biometric modality for door unlocking are explored. The system allows users to select a secret rhythm pattern based on their preferences. The motor of the lock is activated when the knock sequence matches the pre-defined secret pattern. The circuit sensitivity is optimized to consider factors like sound intensity and distance. The stability of the vibration signature, used as the biometric identifier, is evaluated over extended periods, proving its reliability as a unique authentication method. The proposed smart door lock system offers a dual-layered security approach, combining rhythmic knock authentication with traditional methods. This integration enhances the overall security level of the system. The project's implementation includes vibration sensors, an Arduino Uno microcontroller and LEDs. Through experimentation and analysis, it has been demonstrated that rhythmic knocks can be an effective and stable biometric modality for smart door lock systems. The uniqueness and stability of the vibration signature, coupled with its ease of use, make it a promising approach for secure door access. The project provides insights into the development of reliable and convenient smart door lock solutions, contributing to the evolution of advanced security systems.

# *ABSTRAK*

Kemajuan teknologi telah memperkenalkan kaedah inovatif untuk membuka pintu dengan tujuan meningkatkan keselamatan dan kemudahan. Projek ini memberi tumpuan kepada sistem kunci pintu pintar yang menggunakan ketukan berirama sebagai kaedah pengesahan biometrik yang unik. Kaedah tradisional seperti menggunakan kunci atau kad mempunyai kelemahan dari segi keselamatan dan kemudahan. Penyelesaian biometrik seperti pengiktirafan cap jari dan pengiktirafan wajah semakin popular, tetapi penyebaran meluas terhad mereka terhad oleh keperluan infrastruktur. Dalam projek ini, kajian dilakukan untuk meneroka kerealisasian dan keberkesanan penggunaan ketukan berirama sebagai modaliti pengesahan biometrik untuk membuka pintu. Sistem ini membolehkan pengguna memilih corak ketukan rahsia berdasarkan keutamaan mereka. Motor kunci akan diaktifkan apabila corak ketukan sepadan dengan corak rahsia yang telah ditetapkan. Kepekaan litar telah dioptimumkan dengan mengambil kira faktor seperti intensiti bunyi dan jarak. Kestabilan tandatangan getaran yang digunakan sebagai pengenal biometrik dinilai dalam tempoh masa yang panjang, membuktikan kebolehpercayaannya sebagai kaedah pengesahan yang unik. Sistem kunci pintar yang dicadangkan ini menawarkan pendekatan keselamatan berlapis dengan menggabungkan pengesahan ketukan berirama dengan kaedah tradisional. Integrasi ini meningkatkan tahap keselamatan keseluruhan sistem. Implementasi projek merangkumi penggunaan sensor getaran, mikrokontroler Arduino Uno, dan LED. Melalui eksperimen dan analisis, terbukti bahawa ketukan berirama boleh menjadi modaliti biometrik yang efektif dan stabil untuk sistem kunci pintar. Keunikan dan kestabilan tandatangan getaran, berserta kemudahan penggunaannya, menjadikannya pendekatan yang berpotensi untuk akses pintu yang selamat. Projek ini memberikan pandangan tentang pembangunan penyelesaian kunci pintar yang boleh dipercayai dan mudah digunakan, menyumbang kepada perkembangan sistem keselamatan canggih.

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# LIST OF SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| RFID | - | Radio Frequency Identification |
| ID | - | Identity Document |
| IDE | - | Integrated Development Environment |
| IOT | - | Internet of Things |
| LCD | - | Liquid Crystal Display |
| PCC | - | Pearson Correlation Coefficient |
| TP | - | True Positive |
| TN | - | True Negative |
| FP | - | False Positive |
| FN | - | False Negative |
| FAR | - | False Accept Rate |
| FRR | - | False Reject Rate |
| TDOA | - | Time Difference of Arrival |
| DWT | - | Discrete Wavelet Transform |
| LED | - | Light-Emitting Diode |
| 2D | - | Two dimentional |
| AC | - | analog circuit |
| DC | - | digital circuit |
| PWM | - | Pulse Width Modulation |
| DOF | - | Degree of Freedom |
| f | - | force |
| m | - | mass |
| a | - | acceleration |
| t | - | time |
| x | - | displacement |
| v | - | speed |
| cm | - | centimeter |
| d | - | diameter |
| V | - | voltage |
| L | - | distance from the center |
| M | - | torque of turning the lock |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Motivation

Traditional door locks can be inconvenient and pose security risks if keys or passcodes fall into the wrong hands. Smart door locks using rhythmic knocks have the potential to offer a more convenient and secure alternative by utilizing unique patterns of rhythmic knocks as access control. This technology could provide an intuitive and personalized experience for users, especially those who have difficulty using traditional key-based locks. The use of rhythmic knocks also eliminates the need for physical keys or passcodes, which can be lost, forgotten, or easily guessed by intruders. Moreover, traditional door locks can be bypassed by criminals using lock-picking tools or other techniques, leaving homes and businesses vulnerable to theft or burglary. Smart door locks using rhythmic knocks can offer a more secure alternative by providing a personalized and unique access control mechanism that is difficult to duplicate. The use of advanced algorithms and biometric technology can also enhance the system security by detecting and preventing spoofing attacks and unauthorized access attempts. Finally, the development of a smart door lock using rhythmic knocks has benefits for society, such as reducing the incidence of break-ins and thefts, improving accessibility for individuals with disabilities or mobility issues, and providing a more convenient and personalized user experience. The success of such a project would require a multi-disciplinary approach that combines expertise in software development, security, human-computer interaction, and hardware design. Addressing the challenges associated with the development of a smart door lock using rhythmic knocks would represent a significant step forward in the field of access control and security, with potential applications in both residential and commercial settings.

## 1.2 Problem Statement / Hypotesis

There are some houses still using traditional-key based method on their home security management in order to lock and unlock the door. The house keys were usually carried out together in pockets when people went out from their house. Sometimes people may forgot to bring the keys while the door already locked from inside or accidently locked. This situation usually occurred to students going to the toilet and leave their room. Most people may lose their keys all the way outside the house. This, traditional door locks can be inconvenient and pose a security risk if the keys fall into the wrong hands in which can contribute to the occurrence of housebreaking crimes. There has an alternative to used traditional-keys where authorized the door lock with RFID or ID cards, Biometric and fingerprint but other different alternatives have not been developed much. Moreover, none of them carries the sensory understanding dimension of the person and it is not possible to determine whether or not the entrance request has been made by that person.

### 1.3 Project Objective

This project is developed with the purposed to optimizing the productivity, minimizing the cost of the project and make no human mistakes. The main thing of this project is to study on how to communicate the programming language with the sensor. After that, the motor will make its own decision of rotation that been programmed. The objective can be summarized as below:

1. To design and develop a prototype of efficient door lock system based on knocking rhythms

2. To obtain the responses of vibration sensor activated by a knock sequence

3. To analyze the knock performance based on the presence of sound

### 1.4 Scope and Limitation

This project is subjected to several scope and limitations that are narrowed down to the study. There are a few scopes and guidelines to unsure the project is conducted within its intended boundary. This is to ensure the project is heading in the right direction to achieve its intended objectives. The scopes are:

First, for designing the smart door system, a piezoelectric sensor is used for detecting any knock sequence on a door.

Second, the type and material of the door that used as a main surface for knocking process is only used wooden door while other door materials are not considered in this research.

Third, for developing the design system, a piezoelectric sensor and servo motor will be used for detection and locking movement process.

Fourth, for analyze the system performance, a low cost microcontroller such as Arduino Uno is used as operating system in controlling the whole process. The data from the sensor is then sends to the Serial Monitor in Arduino IDE software. Therefore, the results obtained by sensor will be analyzed.

Fifth, in the detection process on knocks, the knocking forces detection is not considering the whole area of the door but only detected on the selected area of the door.

Lastly, a prototype design is used in designing the hardware parts. The prototype only focus on detection and recognition process which include the door size of 35cm x 4cm x 58cm.

### 1.5 Report Structure

Chapter one briefly introduces the overall of the project title about Smart Door Lock Using Rhythmic Knocks. It consists of motivation, project objective, problem statement, scope of work, limitation and structure report.

Chapter two discuss about the background of study related to separation system. Literature review will produce overall structure of the Smart Door Lock which shows the relationship between project research and theoretical concept.

Chapter three explain about the project methodology. Project methodology give details about the method used to solve the problem to complete the project. The method used such as collecting data method, process and analysis data method and modelling

Chapter four consists of result and discussion of the project, finding and analysis throughout the research and project development.

Lastly, chapter five is the project conclusion. This chapter rounds up the attained achievement of the whole project and reserves suggestions for possible future researches.

## CHAPTER 2

## LITERATURE REVIEW

### 2.1 Introduction

The aims of this chapter is to highlight past studies and research related topic on the door locking system using knocks detection with rhythms and patterns. This chapter covered the fundamental knowledge and understanding of knock interaction, vibration mechanism, system performance techniques, various impaction by the approaches, filtering process, localization, knock rhythms and IOT based recognition. To determine the best method for knocks detection according to their accuracy, precision and simplicity, various approaches are also introduced and reviewed.

### 2.2 Project Background

The development of smart door lock systems has revolutionized the way we secure our homes and access our living spaces. Traditional lock and key mechanisms have gradually been replaced by advanced technologies that offer convenience, enhanced security, and seamless integration with modern lifestyles. One such innovative approach involves utilizing rhythmic knocks as a means of authentication and access control. The concept behind the project is to leverage the unique rhythmic patterns created by a user's knocking actions on the door to authenticate and grant access. By analyzing and recognizing the specific rhythm and sequence of knocks, the smart door lock system can accurately identify authorized users and allow entry, while preventing unauthorized individuals from gaining access.

This project aims to explore the potential of using rhythmic knocks as a secure and intuitive method for door unlocking. It focuses on developing a robust algorithm and implementing it within a smart lock system that integrates seamlessly with existing door hardware. The system will incorporate sensors capable of capturing and analyzing the vibrations generated by knocking on the door, extracting distinct rhythmic patterns, and comparing them with pre-registered user profiles. The project will also address various challenges associated with implementing a reliable and accurate knocking-based authentication system. Factors such as ambient noise, variations in knocking techniques, and environmental conditions will be taken into consideration to ensure optimal performance and minimize false positives or false negatives.

In addition to security and convenience, the use of rhythmic knocks as an authentication method offers several advantages. It eliminates the need for physical keys or electronic access cards, reducing the risk of loss, theft, or unauthorized duplication. Furthermore, it provides a natural and intuitive way for users to interact with the smart door lock system, requiring only a simple knocking gesture to gain entry. Through this project, the team aims to demonstrate the feasibility, effectiveness, and user-friendliness of a smart door lock system that utilizes rhythmic knocks as an authentication mechanism. By harnessing the power of vibrations and analyzing unique rhythmic patterns, the system aims to provide a secure and convenient solution for modern access control requirements.



## 2.3 Type of Security Access System

There are various method used to unlock any locked devices, particularly door, including carrying devices such as door keys and RFID cards, as well as using biometric solutions. Biometric solutions encompass technologies such as fingerprint recognition face recognition, voice recognition, eye recognition, and keystroke dynamics [1]. Several type of security access system are represented in Table 2.1.

Table 2-1 Type of Security Access System

| Type of Security Access | Security | Description |
|---|---|---|
| Simple knock lock | Partially | - Easily to be unlocked by trial and error method |
| Fingerprint | High | - Quite greater error rate<br>- In special case may involve complexity |
| Voice | Least | - Easy to broken down by recorded voice/voice artists |
| Face | Partially | - Capable to be decoded with similar recognize faces/photograph display |



## 2.4 Keystroke Dynamics

Keystroke dynamics is one of the biometric solution utilized on door locking and unlocking system. Keystroke dynamics method involve analyzing the special rhythm and timing of keystrokes applied on a keyboard. Figure 2.1 shows the graph of writing process of a person for the same text while Figure 2.2 shows the graph of writing process by difference people for the same text. By comparing both recorded keystrokes with the actual keystrokes, discrepancies can be identified [1].

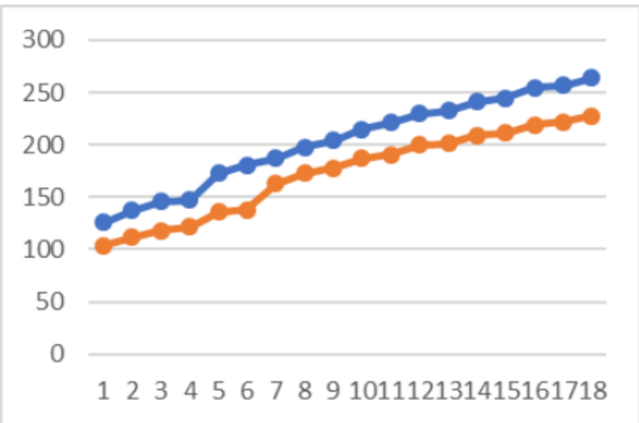



Figure 2.1 Graph of writing process for a person on the same text [1]

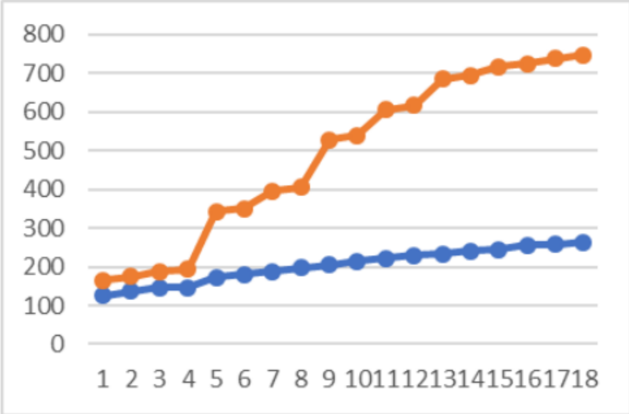



Figure 2.2 Graph of writing process for different person on the same text [1]

However, relying solely on keystroke dynamics for identification purposes is not sufficient. To enhance system security, a dual-layer approach combining knock patterns and fingerprint recognition has been proposed, complementing traditional methods [15,20]. The feasibility of applying rhythm factors to keyboards or buttons has been explored based on pressure values. According to Preethi (2021), the knocking process will detected and door is opened when the applied force matches a predefined threshold. The system comprises two vibration sensors placed at specific distances, an Arduino Nano Microcontroller, an R307 Fingerprint sensor, a keyboard, and an LCD display [15,17]. Knocking pattern is interlaced and array of pattern is stored during recording and checking time. If the sensor fails to detect the pattern, the actuator or motor remains idle, and the door remains closed or locked [27]. Based on Figure 2.3 and Figure 2.4, different individuals produce varying force outputs, contributing to an increased level of security.

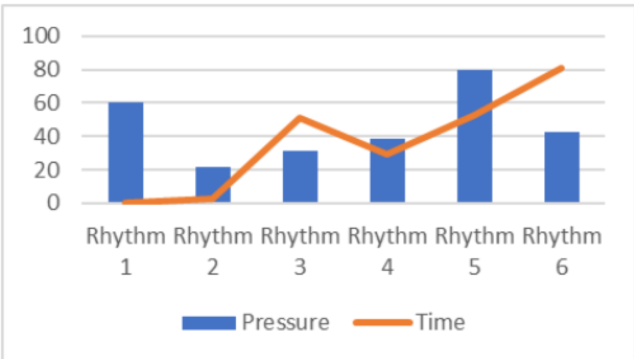



Figure 2.3 Pressure and time by Person 1 [1]

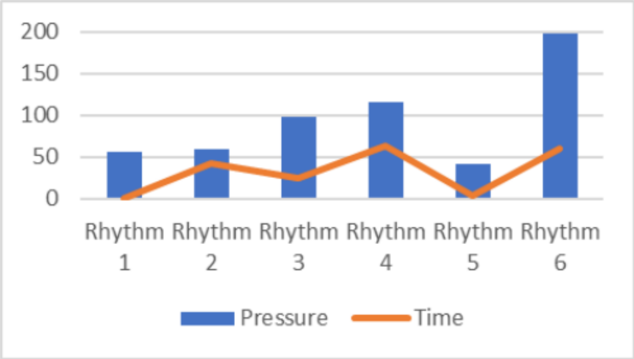


Figure 2.4 Pressure and time by Person 2 [1]

The data were processed with considering incoming values and arrival time [1] as given Equation (2.1) and (2.2).

$$\bar{t}_j = \frac{\sum_{i=1}^{n} t_i - t_{i-1}}{n} \tag{2-1}$$

$$\bar{P}_j = \frac{\sum_{i=1}^{n} P_i}{n} \tag{2-2}$$

Where;

$n = number\ of\ attempts$

$t = duration\ of\ stroke$

$\bar{t} = average\ of\ stroking\ time$

$j = number\ of\ rhythms$

$P = value\ of\ pressure$

$\bar{P} = average\ of\ pressure$

$\bar{P}_j = average\ pressure\ for\ rhythm\ j$

$\bar{t}_j = average\ duration\ for\ rhythm\ j$

## 2.5 Hand Knock Interaction

Knocking on doors using hand gesture has been a widely practiced and intuitive method for requesting access to a space for thousands of years. The intrinsic differences among human users in bone structure, muscle distribution, and shape of hands physical contact between hand and door jointly forms a unique system [3]. Triggered by the knocking force, this system generates hand-dependent vibration signals unique to individual users [3]. When a user applies force through knocking, this unique hand-door system is set into motion, resulting in the generation of vibrations that are intricately linked to the characteristics of the user's hand. These vibrations are specific and exclusive to each individual, serving as a personalized signature embedded within the knocking action. Hence, by simply observing and analyzing the vibration signals produced during hand-door interaction, one can effectively identify and distinguish between different users based on their distinctive vibration patterns [3].

## 2.6 Vibration Mechanism

When knocks are applied to the surface of a door, it causes deformation in the contact area known as the force-bearing area, leading to the generation of vibration waves [3]. Chao (2022) state that, the generation and propagation of these vibrations rely on the structural properties of both the hand and the door, such as the spring constant and damper coefficient, which together form an oscillator. The specific vibration signature can be produced by multiple knocking of certain user on the same door [3]. The hand parameters, including the unique bone structure of the hand, play a significant role in oscillation process.



The vibration generation process in the hand-door oscillator can be described as a forced spring system with two stages which are compression and stretch. In the compression stage, the force exerted by the hand on the door deforms the force-bearing area, converting kinetic energy into elastic potential energy. When the applied force surpasses the resistance of the door material, the force-bearing area reaches maximum deformation. In the stretch stage, the force-bearing area gradually returns to its original state, releasing energy and generating vibrations. As shown in Figure 2.5, this process can be represented using a mass-spring-damper model, where the characteristics of the hand-door oscillator, such as mass, spring constant, and damper coefficient, are determined by the individual's hand structure, including bones, muscles, and shape of the user's hand.

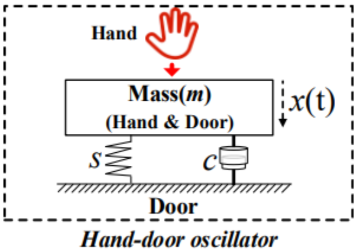



Figure 2.5 Mass spring damper model [3]

Hooke's law and Newton's law play a role in describing the mechanism of hand knocking that is formulated as Equation (2.3) and Equation (2.4) [3].

$$f_{t=0} = ma\,(t) + cv(t) + sx(t) \qquad (2\text{-}3)$$

$$f_{t=0} = m\frac{d^2x(t)}{dt^2} + c\frac{dx(t)}{dt} + sx(t) \qquad (2\text{-}4)$$



Where a(t) and v(t) are represent as acceleration and door speed respectively. As changes in ft=0 only affect vibration amplitude, the shape of vibration envelope (morphology) can be regarded as a unique signature. Since alterations in the force solely impact the amplitude of the vibrations, the distinct shape of the vibration envelope, or its morphology, can be considered as a distinctive signature [3].

### 2.6.1 Vibration Authentication

According to Chao (2022), the knocking analysis was conducted in real-time with a sampling rate of 10 Hz. The right hand of the user performed the knocking gesture on a wooden door, maintaining contact for approximately two seconds to ensure proper oscillation and propagation of vibrations. The effectiveness of vibration authentication relies on the uniqueness, stability, and sensitivity of the vibration signature. The uniqueness of the vibration signature can be verified through the measurement of three critical parameters as shown in Figure 2.6 which is length, breadth, and circumference, correspond to the identical hand shape that produces the knocks on the door [3].

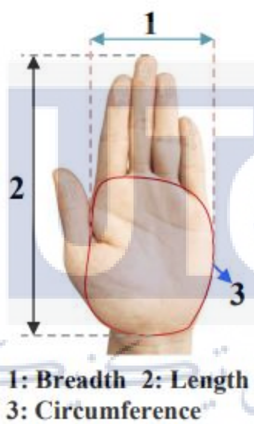





Figure 2.6 Hand parameters [3]

## 2.7 Knock Localization

Knock localization is also the method used in order to detect and recognize the position of the knocks as well as the sequences. This knock localization includes two method which are simple TDOA and TDOA with geometrical constraints.

### 2.7.1 Simple TDOA

Simple Time Difference of Arrival (TDOA) method provide sensors placement based on the knock region that will be applied. According to Figure 2.7, this method involves dividing the door into four different regions for the knock detection process. Sensor 1 is only triggered at region 1, and the same applies to the other sensors. The user need to remember and execute knock sequence with rhythmic and geometric precision where basically can be localized at any position [4].

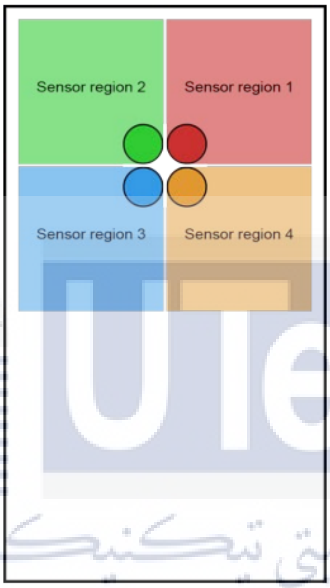



Figure 2.7 Door sensor localization for simple TDOA [4]



### 2.7.2 TDOA with geometrical constraints

TDOA with geometrical constraints for the research by [4] assumes the door as isotropic and having a constant speed of knock vibration. This method utilizes three sensors attached to the door. By having three sensors, the system had four unknown parameters; the distance d between the knock location and the closest sensor, and the angles α, β and φ. The sensor localization using TDOA with geometrical constraints illustrated in Figure 2.8 below.

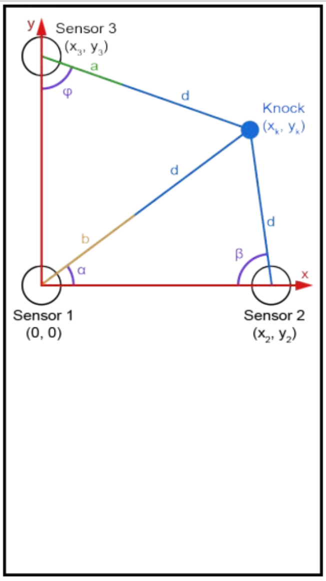



Figure 2.8 Door sensor localization for TDOA with geometrical constraints [4]

The geometric constraints are described by equations, and the coordinates (xk, yk) are calculated to find the knock location using the roots of the system of equations. Analyzing this nonlinear system would typically require matrix operations, which can be done easily in MATLAB using Newton-Raphson's method. The geometrical constraints formula described in Equation (2.5), (2.6), (2.7) and (2.8).

$$\overline{e_x} : (b + d).\cos(\alpha) + d.\cos(\beta) = x_2 \quad (2\text{-}5)$$

$$\overline{e_y} : (b + d).\sin(\alpha) - d.\sin(\beta) = 0 \quad (2\text{-}6)$$

Therefore,

$$\overline{e_x} : (b + d).\cos(\alpha) - (a + d).\sin(\varphi) = 0 \quad (2\text{-}7)$$

$$\overline{e_y} : (b + d).\sin(\alpha) + (a + d).\cos(\varphi) = y_3 \quad (2\text{-}8)$$

Even both method are constructed to measure and detect the exact position of knocks, it is also can be used to detect the knocks sequences as recognition from the sequence triggerred by region and coordinated. The differences between each localization method are summarized in Table 2.2 based on their advantages and disadvantages of use.

Table 2-2 Advantages and Disadvantages between keystroke dynamics, simple TDOA and TDOA with geometrical constraints

| Knock Sequence Recognition | Advantages | Disadvantages |
|---|---|---|
| Keystroke Dynamics | - Can only use for 1 sensor<br>- Based on rhythms and timing of knock | - Not specific for knock location<br>- Require region of knock area on a door |
| Simple TDOA | - Use 4 sensors<br>- Easy to implement matrix operation; multiplication and inversion<br>- Based on sequence region triggered<br>- Triggered at specific region | - Less accurate because only distingushes deifferences between regions |
| TDOA with geometrical constraints | - Use 3 sensors<br>- Based on knocking coordinates<br>- More accurate to detect the location of knocks<br>- Give exact position | - Need assume specific door and vibration transmition to avoid rigorous testing and advance calculation; isotropic with constant speed<br>- Hard analysis for nonlinear system<br>- Need to remember knock rhythms sequence and geoetrical precision |

## 2.8 Similarity Method

The similairty method is used to measure the similairty of knock's samples by comparing the registered knocks with the actual knocks applied.

### 2.8.1 Pearson Correlation Coefficient (PCC)

Pearson Correlation Coefficient (PCC) is a technique used to measure sample similarity by comparing arbitrary signatures from the same user (Intra-PCC) and signatures from different or distinct users (Inter-PCC) [3]. As depicted in Figure 2.9, the analysis of 47 user signatures reveals a minimum Intra-PCC value of 0.91, significantly higher than the maximum Inter-PCC value of 0.57. This stark difference between Intra-PCC and Inter-PCC values indicates the signatures can be accurately classified and effectively represent the identities of individual users.

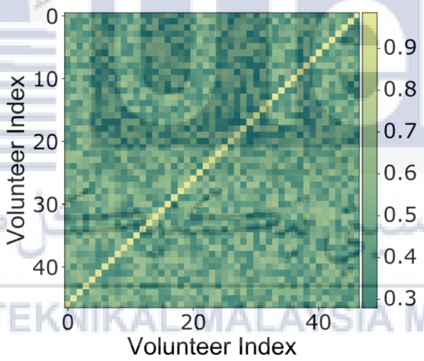





Figure 2.9 Vibration signal similarity using PCC [3]

#### 2.8.1.1 Impaction with Long-Term Stabilization

The stability of the vibration signature over time for the same user can also be analyzed using the Pearson Correlation Coefficient (PCC). Users were instructed to perform knocking actions at six different time periods, spanning several months. As a result on Figure 2.10, average value of Intra-PCCs drops by a mere 0.05 while maintaining a significant difference from Inter-PCCs. From the findings, the hand knocking vibration signature remains stable over an extended period of time, reinforcing its reliability as a unique identifier [3].

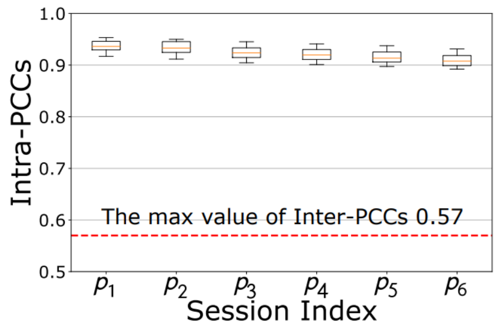



Figure 2.10 Temporal stability of PCC [3]

### 2.8.1.2 Impaction with Door Material

The impact of different door materials, such as wood, aluminum, and zinc alloy, on the vibration signature of hand knocking can be analyzed. From Chao (2022) findings, there is a significant disparity between the Inter-PCC (inter-class pairwise correlation coefficient) and Intra-PCC (intra-class pairwise correlation coefficient) for each material. The impact of door material on the overall process of capturing and analyzing vibration signatures was found to be insignificant. Therefore, the specific type of door material can be considered negligible in terms of its effect on the accuracy and reliability of the vibration signature-based system. Figure 2.11 shows the analysis of impaction of different door material.



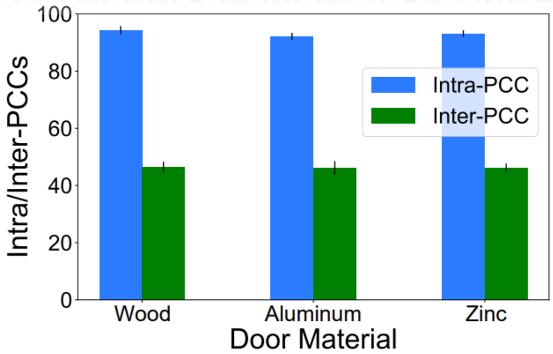



Figure 2.11 PCCS for door material [3]

#### 2.8.1.3 Impaction with Knocking Position

The variation in the placement of knocks has a significant impact on the overall vibration performance, particularly when considering the deviation in distance. The [3] study conducted an analysis focusing on three different positions which are 0.5 cm, 1 cm, and 1.5 cm. Figure 2.12 demonstrate a decrease in signature similarity, reaching as low as 0.72 with the position deviation increases to 1.5 cm. This decrease in similarity leads to a higher false positive rate, indicating a higher likelihood of incorrectly identifying a knock as a valid signal [3]. There is a noticeable decrease in similarity when the knock position deviates from the sensing area on the door. As the knock position moves further away from the designated contact area, the sensitivity of the detection system diminishes. The system's ability to accurately capture and interpret knock vibrations is highly dependent on the proximity of the knock to the designated sensing area.

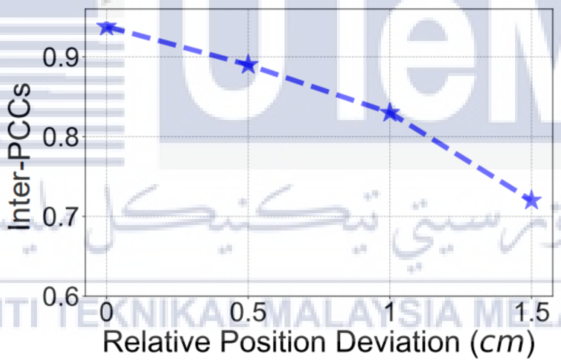



Figure 2.12 Knocking position with PCCs [3]

### 2.8.2 Hankey Method

Chao (2022) proposed a methodology for evaluating the similarity and performance of hand detection vibrations. The approach incorporates four fundamental metrics used in the research, true positive (TP), true negative (TN), false positive (FP), and false negative (FN). In this method there are using False Accept Rate (FAR), False Reject Rate (FRR), Precision, and Accuracy as key indicators. FAR is employed to assess the ratio of illegitimate users incorrectly accepted by the authentication system, while FRR measures the ratio of legitimate users being incorrectly rejected. Precision serves as a measure of the overall system performance, whereas Accuracy represents the ratio of samples correctly classified. In order to establish a secure and effective unlocking system, it is desirable to have low values for both FAR and FRR, while aiming for high values of Precision and Accuracy [3]. The formulas for calculating FAR, FRR, Precision, and Accuracy are provided in Equation (2.9), (2.10), (2.11) and (2.12).

$$FAR = \frac{FP}{FP + TP} \tag{2-9}$$

$$FRR = \frac{FN}{FN + TP} \tag{2-10}$$

$$Precision = \frac{TP}{TP + FP} \tag{2-11}$$

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \tag{2-12}$$

#### 2.8.2.1 Impact of Door Material

Through Chao (2022) findings, upon computing the average values of the two aforementioned metrics, it was observed that the False Acceptance Rate (FAR) stood at a modest 1.87%, while the False Rejection Rate (FRR) reached a similarly modest 2.72%. These results signify that the system's ability to accurately verify the identity of users is prone to occasional errors, albeit at a relatively low frequency.

The findings derived from the analysis conducted distinctly indicate that the type of door material employed has a negligible or inconsequential influence on the overall performance and efficacy of the unlocking process. The system is capable of delivering consistent performance across different door materials, ensuring reliable functionality regardless of the specific material employed. The performance of the system with different door material represented in Figure 2.13.

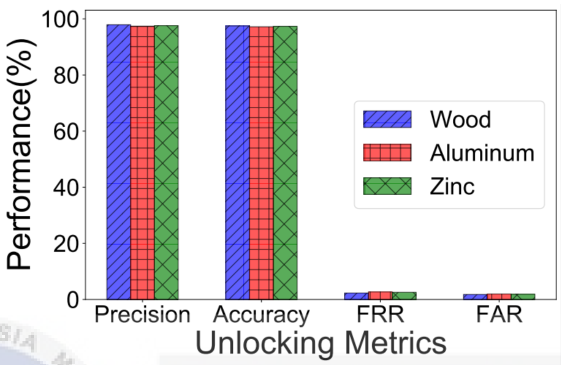



Figure 2.13 Performance with difference door materials [3]

### 2.8.2.2 Impact of Hand Selection

To comprehensively evaluate the impact on system performance, an investigation was carried out involving the utilization of both the right hand and the left hand as means of door knocking analysis [3]. It was acknowledged that individuals possess inherent variances in terms of their abilities, strengths, and habitual tendencies when it comes to executing the act of door knocking, thereby leading certain users to gravitate towards their dominant hand, such as the right hand, as opposed to their non-dominant hand. Figure 2.14 illustrate the unlocking performances using right hand and left hand. Based on the enlightening conclusions drawn by Chao (2022), it was ascertained that irrespective of the hand employed, be it the right hand or the left hand, both were unequivocally capable of generating distinct and unique signatures, as indicated by an impressive Precision score of 98% and a commendable Accuracy score of 96%. It is emphasize the robustness and effectiveness of the system, irrespective of the hand utilized for door knocking.

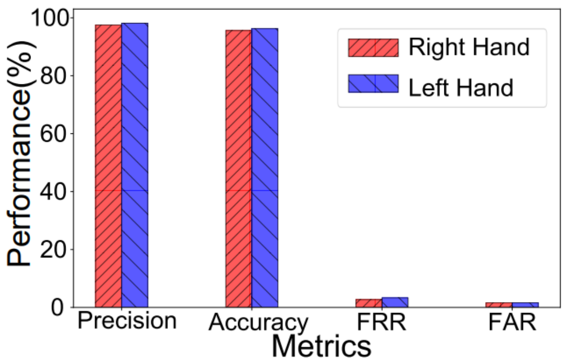



Figure 2.14 Unlocking performance using right and left hand [3]

### 2.8.2.3 Impact of Accessory Wear

By conducting a comparative analysis between the registration data of individuals in a state of non-wearing and the data of individuals donning various accessories, including watches, rings, intelligent wristbands, and hand gloves [3], the consequential influence of these accessories on the comprehensive performance of door detection can be ascertained. Accessory indirectly affect the overall performance of the door detection. Illustrated in Figure 2.16, it becomes evident that individuals sporting gloves exhibit a discernibly higher magnitude of the False Rejection Rate (FRR) amounting to 6.83%, in contrast to those adorning bracelets and watches. This augmented FRR can be attributed to minute fluctuations that transpire due to the complete coverage of the hand by the glove, thereby inducing slight oscillatory deviations in the acquired data.

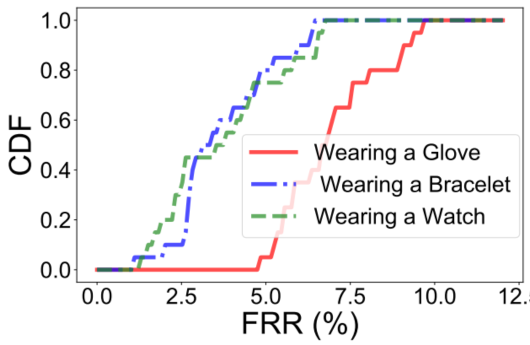



Figure 2.15 FRR with different accessories [3]

## 2.9 Unlocking/Locking Mechanism

According to the Andersson (2020), the mechanism used include servo motor, gearing system and timing belt. Servo motor is chosen since the rotation to unlock standard door lock is roughly 90° and precision is not vital. A servo motor is an electric motor with fixed rotational freedom and a built-in sensor which keeps track of the motor's general position. A timing belt connecting parallel gears together distributed the torque force as a key factor in assembly.

### 2.9.1 Torque

Torque is acquired as a task to turn a lock. The determination of turning torque is used to know the actual torque needed to allow user tuning the lock since it can be used to choose a suitable motor. In the research paper by Andersson (2020), there has a testing tool with a lever mounted on a lock turning knob. It then be turned by pulling it at a known distance from the center, L, with a Newton meter in the direction perpendicular to the lever and registering the required force F. The torque of turning the lock could be calculated using Equation (2.13).

$$\boldsymbol{M = F.L} \quad (2\text{-}13)$$



According to the Andersson (2020) experiment, the turning torque for different door lock were obtained and determined as shown in Table 2.3. It is shows that the average torque requires for turning the lock is around 0.24 Nm.

Table 2-3 Turning torque for seven different door lock [4]

| Door lock | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Turning torque [Nm] | 0.27 | 0.27 | 0.36 | 0.18 | 0.13 | 0.25 | 0.20 |

## 2.10 Signal Interpretation and Preprocessing

In this application the sensors were positioned on the interior side of the door that function to capture the vibrations caused by knocking that propagate through the door [4]. The signal interpretation involve detection of knocking on a door with data segmentation and filtering process.

### 2.10.1 Knock Detection and Data Segmentation

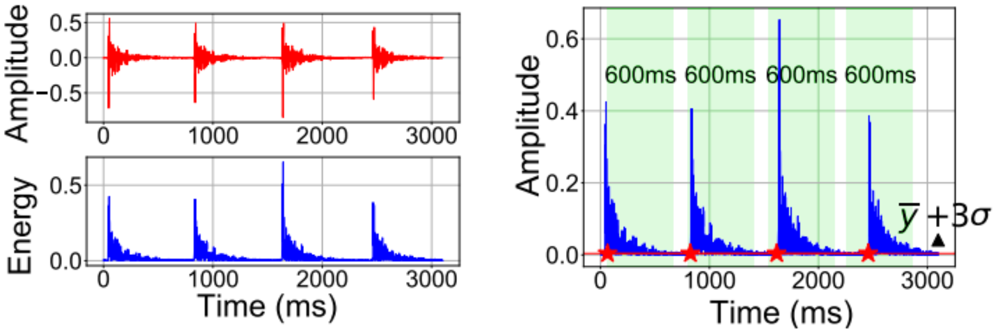
The piezo sensor connected to the Arduino Uno converts sensor readings to digital values, registering individual knocks. The software stores time intervals between knocks in an array, enabling analysis to verify the correct sequence execution [4]. The knowledge of fluctuation threshold-based sliding window are leveraged on the knocking detection [3], as formula (2.14) and (2.15) follows;

$$\bar{y} = \frac{1}{T}\sum_{t=0}^{T-1}|yidle(t+1) - yidle(t)| \qquad (2\text{-}14)$$

$$\sigma = \sqrt{\frac{1}{T}\sum_{t=0}^{T-1}(|yidle(t+1) - yidle(t)| - \bar{y})^2} \qquad (2\text{-}15)$$



Where T is the samples number. The sensed vibration data from idle or non-knocking period is denoted as yidle(t). The energy fluctuation ybar and σ represent mean and standard deviation respectively. Figure 2.16 presents the result of data segmentation with starting times of knocking, marked with red stars [3].




a) b)

Figure 2.16 a) Vibration signal by energy and amplitude and b) Starting recognition point [3]

### 2.10.2 Noise Filtering and Background Noise

Data captured often includes background noise and intrinsic noise by internal electromagnetic components [3]. Background noise levels vary across different buildings, and signal filtering may need to be adjusted accordingly to account the variations. However, Andersson (2020) found that the sensors used were not sensitive enough to detect significant ambient noise. The most effective filter is achieved by using an amplitude high-pass filter and the multi-resolution characteristics of Discrete Wavelet Transform (DWT). By setting a threshold value, noise components can be effectively removed while retaining the necessary signal components [3,4]. Figure 2.17 shows the piezo sensor readings with knock strenght with the threshold applied and filtering of signal. There are two type of vibration data by DWT method include approximate coefficients corresponding to low frequency bands and detail coefficients corresponding to high-frequency bands. DWT formulated respectively in Equation (2.16) and (2.17).



$$\boldsymbol{\omega_j = 2^{-j/2} \int y(t)\varphi(2^{-j}t - 2k)dt} \tag{2-16}$$

$$\boldsymbol{u_j = 2^{-j/2} \int y(t)\psi(2^{-j}t - 2k)dt} \tag{2-17}$$

Where;

$$\boldsymbol{\omega} = approximate\ corresponding\ to\ low\ frequency\ bands$$

$$u = approximate\ corresponding\ to\ high\ frequency\ bands$$

$$\varphi = scaling\ function$$

$$\psi = wavelet\ function$$

$$j = scaling\ parameter$$

$$k = movement\ step$$

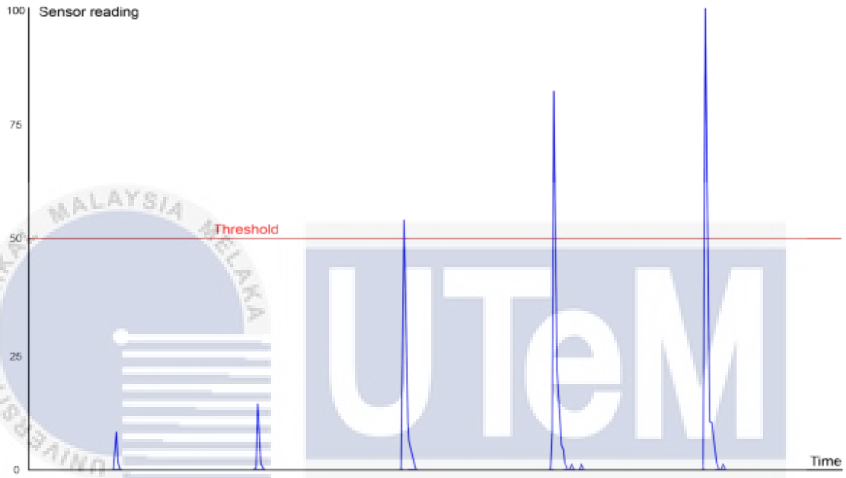



Figure 2.17 Piezo sensor reading with knock strength [4]



### 2.10.3 Filtering with Capacitor and Calibration

In the filtering stage, the use of two capacitors can be implemented to remove fluctuations or pulsations, known as ripples, present in the output voltage supplied by the rectifier [26]. This further enhances the quality of the signal. The final system allows the end-user to easily calibrate these parameters as well as adjusting the filtering process according to their specific requirements.

## 2.11 Knock Rhythm Recognition

Knock rhythm recognition involves analyzing the knock pattern by dividing all time periods between knocks with the longest time period. These time periods are expressed as fractions of the longest one in the sequence. Differences between the registered knock sequence and the secret knock sequence are used to classify the knock rhythm. If the differences are within a tolerance of 0.2, the knock is considered correct [4]. The number of knocks, duration, and vibration sensitivities play a role in opening the door [7]. Satwikayadnya research [8] has conducted an experiment on unlocking system for blind person that identifies the knock pattern based on how much the vibration or rhythmic beats is applied accordance with the previously saved and the duration of knocks that will be analyzed of knock tolerance [8,10,11,13]. The knock has its special rhythm that match with the code that’s inputted by the owner [9].

The system will start working by doing the accuracy of the interval between beats, when the rhythm knock based on the previously data stored then the system be active [24]. In case of errors in the feedback code was out of interval rhythms that have been determined, then the system lock or unlock does not work [10-11]. Rahman (2021) has conducted algorithm for knock pattern detection with a reset button alongside two statuses LEDs that are valuable for the testing of the task and enlisting or registering new knock patterns. When the vibrating sensor detects a vibration, the indicator LED on the vibration sensor will flash quickly as a result of the vibrating electrode [18]. The collected data of the delays between knocks must match the user-set knock pattern, contain the same number of knocks, have the delay between each individual knock within the 100-milisecond tolerance range and the total sum of the delays between knocks not exceeding the 500-miliseconds tolerance range. The tolerance range is need to compensate the imperfection between the recorded pattern and the user input [23].

## 2.12 IOT Based Recognition

Internet of Things (IoT) is utilized to connect and exchange data with other devices and systems using the internet. IoT-based recognition integrates IoT technology into door locking systems. Nagalakshmi (2021) was proposed the door locking system with IOT based as the lock is controlled by IOT and Bylynk app. The status of delivered signal about unlocking and locking door are received by client or user via Bylynk app and continuously monitored [20]. If suppose any unauthenticated person trying to open the door immediately alert will be given to the client mobile. While it offers advantages in terms of remote control, Alexa integration for voice commands, email notifications for detected knocks, and generation of temporary passcodes, privacy and security concerns need to be addressed. The hardware gets the command from the software via the wireless router and web application runs on the mobile phone or the tablet serves as an interface to the user. Raspberry Pi send an email to notify user as a door was detected knocks by someone [28]. Thus, various research papers have proposed IoT-based door locking systems, including the use of the Bylynk app, Amazon Alexa integration using AWS, and Raspberry Pi for email notifications. The user administration function represented in Figure 2.18.



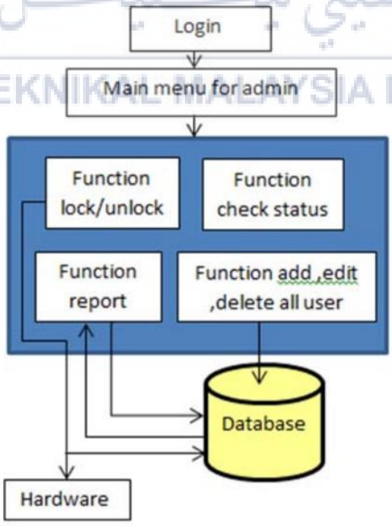



Figure 2.18 User administration function [20]

## 2.13 Research Gap

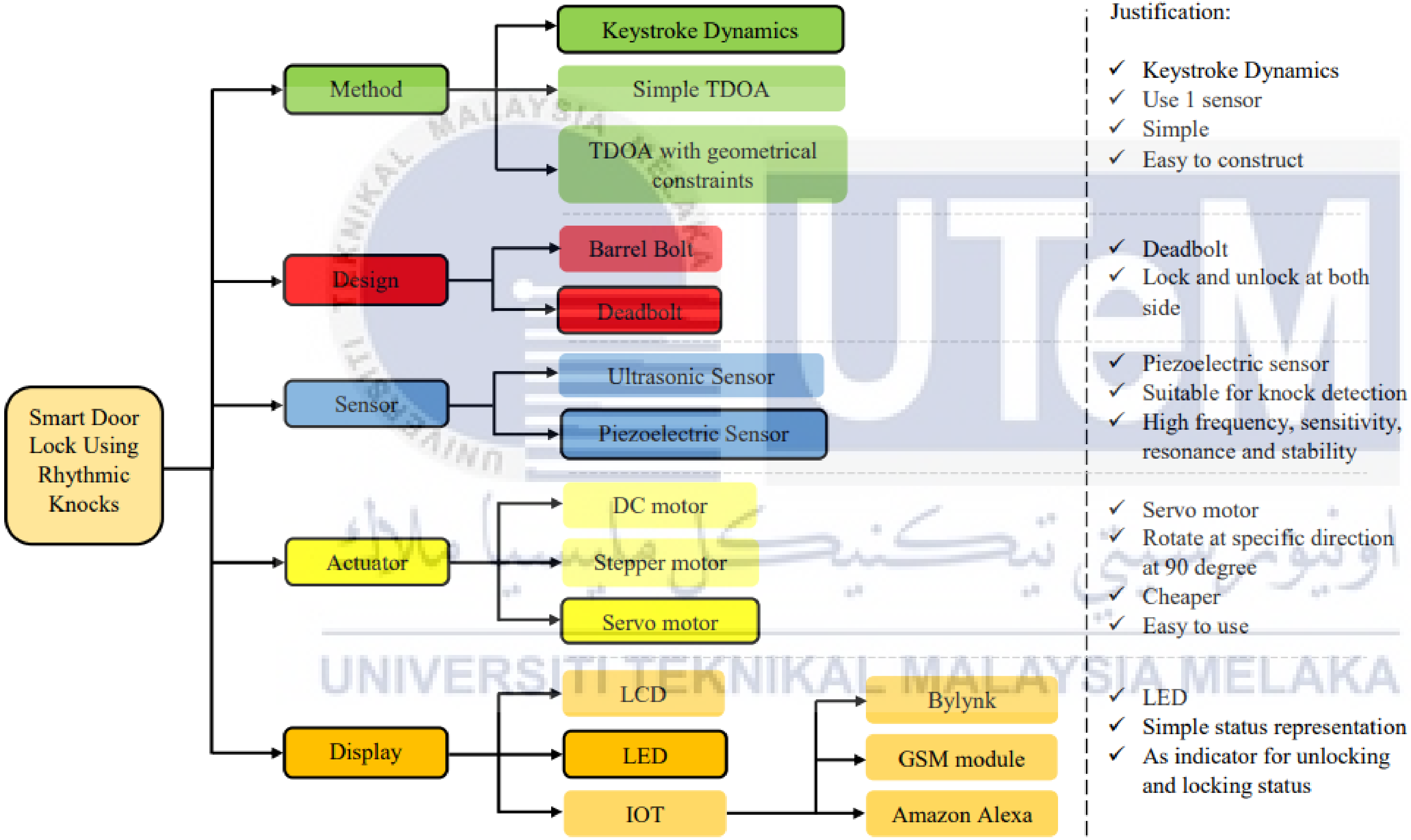





Figure 2.19 Taximony of Proposed Design

Based on the literature review from the several research paper, a taximoy of proposed design for the door lock system is constructed as shown in Figure 2.19. In Final Year Project 1 and 2, there has several elements selected and considered as the methodology approach. It is including the method of door detection, door system design, sensor to be used for recognition of knocks, actuator as locking system mechanism, and display for the locking status. At first, keystroke dynamics method is chosen because its reliance on a single sensor, unlike the simple TDOA and TDOA with geometrical constraint methods, which require multiple force sensors which has four sensors and three sensors, respectively. Keystroke dynamic is a straightforward and easily constructible approach.

Deadbolt lock is chosen as it is based on its widespread use in residential door locks. Deadbolts have the advantage of being able to lock and unlock from both the inside and outside of the house using a single thumb turn mechanism. On the other hand, barrel bolts are typically installed on the interior side of the door and can only be locked and unlocked from one side. In emergency situations, if the user locks the door using the barrel bolt from the inside, individuals outside the door cannot directly open it using a key.



The selection of a piezoelectric speaker is based on its desirable qualities, including high sensitivity, frequency, resonance, and stability. This type of sensor is capable of converting mechanical force into electrical energy (voltage), making it a suitable choice for generating sound or vibrations.

Servo motor is chosen as has ability to rotate precisely at specific angles, such as 0°, 90°, and 180°. Unlike a DC motor, that cannot rotate at specific direction or position. While a stepper motor can achieve specific direction but is more complex and costly, the servo motor proves to be a suitable choice. Since the door lock requires a maximum rotation of 90° to lock and unlock the bolt, the simplicity and ease of use offered by the servo motor make it a suitable option.

LED is chosen to display the operation or status of the knock system. It is simple that only involve green and red led to represent the status of locking process whether it unlocked or locked. LCD display require complex circuit and more wires. GSM module also chosen for the IOT based by notifying user about the unrecognized knocking on their door's house. It also can be used to show the locking status and door opening status via smartphone or Telegram. GSM module is suitable to be used with Arduino controller while Amazon Alexa is suitable to use with Raspberry Pi controller. Amazon Alexa is more complex than GSM module.

The design of the display component for final year project 1 and 2 has been constrained, leading to the choice of exclusively using LEDs as indicators to display the door locking status. The implementation of IoT is not currently incorporated in this project, and it is a possibility that it will be explored in future endeavors.

## 2.14 Summary

Previous studies focused on developing reliable algorithms for accurately identifying rhythmic knocks. These methods utilize various signal processing techniques, such as Fast Fourier Transform (FFT), autocorrelation, and pattern matching, to analyze the audio signals produced by knocks. Additionally, knock localization, such as Simple TDOA and TDOA with geometrical constraints that can be utilised to identify knocks. Researchers have investigated different approaches for generating unique knock patterns for individual users. These methods include utilizing machine learning algorithms, accelerometer sensors, and user-defined templates to create distinct patterns that can be easily recognized. Studies have looked into potential weaknesses and defences against attacks, including unauthorised knock pattern detection, brute force efforts, and replay attacks. User acceptance and satisfaction are crucial factors for the widespread adoption of smart door locks. Some studies have explored the integration of rhythmic knock authentication with other technologies, such as mobile applications, fingerprint recognition to enhance the overall security and convenience of door lock systems. A summary of the previous research papers can be found in Appendix A.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

All relevant experimental and descriptive techniques used in the project is outlined in this chapter as detail the approach and methods utilized to complete this final project. The flow chart of knock detection system are clearly explained to present the project methodology with the whole project process and overview for the graduate result in an enhanced. The specified microcontroller, the hardware, will be discussed next. The next step is to demonstrate and describe the system illustration.

## 3.2 Project Overview

Project Overview Flowchart in Figure 3.1 illustrate the overall methodology. The project's success can be guaranteed by adhering to the sequence of steps depicted in the following flowchart as representation that outlines the necessary actions to achieve a successful completion of the project.

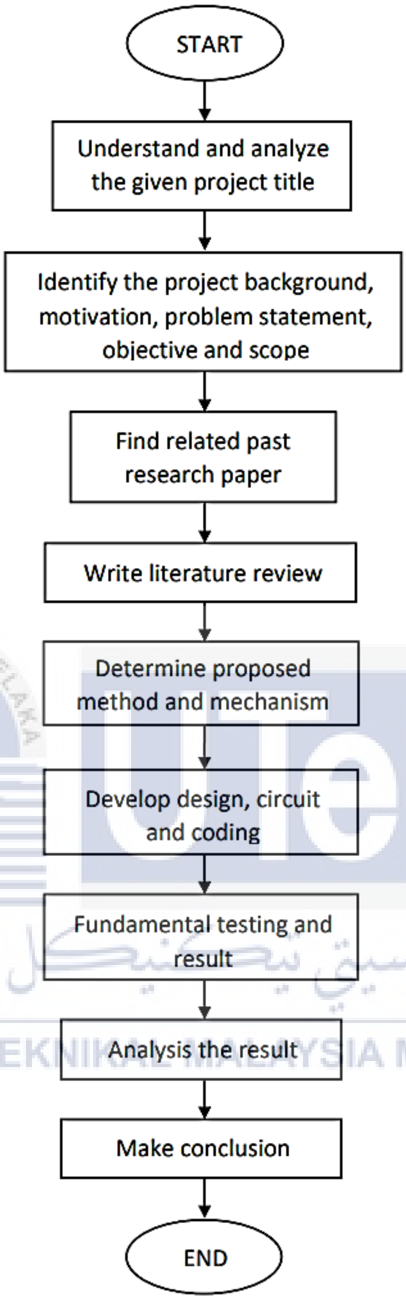



Figure 3.1 Flowchart of Project Overview

## 3.3 Specifications and Requirements for Door Lock System

Specifications and requirements for a door lock system using rhythmic knocks would involve unique characteristics specific to this type of locking mechanism. Table 3.1 below illustrate some specifications and requirements to consider.

Table 3-1 Specifications and requirement for door lock system

| Specifications | Requirements |
|---|---|
| Knock Patterns | The system should support the recognition of specific knock patterns as a means of authentication. Each authorized user would have a unique knock pattern assigned to them. The system should be able to detect and interpret these patterns accurately. |
| Sensitivity and Accuracy | The system should be designed to accurately detect and interpret the rhythmic knocks. It should be sensitive enough to differentiate between intentional knocks and accidental noise, ensuring that only valid knock patterns are recognized. |
| Training and Enrollment | The system should provide a user-friendly interface or process for training and enrolling authorized users. This may involve allowing users to practice and record their knock patterns during the setup process. |
| Security | While the system may offer a unique and unconventional approach to door locking, security should remain a top priority. The system should employ encryption and secure communication protocols to prevent unauthorized access or manipulation of the lock mechanism. |
| Power Efficiency | The system should be designed to optimize power consumption and efficiency, considering that the recognition and processing of knock patterns may require continuous operation. |
| Emergency Access | The system should include provisions for emergency access in case a user forgets their knock pattern or is unable to perform it. This could involve alternative authentication methods, such as a backup key or an override code, to grant access in emergency situations. |
| Durability | The physical components of the door lock system, including sensors, actuators, and the locking mechanism itself, should be durable and resistant to wear and tear over time. |

### 3.3.1 System Flow Chart

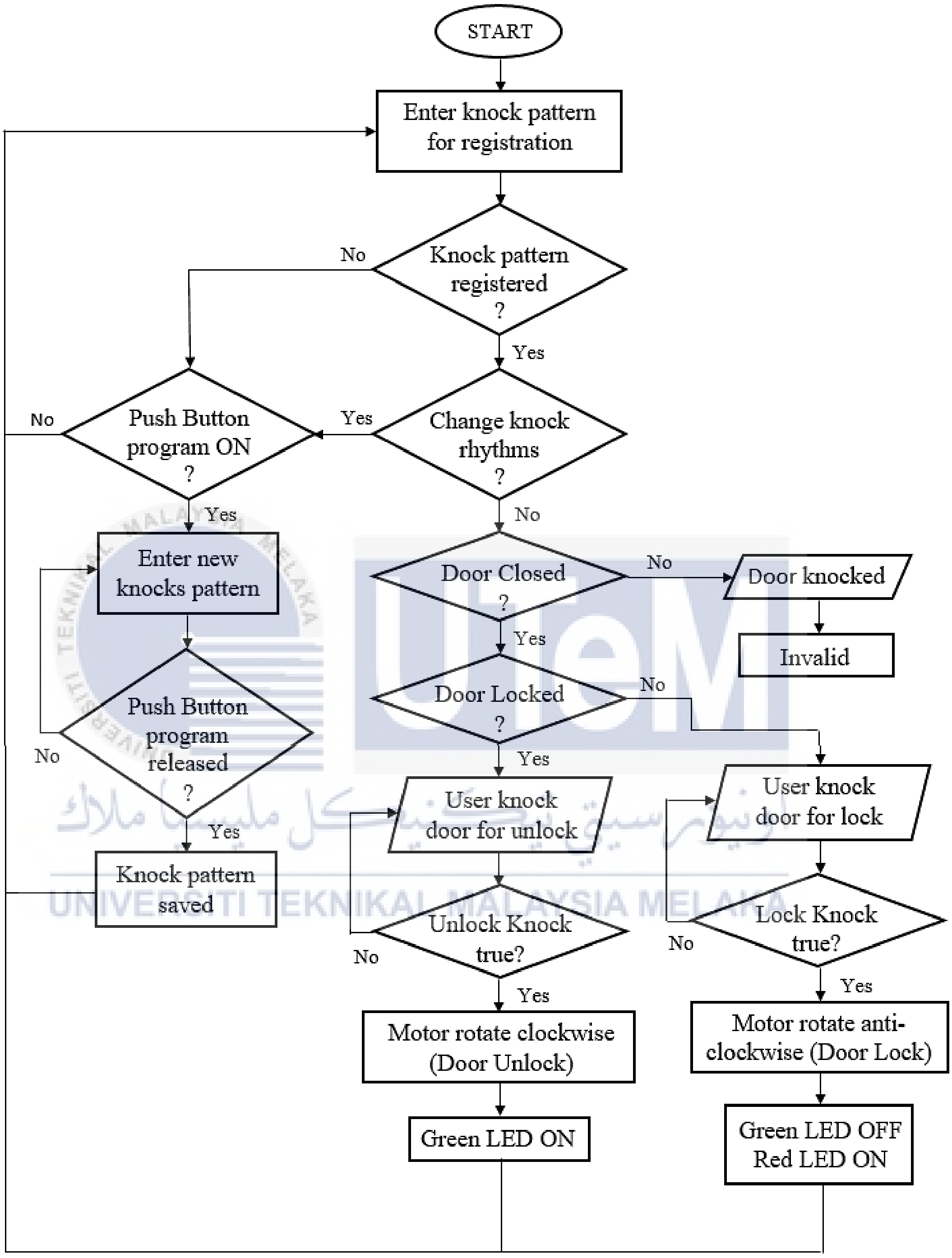



Figure 3.2 System Flow Cart

Based on system flow chart as shown in Figure 3.2, the system initiates when it receives power from the power source. In the initial setup, the user is required to enter a new password or knock patterns for registration purposes. This involves pressing and holding a push button while entering the knocks. Releasing the button will store the knocks in the memory. Once completed, the system is ready for additional operations. If the user wishes to change the rhythms to a new set, they must follow the same process as before. Two indicators, a green LED and a red LED, are present. Both LEDs monitor and indicate the status of the door lock.

In the event that the door is in a closed and locked state, the red LED will be activated, indicating its status. As the user applies a knock force to the door surface, the system detects the presence of a knock. If the entered pattern matches the registered knocks, the system verifies the validity of the unlock knocks, prompting it to send a signal to the controller to initiate the unlocking process. Subsequently, the motor rotates in a clockwise direction, effectively releasing the door locks and allowing for its opening. To visually communicate the successful unlocking, the green LED illuminates, providing a clear indication that the door is now ready to be opened by the user. At the condition where the door is closed and not locked, any knocks applied to door's surface will be deemed invalid and go unnoticed. The system will not read or detect the applied knocks.



If the door is currently open and the user intends to lock it before leaving the area, the initial requirement is to ensure that the door is fully closed, guaranteeing the system is properly aligned. Once the user enters the predetermined lock pattern of knocks and it is recognized, a signal is transmitted to the controller to execute the locking procedure. Consequently, the motor rotates counterclockwise to secure the door, and the activation of the red indicator denotes a successful locking operation, confirming that the door is now in a locked state. The entire system will keep repeating its operations until the power supply is switched off.

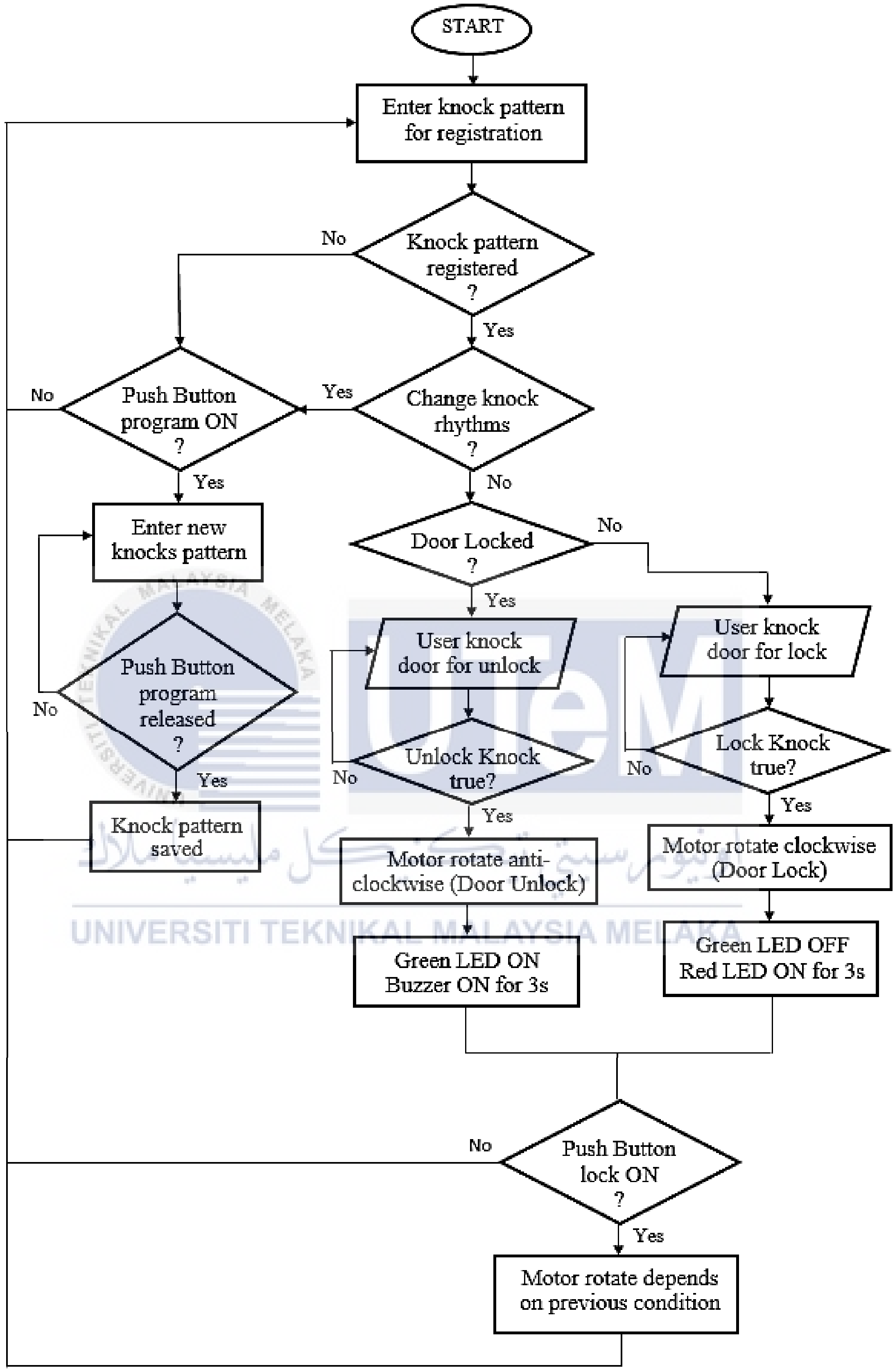



Figure 3.3 Updated System Flow Chart

In this Final Year Project 2, some modification on the flow chart of the system has been made for some reason. Based on system flow chart as shown in Figure 3.3, Initially, user is need to enter a new knock patterns by pressing and holding a push button program while entering the knocks. The knocks then registered in the memory as long as the button is released. This process required if there has any new pattern to be used. As mention in previous flow chart, it is also the same where there has two indicators to indicate the status of door lock by using a green LED and a red LED.

Once the system activated, the green LED will turn ON. As the user applies knock pattern onto the door surface, system detects the presence of a knock. If the entered pattern matches the registered knocks, the system verifies the validity of the unlock knocks, prompting it to send a signal to the controller to initiate the unlocking process. Subsequently, the motor rotates at anti-clockwise direction, effectively releasing the door locks and allowing the door to be opened.

If the door is currently open and the user intends to lock it before leaving the area, the initial requirement is to ensure that the door is fully closed, guaranteeing the system is properly aligned. Once the user enters the predetermined lock pattern of knocks and it is recognized, a signal is transmitted to the controller to execute the locking procedure. Consequently, the motor rotates counterclockwise to secure the door, and the activation of the red indicator about 3 seconds denotes a successful locking operation, confirming that the door is now in a locked state. All operation of the system will keep repeating until the power supply is switched off.

### 3.3.2 Functional Block Diagram

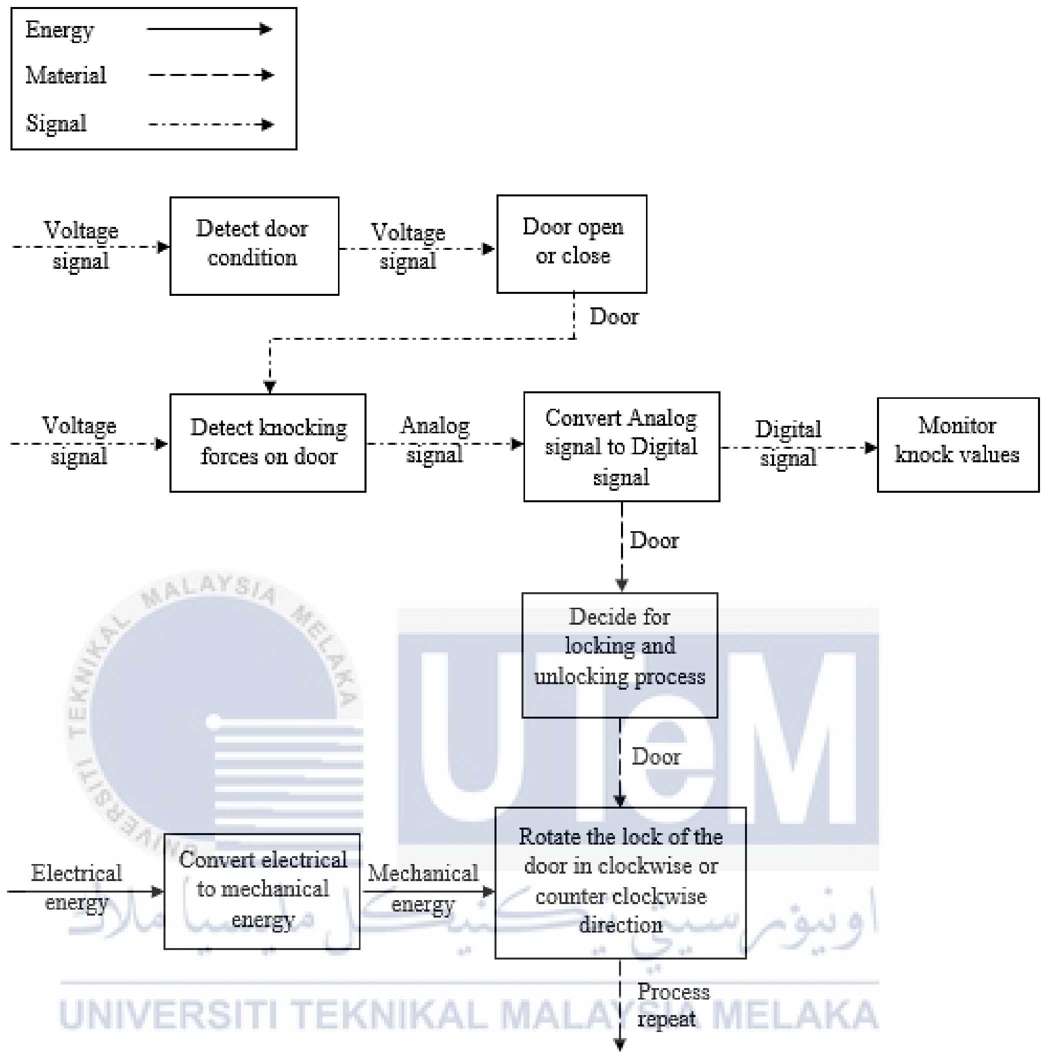





Figure 3.4 System Functional Block Diagram

Functional block diagram in Figure 3.4 above represent the overall system flow via its energy, material and signal transmitted. There have three functions include to detect the door condition, to detect the knocking forces on a door and to convert electrical energy to mechanical energy. The first function is detect door condition where it is require voltage signal received from a sensor triggered whether the door is close or open. The signal transmitted to the second function which is detect knocking forces on door, in order to allow process of knocks detection.

The knocking process will be made if the door in close condition. The knocking process will generates voltage signal and transmitted to the computer in digital signal to be monitored through serial monitor. Signal of the knocks will make the microcontroller to decide for lock or unlock of the door. The material used in the system is a door. Lastly, from the decision making, it will proceed to the third function where actuator converting the electrical energy to mechanical energy, the voltage signal convert to the rotation of an actuator in a certain angle on the process of lock and unlock in which clockwise or counter clockwise direction. The system is repeated until the system end.

## 3.4 Conceptual Design

In this conceptual design phase, sketching and drawing play a crucial role in visualizing some aspects of the door from multiple perspectives. Through sketching, various design possibilities can explored and capturing the essence of the desired aesthetics and functionality. The exterior door view sketches allow to experiment with different shapes, sizes, and materials to create an appealing and harmonious design that complements the overall architectural style. Interior door sketches help to envision the interaction between the door and its surroundings, considering factors such as ergonomics and ease of use. Side and top view drawings provide a comprehensive understanding of the door's dimensions, proportions, and structural details. Ultimately, this conceptual design phase will serve as a foundation for further development and refinement in subsequent stages of the project. For the earlier part of this final year project, the conceptual design focuses on utilizing a 2D approach. The door measurements are based on the provided door measurements where accordance with the specified measurements of 35cm x 4cm x 58cm. Each sketching and drawing are representing in centimeter unit.

### 3.4.1 Overall System Design

Several design are made in order to select the most efficient and suitable design for the project. There have three design provided where each has different ways of the lock mechanism. The sketching for several design can be represented as shown in Figure 3.5, Figure 3.6 and Figure 3.7. From Figure 3.5 below, the position of indicator green and red are located at door exterior above the key deadbolt lock. Others components are attached at interior side. Design 1 indicates the use of gripper as mechanism component between actuator and deadbolt lock. The gripper is attached on the thumb turn of deadbolt in parallel and horizontal axis. Most of the components are placed inside the casing includes deadbolt, Arduino Uno, battery, actuator and push button. The sensor are placed at the center of the door.

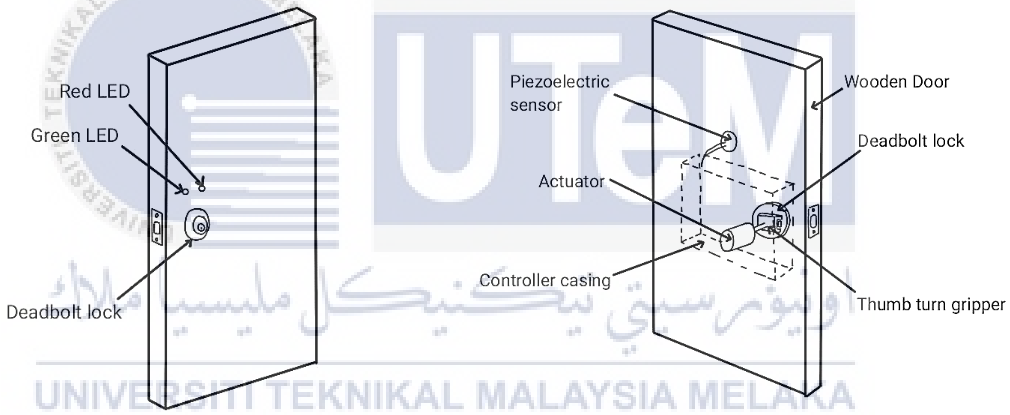



Figure 3.5 Design 1

According to Design 2 as illustrated in Figure 3.6, the position of indicator green and red are the same with Design 1 which located at door exterior above the key deadbolt lock. At interior side, belting system is implemented for lock mechanism between deadbolt and actuator. It is attached inside the door while the actuator at the outside of the door. The casing is positioned by Arduino Uno, actuator, sensor, battery and push button while the deadbolt lock is not included in the casing.

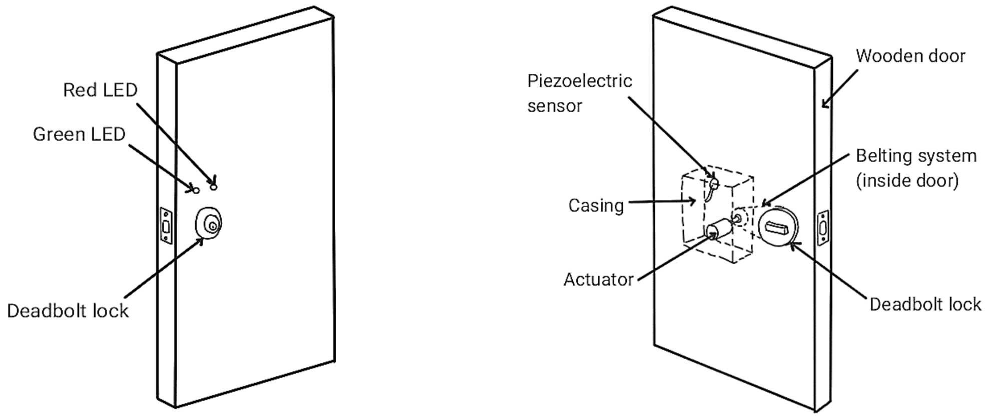



Figure 3.6 Design 2

Design 3 as shown in Figure 3.7, the green and red indicator location are as same as previous designs. For the lock mechanism, the actuator is connected with deadbolt using a rope and metals. The metal is use to make the deadbolt's thumb turn can be moved with the help of rope tied together. Arduino Uno, actuator, battery and push button are placed into the casing.



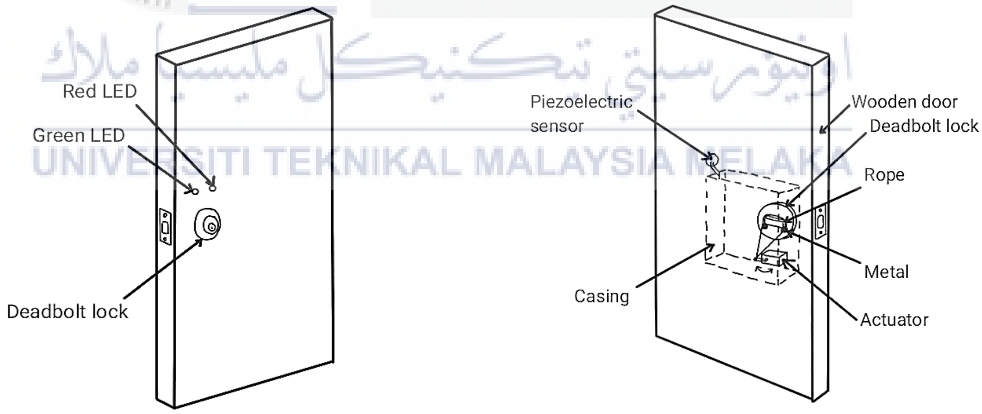



Figure 3.7 Design 3

Based on the consideration, Design 1 is chosen for the door lock system using rhythmic knocks. With the help of a gripper to the thumb turn deadbolt, it will make the deadbolt turn easily because most of the deadbolt's thumb turn area are considered. Compared with Design 3, there are using minimal area of thumb turn deadbolt. The Design 2 is tidy in which the mechanism part invisible, but it is difficult to be constructed. The door structure need to be open in order to place the belt system into it. Maintenance activity also difficult to be held. The sensor are placed at the center of the door to able receive knocking signal.

### 3.4.2 Door Sketching

Rough sketching are made in order to illustrate the door dimension. Door sketching include the door and door cushion measurement. The dimension for both door and it's cushion are based on the provided door prototype. The door dimension includes 35cm x 4cm x 58cm while door cushion dimension is 40cm x 5cm x 61cm. The cushion base dimension is 40cm x 13.5cm x 1cm. The rough sketching for door and it's cushion are shown in Figure 3.8.



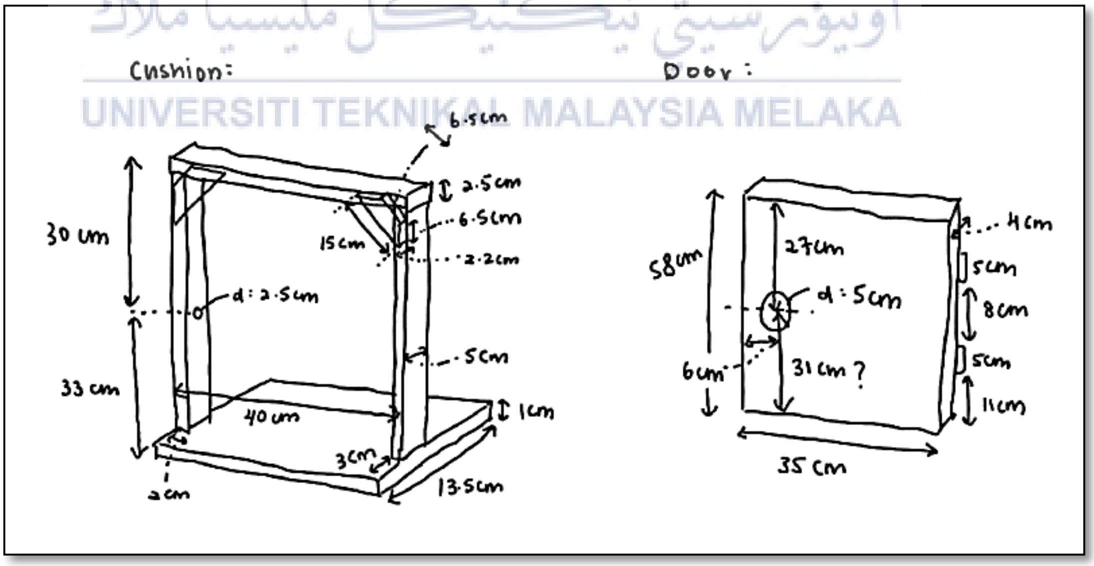



Figure 3.8 Rough sketching for door and door cushion

### 3.4.3 Component Placement Sketching

The sketching is used to illustrate the position of components within a casing. The components encompass the Arduino Uno, push buttons, battery, wire board, casing, deadbolt thumb turn, and actuator. There are two conveniently positioned push buttons on the side of the casing to facilitate easy access for users to record new knock patterns. In that section of the casing, there will be a space provided for the user's hand to reach the push buttons. The rough sketching are shown in Figure 3.9.

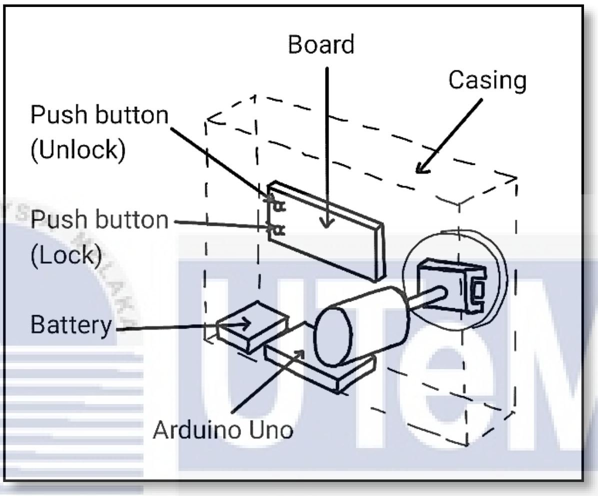



Figure 3.9 Rough sketching of components placement

## 3.5 Equipment and Component (Hardware)

In this study, the main control unit of this system is the Arduino Uno microcontroller. It utilizes a knock sensor to provide enhanced security measures. The entire system operates on a 12V electrical power supply, which serves as the primary source for all components. This power supply is connected to a power supply circuit that distributes power to the entire system, including both input and output components. The overall hardware design of the door locking system can be seen in the Figure 3.12.

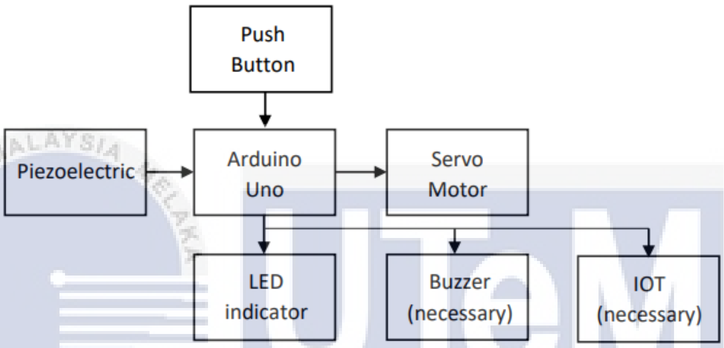



Figure 3.10 Block diagram for hardware design



### 3.5.1 Arduino Uno

The Arduino Uno R3 has upgraded from using the 8U2 or FTDI found on previous generations to the ATmega16U2. It is a microcontroller board that utilizes the Microchip ATmega328P microcontroller. This particular Arduino model is developed by Arduino.cc. One of its primary functions is to read and execute the stored code within it.

This enables faster data transfer rates and increased memory capacity. Linux and Mac systems do not require additional drivers (an inf file is included in the Arduino IDE for Windows), and the Arduino Uno can be recognized as a keyboard, mouse, joystick, etc. Additionally, the Uno R3 introduces SDA and SCL pins alongside the AREF pin. Two new pins near the RESET pin are also included. One of these pins, IOREF, allows shields to adjust to the voltage provided by the board. The other pin is currently not connected and reserved for future use. The Uno R3 is compatible with existing shields and can also accommodate new shields that utilize these additional pins. Arduino is an open-source platform for physical computing, consisting of a simple I/O board and a development environment that supports the Processing/Wiring language. Arduino can be used to create interactive standalone objects or can be connected to software on a computer, such as Flash, Processing, or MaxMSP. The open-source Arduino IDE is available for free download and is compatible with Mac OS X, Windows, and Linux operating systems. The Arduino Uno R3 as shown in Figure 3.13, has been selected as the central component for the detection process in the early of the project for testing process. This is the main component or features in the Arduino Uno R3 such as:

1. Microcontroller ATmega328P
2. Operating Voltage : 5V
3. Input voltage : 7-12V
4. 14 Digital I/O Pins and 6 Analog Input Pins
5. 14 (of which 6 provide PWM outputs) - PWM Digital I/O Pins
6. Flash Memory 32 KB (ATmega328P) of which 0.5 KB used by boot loader
7. 16MHz Clock Speed

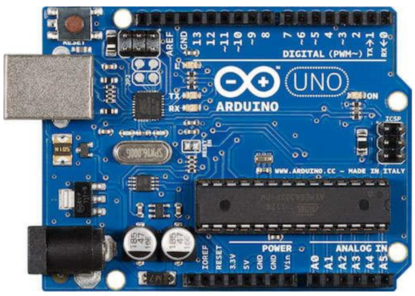



Figure 3.11 Arduino Uno R3

According to the very less usange of input output pins and fulfill the saving of space, Arduino Nano is suitable to be used and selected as the central component for the detection process in Final Year Project 2 due to its lower pin requirements. Since Arduino Nano requires even fewer pins, the main difference between both microcontrollers lies in their output voltage. The Arduino Uno provides an output voltage of 5V, whereas the Arduino Nano operates at 3.3V.

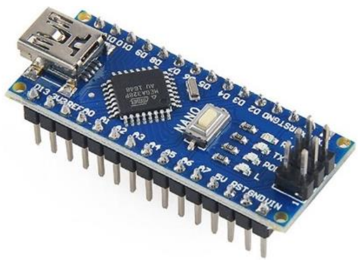


Figure 3.12 Arduino Nano

### 3.5.2 Servo Motor

A Servo Motor is a compact electronic device that provides precise and accurate rotation control for objects. It is commonly used when high accuracy in rotation is required. The functioning principle of a servo motor is based on the servo mechanism concept. It consists of a small motor coupled with a feedback mechanism that allows it to adjust its position based on the input signal it receives. This feedback mechanism enables the servo motor to maintain a specific angle or position, making it suitable for various applications such as robotics, automation, and remote control systems. Depending on the type of power supply, a servo motor can be categorized as either a DC servo motor or an AC servo motor. A DC servo motor operates with a DC power supply, while an AC servo motor operates with an AC power supply.

According to Figure 3.15 as shown below, micro servo sg90 is used in the final year project 1 as function to determine the right angle used for unlocking and locking system of door. The micro servo SG90 offers relatively high torque and speed for its small form factor, making it popular among hobbyists and electronics enthusiasts. It is compatible with most microcontrollers and can be easily integrated into projects that require precise control of movement or positioning.


Figure 3.13 Micro Servo sg90

The servo motor model for the door lock system in this Final Year Project 2 has been changed to the MG996R servo motor, replacing the micro servo SG90. The MG996R is a metal gear servo motor with a maximum stall torque of 11 kg/cm. The motor can rotate from 0 to 180 degrees based on the duty cycle of the PWM wave supplied to its signal pin. What makes the MG996R unique in its development is its capability to not only rotate 180 degrees but also support a 360-degree continuous rotation modification, providing flexibility for specific applications. Its compatibility with various control systems. Below are the MG996R specifications and features :

- Operating Voltage : 4.8 - 6V
- Current: 2.5A (6V)
- Stall Torque: 9.4 kg/cm (at 4.8V)
- Maximum Stall Torque: 11 kg/cm (6V)
- Operating speed : 0.17 s/60°
- Gear Type: Metal
- Rotation : 0°-180°
- Weight of motor : 55gm
- Dimension: 40.7mm × 19.7mm × 42.9mm

The MG996R, depicted in Figure 3.16, was chosen over the micro SG90 because the latter lacks the ability to support and rotate the deadbolt when torque is applied, in addition to insufficient power. The MG996R is employed in the door's unlocking and locking system. Specifically, the MG996R with a 180-degree rotation capability is well-suited for controlling the rotation of the deadbolt lock mechanism due to its high torque and speed. This makes it easily integratable into projects requiring precise control of movement or positioning. The servo motor's rotation is limited to 0, 90, and 180 degrees, aligning with the deadbolt lock mechanism's rotation needs.

Figure 3.14 Servo Motor MG996R

The servo motor operates by utilizing a PWM (Pulse Width Modulation) signal. It requires a frequency of 50Hz, corresponding to a PWM period of 20ms. The motor's position can be controlled by adjusting the on-time duration, ranging from 1ms to 2ms, which corresponds to a rotation range of 0° to 180°. When the on-time is set to 1ms, the motor will be positioned at 0°, while at 1.5ms, it will be at 90°. Similarly, a setting of 2ms will position the motor at 180°. This specific servo motor model is equipped with three gear horns (arms). It finds application as an actuator in various robotic systems, including robotic arms. It is commonly used in RC toys for steering control, as well as in robots that require position control without feedback. Additionally, it is utilized in multi DOF (Degree of Freedom) robots, such as humanoid robots. Figure 3.17 shows PWM signal of servo motor.

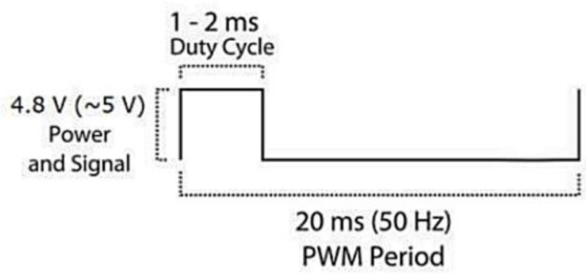



Figure 3.15 PWM signal of servo motor

The MG996R is a compact servo motor, despite its not even very small or very big size, it provides high output power and operates at an ideal voltage range of 4.8V to approximately 6V. Servo motors offer an economical solution for these applications, as they are easy to control and cost-effective to regulate.

### 3.5.3 Buzzer

Buzzer primarily designed to convert audio or voice signals into sound where it can come in electromechanical, piezoelectric, or mechanical types. Typically buzzer is powered by DC voltage and most applications in timers, alarm devices, printers, computers, etc. Its diverse designs allow it to emit various sounds, including alarms, musical tones, bells, and sirens. The buzzer pin configuration shown in Figure 3.18. Buzzer has two pins that denoted as positive and negative. The positive end is indicated by the '+' symbol and powered by 6 volts while the negative end is marked with the '-' symbol that linked to the GND terminal. Regarding active buzzers with positive and negative polarity, it produce sound when a voltage signal is applied to their pins. Nevertheless, active buzzers are characterized by a single tone with a consistent frequency.


Figure 3.16 Buzzer Pin Configuration

Magnetic buzzers utilize an electromagnetic element rather than a piezoelectric one. The buzzer comprises a circuit-connected wire coil generating a magnetic field, along with a flexible ferromagnetic disk, all enclosed in a plastic casing. The operational principle involves passing power through the wire coil, creating a magnetic field. Activation of the magnetic field attracts the flexible ferromagnetic disk to the coil, and it returns to its rest position when the magnetic field is deactivated. By oscillating the signal through the coil, the buzzer generates a varying magnetic field that causes the disk to vibrate, producing the characteristic sound. In this project, buzzer is used to provide notifications to users regarding the effectiveness of door knocks. It signals to users outside the house that the door knock is valid and grants access to enter the premises.

### 3.5.4 Piezoelectric Sensor

Piezoelectric is known as "piezo" originates from the Greek language, where "piezo" or "piezein" means pressure, and "electric" refers to electricity. A piezoelectric sensor is a type of sensor that generates an electrical charge in response to mechanical pressure or vibration. It utilizes the piezoelectric effect, which is the ability of certain materials to generate an electric charge when subjected to mechanical stress. This sensor is selected as able to sensing the door knocks detection in a force manner. Piezoelectric sensor is illustrated in Figure 3.19.



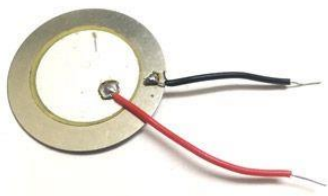


Figure 3.17 Piezoelectric sensor

The piezoelectric sensor involves a piezoelectric material, typically a crystal or ceramic, that is sandwiched between two electrodes. The piezoelectric structure is shown in Figure 3.20. When mechanical pressure or vibration is applied to the sensor, it causes the piezoelectric material to deform, generating an electric charge across the electrodes. Piezoelectric materials are created through the polarization of ceramics where there has specific areas of the molecules possess positive charges, while other areas carry negative charges. This arrangement leads to the formation of electrodes on opposing sides, establishing an electric field within the material. This electric field is capable of undergoing changes when subjected to mechanical forces. When an electric field is applied to the material, the polarized molecules respond by generating induced dipoles within the molecules or crystal structure. As a result of this molecular adjustment, the material undergoes dimensional changes. This fascinating phenomenon is referred to as electrostriction or the piezoelectric effect.

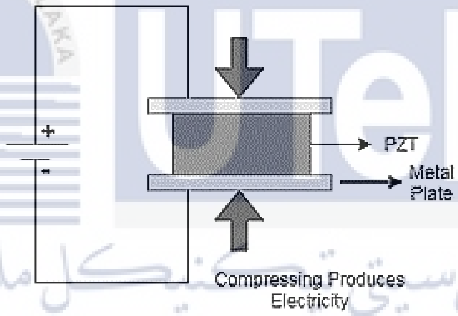



Figure 3.18 Piezoelectric structure



The thin piezoelectric buzzers are commonly used as buzzers or speakers in various devices such as game watches, timers/alarms, and many other products. In addition to functioning as a speaker, the piezoelectric buzzer can also be used as a pressure or vibration/tap sensor. The working principle of peizoelectric buzzer is shown in Figure 3.21. When tapped with a finger or other object, the buzzer generates a voltage proportional to the strength of the applied tap on its surface.

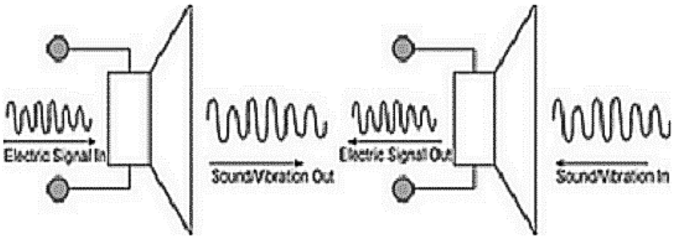


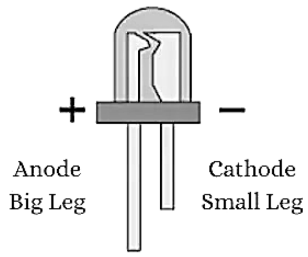
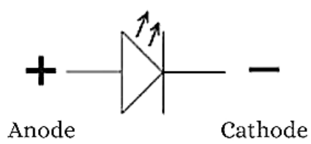

Figure 3.19 Working principle of piezoelectric buzzer

A pizoelectric speaker, when its terminals receive a signal, produces output in the form of vibrations on the diaphragm, resulting in sound. Conversely, when this speaker is used as a sensor the diaphragm layer functions as a vibration detector. When vibrations occur on the diaphragm, it also vibrates (resonates). The vibration of the diaphragm causes the coil to move relative to the permanent magnet core and generates an electrical signal.

### 3.5.5 LED

LED (Light-Emitting Diode) is a semiconductor device that emits light when an electric current passes through it. In door lock system, LED can be used as an indicator to provide visual feedback regarding the lock status. When the door is in a locked state, the LED may emit a red light to indicate that the lock is engaged. Conversely, when the door is unlocked, the LED may emit a green light to indicate that the lock is disengaged and the door is ready to be opened. LED serves as a visual cue for users to easily determine the current status of the door lock system. This type of display method is used in this project because of the compact, cost-effective, and less power requirement. LED diagram and its symbol is shown in Table 3.2.

Table 3-2 LED diagram and its symbol

| Light Emitting Diode (LED) | Symbol of LED |
|---|---|
|   |   |

### 3.5.6 Jumper Wire Connector

Jumper wires are essential components in electronics and prototyping projects. They are typically thin, flexible wires with connectors on each end, used to create temporary connections between electronic components or circuit points. Male-to-male jumper wires have male pins on both ends, allowing for direct connections between components, such as connecting a microcontroller to a breadboard or a sensor to a development board. These wires are commonly used to establish electrical connections and transfer signals within a circuit.

There are several type of jumper wires but in this project, the testing process involve male-to-female and male-to-male connectors as in Figure 3.22. Both male-to-male and male-to-female jumper wires are widely used in prototyping, testing, and connecting electronic components on breadboards or other development platforms. They simplify the process of wiring circuits, allowing for quick and temporary connections, and providing flexibility in designing and experimenting with electronic systems.



Figure 3.20 Male to male jumper wire connector

## 3.6 Equipment and Component (Software)

Software utilized in the door lock system plays a crucial role in controlling and managing its operations. It provides a user-friendly interface and a set of powerful tools to configure, monitor, and interact with the system. Through the software, it is allows for remote access and control, enabling users to monitor and manage the door lock system and their performance.

### 3.6.1 Arduino IDE

The Arduino Integrated Development Environment (IDE) is a specialized software application created specifically for programming Arduino microcontrollers. It offers a range of tools and features that streamline the development process. The IDE includes a user-friendly code editor with features like syntax highlighting and auto-completion, which enhance code writing and editing. It also incorporates a built-in compiler that translates the code into machine language and a programmer that uploads the compiled code to the Arduino board.

The Arduino IDE is written and can supports the languages in functions from C and C++. It is provides a library of pre-written code examples to assist users in getting started quickly. Code can be easily written and uploaded to the Arduino board using the open-source Arduino software (IDE). It features a serial monitor for debugging and monitoring communication between the Arduino board and the computer. Overall, the Arduino IDE simplifies programming and empowers users to unleash their creativity in building a diverse range of projects. In this project, the serial monitor is utilized to monitor and display the door switching and status conditions during the initial stages. Figure 3.23 below shows the Arduino IDE symbol.



Figure 3.21 Arduino IDE

## 3.7 Parameter

The Equation (2-1) and (2-2) are used to measure the incoming pressure value and arrival time;

$$\bar{t}_j = \frac{\sum_{i=1}^{n} t_i - t_{i-1}}{n} \tag{2-1}$$

$$\bar{P}_j = \frac{\sum_{i=1}^{n} P_i}{n} \tag{2-2}$$

Equation (2-11) and (2-12) show the formula of precision and accuracy of the system;

$$Precision = \frac{TP}{TP + FP} \tag{2-11}$$

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \tag{2-12}$$

## 3.8 Design and develop a prototype of efficient door lock system based on knocking rhythms



First objective for this project is design and develop a prototype of efficient door lock system based on knocking rhythms. This section is focused on the design process in order to develop a prototype for door lock system. The innovation lies in the integration of knocking rhythms as a fundamental element in the system's operation. By exploring and implementing this unique approach, the goal is to create a door lock system that not only ensures security but does so with enhanced efficiency and user-friendly features.

The subsequent details delve into the intricate process of conceptualizing, designing, and prototyping this door lock system, highlighting the significance of incorporating rhythmic patterns for heightened functionality. By primary conceptual design sketching on this project, here is the more appropriate design method using AutoCAD and Autodesk Fusion 360 software.

The measurement of each hardware components is important in developing the final design. After conducting comprehensive and finalizing the overall circuit, the project proceeds with the production of a casing for the control panel, involving overall hardware components placement fix into it. The procedure on the casing development are involving two stages, as drawing phase and 3D printing process, constructed as below:

1. The dimension of all hardware components are measured precisely.
2. The maximum dimension of 3D printing machine available in the faculty laboratory was determined for drawing guides and limitation.
3. The hardware was started to be drawn using AutoCAD software for 2 dimensional drawing inclde the door and deadbolt drawing at different views.
4. The system casing was started to be drawn using Autodesk Fusion 360. It is depends on the creativity to incorporate all components into a single casing, ensuring compatibility with the existing door dimensions.
5. The drawings were saved in different files for the part of body, cover, gripper and nuts.
6. Files sent to technician of the laboratory for 3D printing process.



## 3.9 Obtain the responses of vibration sensor activated by a knock sequence

The objective needs to be achieved which is, to obtain the responses of vibration sensor activated by a knock sequence. There are few processes involved in testing of each components to the responses of the sensor. Functionality test is one of the early process of circuit testing in order to implement this project successfully. By proceeding the functionality test, some testing arrangement has been made include servo motor testing based on program control and push button control, piezoelectric sensor response testing, push button program testing, push button lock testing, knock testing distance response testing, and lastly overall system testing. This functionality test ensures that the components are properly connected and functions as intended with the microcontroller board. Arduino Uno microcontroller is predominantly chosen for these tests due to the ease of connection with jumper wires.

### 3.9.1 Testing of Servo Motor with Program Control and Push Button Control

The first functionality test is made for servo motor control. The functionality test verifies that the servo motor responds correctly to the commands, smoothly rotating within the specified angle range. The servo motor's accuracy also can tested by commanding it to specific angles and checking if it aligns accurately. This ensures servo motor properly connected and functions as intended with the Arduino Uno board. The components should first be setting up, by connecting the servo motor to the appropriate pins on Arduino Uno boards, as GND to GND, VCC to 5V, and signal to D9. The controlling process is made directly from the code.

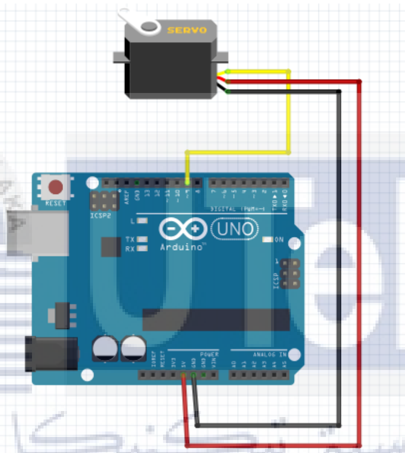



Figure 3.22 Circuit diagram for Arduino Uno and servo motor connection



At the second testing of servo motor, the controlling process implemented using push buttons. Each of push button pins connected to Arduino, which is D5 and D6 respectively as shown in Figure 3.23. By uploading the code to the Arduino IDE that commands the servo motor to rotate at different angles, the motor’s movement can be observed. The procedure on the testing of servo motor are constructed as below:

1. All connection are connected properly based on Figure 3.22.
2. The Arduino Uno cable is connected to the laptop or computer.
3. The program is run for five different angle such as 0, 10, 30, 60 and 90 degree.

4. Actual servo motor angle are measured using protractor.
5. The result is recorded and testing is repeated for about five times
6. The procedures are repeated for push button control based on circuit in Figure 3.23.

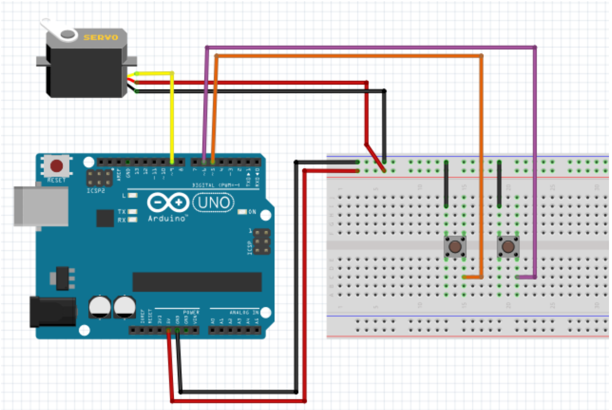



Figure 3.23 Circuit diagram for Arduino Uno and servo motor with push button connection

#### 3.9.1.1 Experimental Setup

Table 3-3 Actual angle of motor rotation for 5 different angles

| Desired Angle (°) | Actual Angle (°) | | | | | | Percentage Error (%) |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | Average | |
| 0 | | | | | | | |
| 10 | | | | | | | |
| 30 | | | | | | | |
| 60 | | | | | | | |
| 90 | | | | | | | |

Table 3-4 Motor movement and its status for two different angle

| Desired Angle (°) | Motor Movement | Status |
|---|---|---|
| 0 | | |
| 90 | | |

### 3.9.2 Piezoelectric Sensor Test

In this testing, the piezo electric sensor is connecting to the appropriate pins on Arduino Uno boards where the positive channel of sensor is attached to pin A0, and the ground channel is linked to the GND pin. A 1Mohm resistor is added between the positive and negative channels of the sensor. To recognize the sensor's activation to applied knocks, a red LED is attached to the Arduino Uno at pin 13. The circuit is constructed as shown in Figure 3.24.

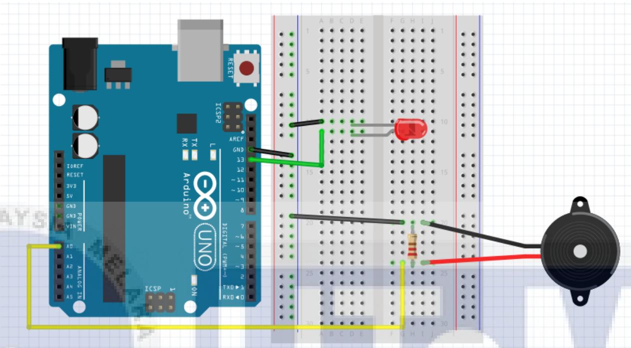



Figure 3.24 Circuit diagram of Arduino Uno and Piezoelectric sensor connection

By uploading the code into the Arduino IDE, the response of piezoelectric sensor can be observed. This test is conducted to identify the appropriate threshold value necessary for executing the knocking process applied to the door system. The procedure on the testing of piezoelectric sensor can be follow as below:



1. The piezoelectric sensor connection with Arduino Uno are followed properly according to Figure 3.24.
2. The Arduino Uno cable is connected to the laptop or computer.
3. The program is run. Serial plotter is opened to obtain the graph respond of sensor reading over time.
4. All results are recorded and tabulated.

### 3.9.2.1 Experimental Setup

Table 3-5 Maximum knock reading in term of numerical value

| Knock applied | Maximum Sensor Reading |
|---|---|
| No | |
| Yes | |

### 3.9.3 Push Button Program Test

For the third functionality test which is push button program test, it is involve a piezoelectric sensor and a push button as shown in Figure 3.25. For the circuit setup, the piezoelectric sensor is connected with 1Mohm resistor where the positive of sensor is connect to A0 pin while GND to GND pin. There have one push button used in this testing. One pin of push button is connected with resistor to ground, one pin is connected to power and other one pin connected to D2 pin. This testing also including red and green LEDs, each connect with D4 and D5 pin of Arduino Uno respectively. The negative of each LED is linked with 1kohm resistor.



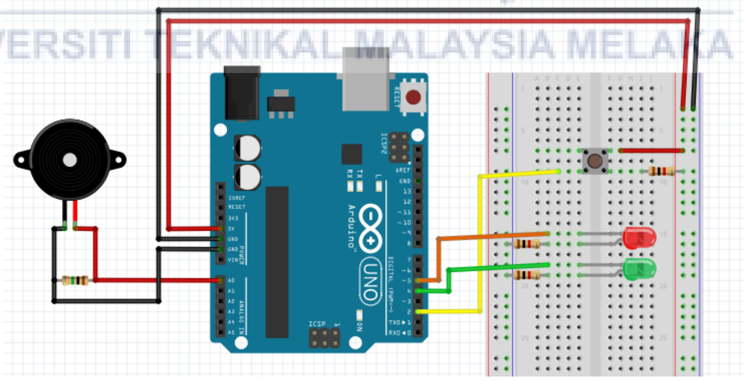



Figure 3.25 Circuit diagram of push button program system

The push button function is making a way to program the knock pattern by user into the microcontroller memory. The push button program testing procedure are listed as follows:

1. The circuit is constructed based on Figure 3.25 below.
2. The Arduino Uno cable is connected to the laptop or computer.
3. The program is uploaded into microcontroller and run.
4. Push button is pressed and hold while entering the knock pattern.
5. The responds are observed. Serial motor is opened to obtain the graph respond of sensor reading over time.
6. All results are recorded and tabulated.

#### 3.9.3.1 Experimental Setup

Table 3-6 Push button program functionality via applied knock

| Push button program | Knock applied | Piezoelectric sensor | Knock pattern saved | Description |
|---|---|---|---|---|
| Not pressed | | | | |
| Pressed | | | | |
| Pressed | | | | |

### 3.9.4 Push Button Lock Test

This testing is conducted using a push button and servo motor components as shown in Figure 3.26. In the apparatus crafted during Experiment 3.9.1, utilizing push button manipulation, this test employs a singular push button to govern the servo motor's motion, directing it either towards the 0 degree or 90 degree position. In this testing, the components firstly setting up by connecting the servo motor to the appropriate pins on Arduino Uno boards, as GND to GND, VCC to 5V, and signal to D9. Controlling part by a push button where one pin of push button is connected with D2 pin and another one pin of push button connected to ground.

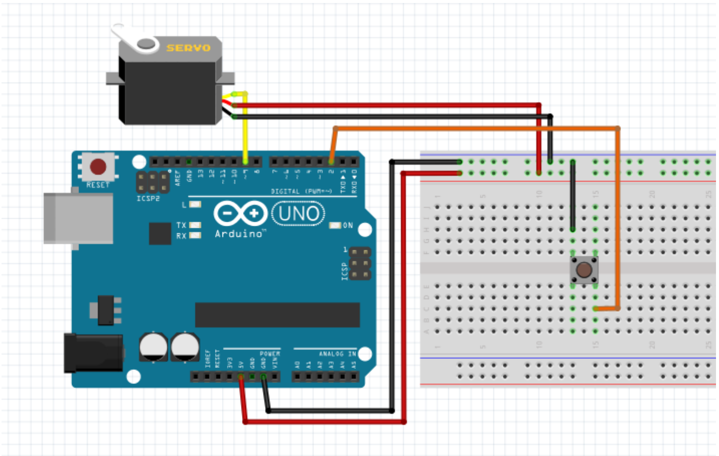



Figure 3.26 Circuit diagram of push button lock system

The procedure on the testing of push button lock are constructed as below:

1. The circuit is constructed based on Figure 3.26.
2. The Arduino Uno cable is connected to the laptop or computer.
3. The program is uploaded into microcontroller and run.
4. Push button is pressed while observing the servo motor movement.
5. The serial motor is opened to obtain the real time respond by manipulating the push button.
6. All results are recorded and tabulated.



#### 3.9.4.1 Experimental Setup

Table 3-7 Push button lock functionality toward servo motor condition

| Push button Lock | Current condition servo motor | Servo Motor movement | New condition servo motor |
|---|---|---|---|
| Not pressed | | | |
| Pressed | | | |
| Pressed | | | |

### 3.9.5 Complete Circuit Composition

The various circuits previously tested are ultimately integrated to form a complete circuit involving knock detection, knock programming, servo motor positioning, and control using a push button. In this section, the Arduino Nano board is used instead of the Arduino Uno. The servo motor and Arduino Nano board are powered separately, with a 9V battery supplying power to the Vin of Arduino Nano, while the servo motor is connected to a 6V battery. The comprehensive circuit diagram connection is illustrated in Figure 3.27 below.

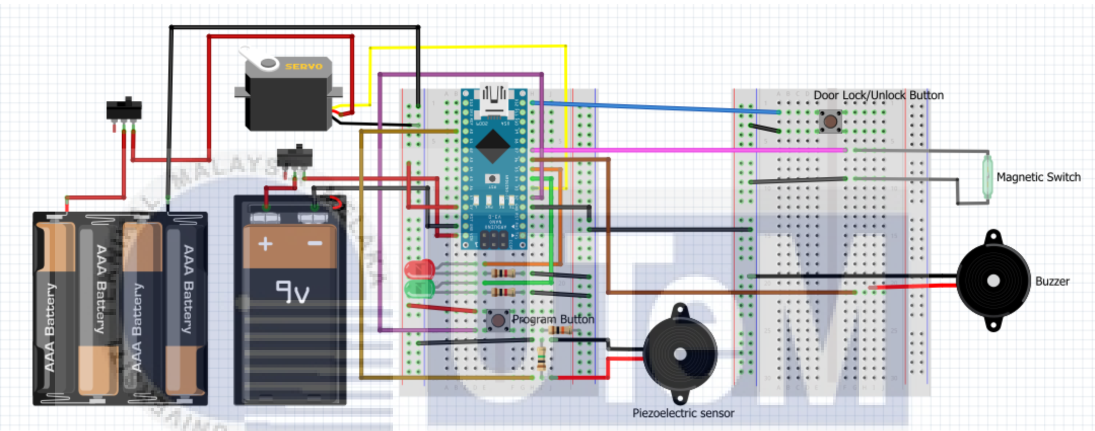



Figure 3.27 Complete circuit diagram of Door Lock System using Knock pattern



Firstly, the components are setting up by connecting the Arduino Nano board from A0 pin to the positive side of piezoelectric sensor and to the ground. A 1Mohm resistor is positioned between the connections of the piezoelectric sensor. The push button lock and push button program are attached to the board at pins D2 and D12, respectively. The servo motor signal is integrated into pin D3 of the board. Additionally, a green LED and a red LED are connected to the board through pins D4 and D5, respectively. Lastly, pin D6 of the Arduino Nano is affiliated with a buzzer, and the magnetic switch is connected through pin D7. The subsequent procedure for constructing the testing and experimentaion of the complete system are outlined as below:

1. The hardware components are constructed such circuit in Figure 3.27.
2. The Arduino Nano cable is connected to the laptop or computer. Make sure the correct selection of “Port” and “Processor” at the Tool bar to prevent errors.
3. The coding is uploaded into microcontroller and run.
4. Knocks are applied according to the default setting in the coding.
5. Serial monitor and serial plotter are opened to acquire responses including monitoring motor movement.
6. New knock pattern is entered by pressing the push button program. Knocks are applied in accordance with the updated pattern.
7. The push button lock is pressed once and then pressed again to activate the second condition.
8. All result are observed and recorded.

### 3.9.5.1 Experiment Setup

Table 3-8 Components observation based on the impact of knock

| Knock applied / vibration | Knock true/false | Component Observation | | | |
|---|---|---|---|---|---|
| | | Piezoelectric Sensor | Buzzer | LED | Servo Motor |
| No knock | - | | | | |
| Knock lock | True | | | | |
| | False | | | | |
| Knock unlock | True | | | | |
| | False | | | | |

### 3.10 Analyze the knock performance based on the presence of sound

The final objective of this project is to analyze the relationship between sensor readings and manual sound level measurements derived from knocking rhythms. This section is dedicated to determine the responses between measurement values obtained through software and manual methods over time. The goal is to identify both the numerical value and the corresponding decibels (dB) value of the knock, and obtain the higher and lower value by assess strength of the applied knocks in decibels (dB). The procedure of this experiment constructed as follows;

Figure 3.28 The system installed on the door prototype



1. The system is installed on the door prototype as shown in Figure 3.28 above.

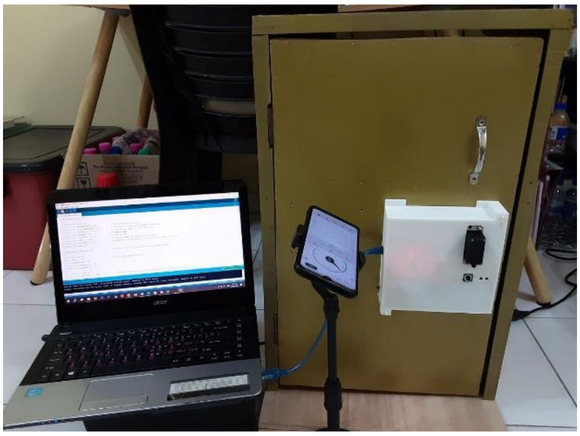


Figure 3.29 Position of measurement device at the door lock

2. The measurement device is setting up as shown in Figure 3.29. Make sure the application of Sound Meter is opened as shown in Figure 3.30 below.

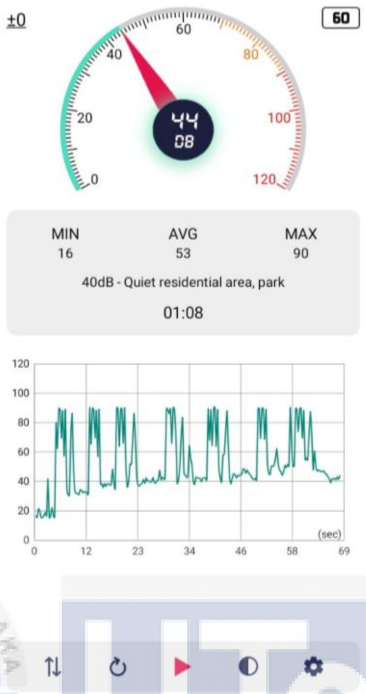



Figure 3.30 Display of Sound Meter

3. The Arduino Nano cable is connected to the laptop or computer. Make sure the correct selection of "Port" and "Processor" at the Tool bar to prevent errors.
4. Serial monitor on the Arduino IDE is opened and the Sound Meter is started simultaneously. The initial value where no applied knock is determined.
5. The smooth and hard knocks are given to the door at the certain time. Sound Meter is stopped.
6. The result obtained in Serial Monitor is taken. The data of audio can be obtained from history.
7. Step 4 is repeated for knocks are applied according to the default setting in the coding.
8. At certain time, the Sound Meter and Serial Monitor are stopped. Both results are obtained.
9. Step 4 until 8 are repeated about 3 times.
10. All the results for both method are determined and recorded in Microsoft Excel. The graph response for both method is observed.

### 3.10.1 Experimental Setup

Table 3-9 Knock value measurement using piezoelectric sensor and Sound Meter for default knock pattern

| No. | Sensor Readings | | | | Sound Meter Measurement (dB) | | | |
|---|---|---|---|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | Average | Test 1 | Test 2 | Test 3 | Average |
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | | | | | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |

Table 3-10 Knock value measurement using piezoelectric sensor and Sound Meter by applying hard knock

| No. | Sensor Readings | | | | Sound Meter Measurement (dB) | | | |
|---|---|---|---|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | Average | Test 1 | Test 2 | Test 3 | Average |
| 1 | | | | | | | | |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | | | | | |
| 7 | | | | | | | | |
| 8 | | | | | | | | |
| 9 | | | | | | | | |
| 10 | | | | | | | | |



Table 3-11 Maximum and minimum of sensor reading and sound meter measurement

| Knock Value | Sensor Readings | Sound Meter Measurement (dB) |
|---|---|---|
| Initial | | |
| Maximum | | |
| Minumum | | |

### 3.11 Ethics and Safety of Method

Ethics and safety of methods refer to the principles, standards, and factors that direct the ethical behavior and well-being of individuals engaged in the project where along with the consequences of the employed methods on the wider community and environment. This project of Smart Door Lock using Rhythmic Knocks involves using an Arduino, piezoelectric sensor, a buzzer, a servo motor, push buttons and LEDs to create a door lock that can detect the pattern of knocks and open or close only if the pattern matches the correct one. There have some ethics and safety that must be followed in order to operate the method carefully. The ethics that need to be follows as an engineer is the professional responsibility which prioritize public safety, ensuring that the technology does not pose undue risks to users or the general public.

Some projects may have their own risk and hazard. The potential hazards and risks of using the electrical hardware components like Arduino, sensor, buzzer, servo motor, push button and LEDs such as electric shock, fire, malfunction, or damage. Therefore, the risk assessments, user safety and considering environment impact must be conducted in order to identify potential safety hazards, including the risk of unauthorized access or system malfunctions, design the system with safety features, such as fail-safes to prevent accidental lockouts, lastly choose materials with minimal environmental impact and adhere to recycling practices. The measures taken to prevent or minimize these hazards and risks by using proper wiring, insulation, protection, and components testing. Additional, the system should not have any physical components that could harm users during regular operation. The ethical and professional responsibility of the engineer to ensure the security, privacy, and reliability of the smart door lock, such as using a strong and unique knock pattern. It is avoiding unauthorized access, and informing the users of the limitations and risks of the system. Thus, National Society of Professional Engineers (NSPE) Code of Ethics for Engineers must be followed accordingly that can develop standard engineer behavior. The compliance of the method and tools with the Mississippi Board of Licensure for Professional Engineers (MS Code of Practice), which is a set of standards and guidelines for engineering practice in Malaysia.

### 3.12 Summary

It's essential to note that a door lock system based on rhythmic knocks may have its limitations and may not be suitable for high-security applications or environments where precise control over access is necessary. The use of keystroke dynamics in a smart door lock system also poses certain limitations. One significant limitation is the potential vulnerability to spoofing or impersonation attacks. Since keystroke dynamics relies on the unique typing patterns of individuals, sophisticated attackers may attempt to mimic the typing style of an authorized user to gain unauthorized access. Moreover, the system may struggle to handle variations in typing patterns caused by factors such as changes in hand posture, typing with gloves, or different input devices. These limitations underline the importance of implementing robust security measures and ongoing system maintenance to mitigate potential risks and ensure the effectiveness of the smart door lock system.

This chapter presents the proposed methodology in order to achieve the objectives of the project as to design and develop a system that can detect knocking by human hand and control the door locking movements with appropriate mechanism. This is also achieved by managing the method use for the door lock system. The knocks are analyzed to determine if they match the predefined rhythmic sequence. If a match is found, the microcontroller activates the servo motor to unlock the door. To implement this, the system is designed using an Arduino microcontroller and programmed using the Arduino IDE. The knock detection algorithm is developed and integrated into the system. The functionality of the system is tested by simulating different knock patterns and verifying the accuracy of the lock or unlock mechanism.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1 Introduction

The findings of this experiment will be explained briefly in this chapter. It will also analyze performance factors such as identifying the desired angles, as well as cover the findings received from the established approach. The method to achieve the experiment result has been explained in previous chapter. The successful of the experimental and testing are based on the project objectives. The first objective of this project is to design and develop a prototype of the efficient door lock system based on knocking rhythms. The second project objective is to obtain the responses of vibration sensor activated by a knock sequence while the third objective include the analysis the relationship between sensor readings and sound level measurement.

## 4.2 Design and develop a prototype of efficient door lock system based on knocking rhythms



The goal of this project is to design and develop the efficient smart door based on knocking rhythms. A door locking system will be used to automatically lock and unlock the door system with key-less approach in the real time with a high degree of accuracy. The locking system will be designed to be suitable for the use of deadbolt locks as it very common use by people that the device is easy to use, with a user-friendly interface and a simple display. To achieve this objective, researchers will conduct extensive research and a testing at the time to identify the control process of actuator and the methods for lock mechanism.

### 4.2.1 2D Drawing Results

By designing and developing a prototype of the efficient smart door based on knocking rhythms, the drawings of equipment dimensions are required. The drawings are made using AutoCAD software. The 2D drawings include door, door cushion and deadbolt measurement. All measurement is in millimeter.

#### 4.2.1.1 Door

The drawing of exterior side of door as shown in Figure 4.1 has include the knock area, deadbolt hole, door and cushion measurement and it's position.

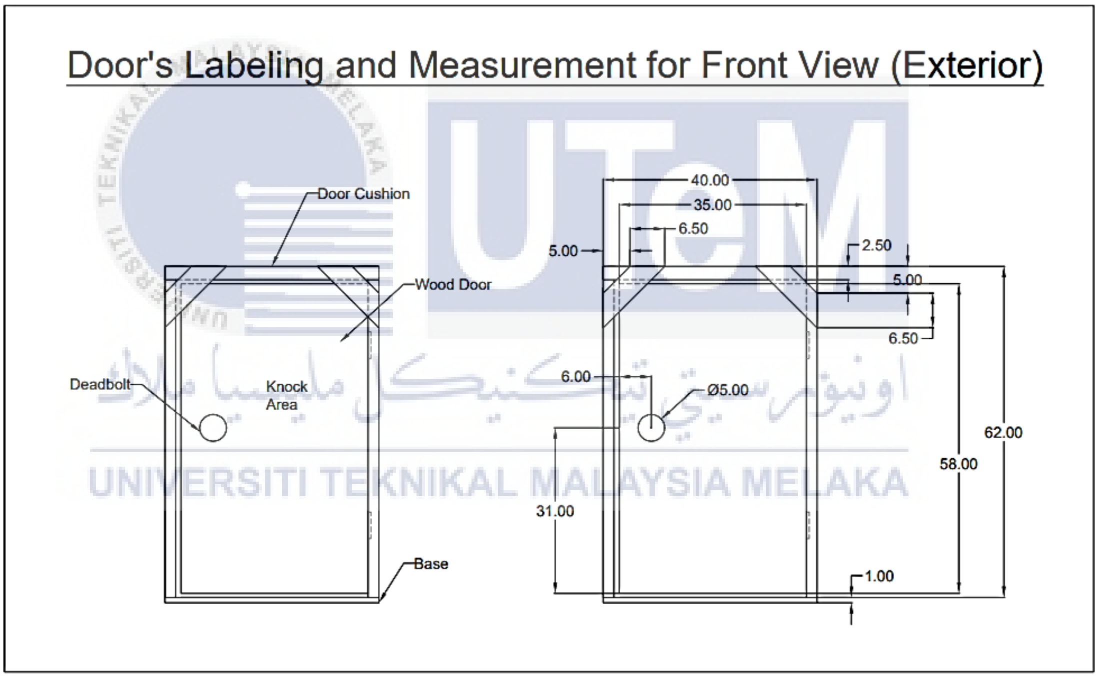



Figure 4.1 Door drawing at exterior front view

The drawing of interior side of door as shown in Figure 4.2 has include the piezoelectric sensor, deadbolt hole, door and cushion measurement and it's position. The drawing of controller box for components placement like Arduino Uno, battery, and wires also provided. The piezoelectric sensor is located at the center of the door within the knock area to efficiently receive the signal of knocks.

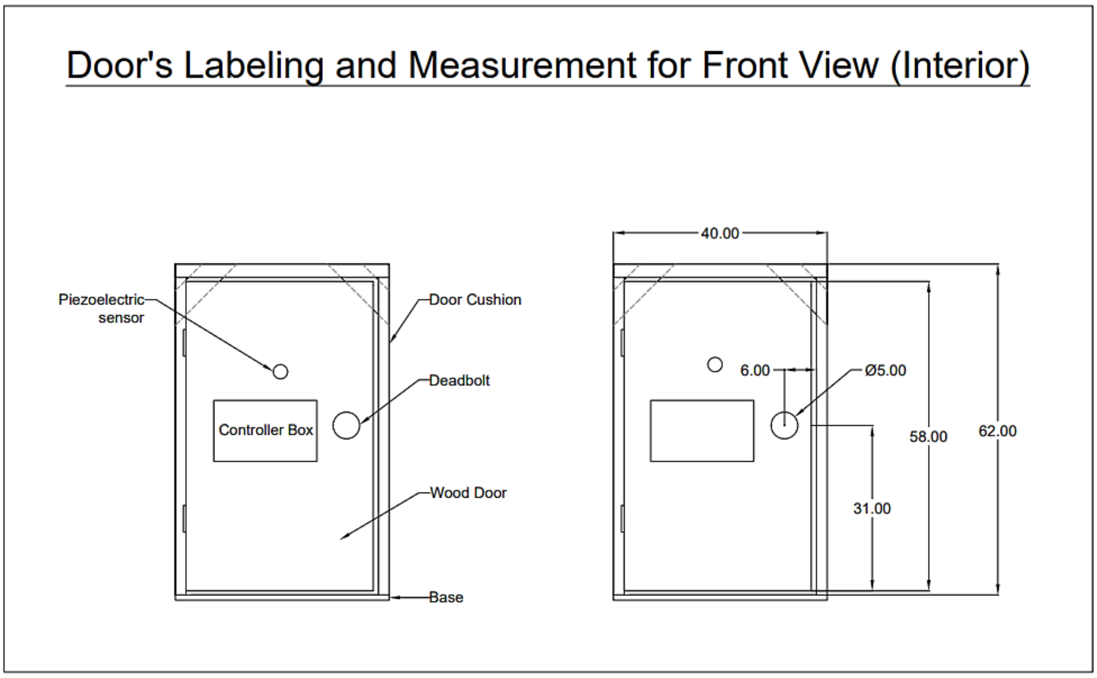



Figure 4.2 Door drawing at interior front view

Figure 4.3 shows the drawing of door at right side view. According to the drawing, there has additional wood plate at the top area of the cushion since it is function to limit the door movement, so that the door only can be move at one side.



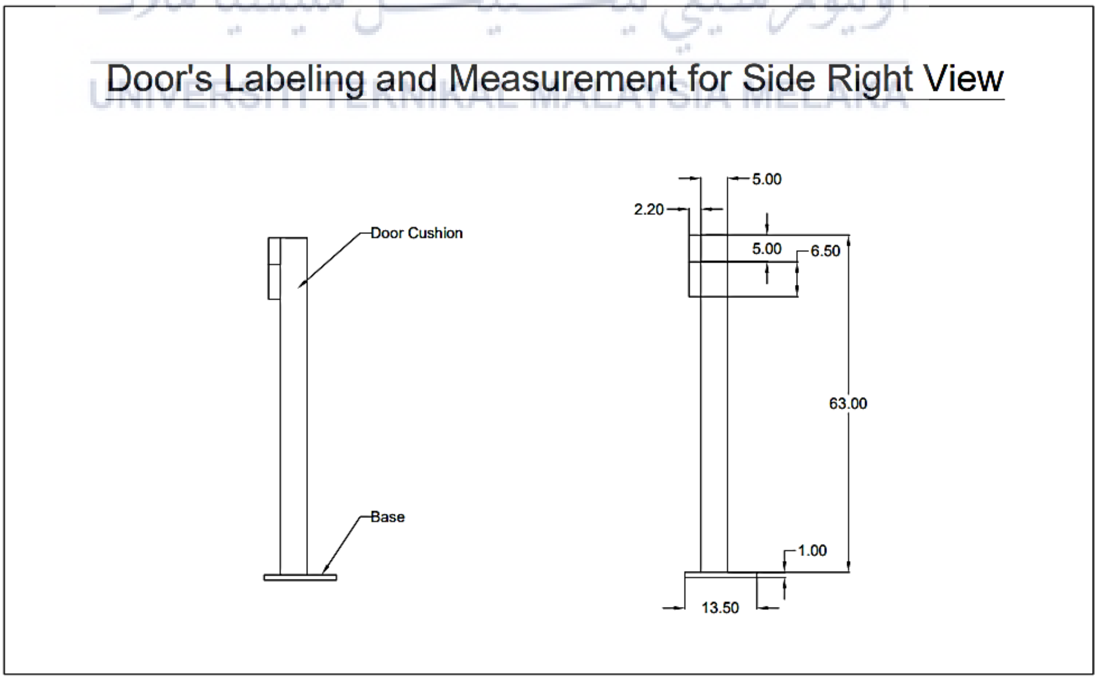



Figure 4.3 Door drawing at right side view

Figure 4.4 shows the door drawing at left side view. It is consist of the additional wood plate at the top are of door and lock hole.

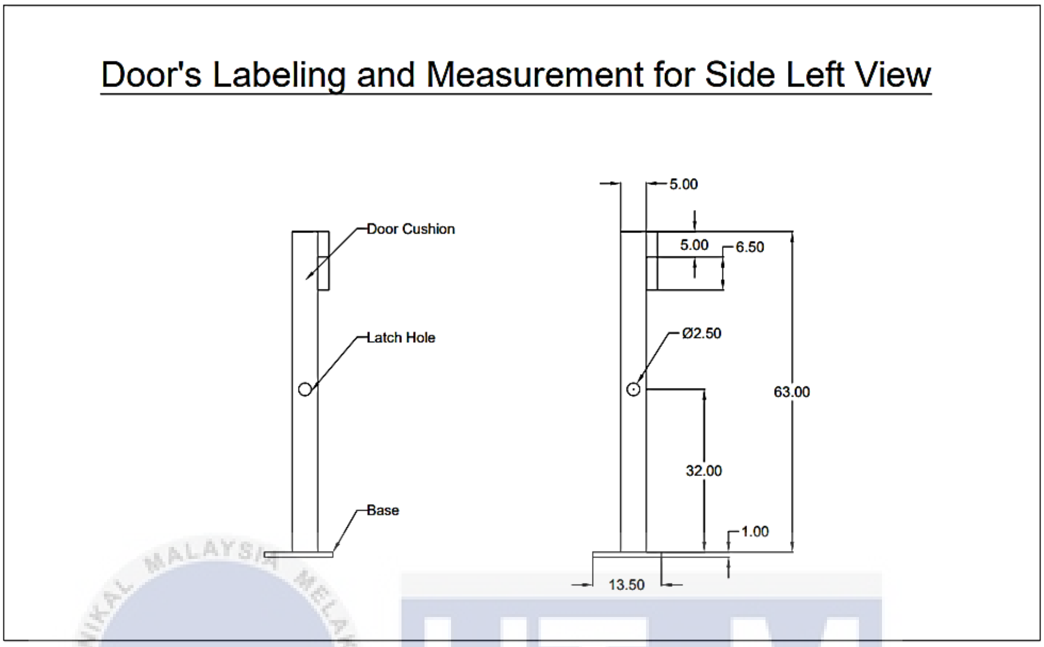



Figure 4.4 Door drawing at left side view

At the top of the view, the drawing involve the door cushion and door base measurement as shown in Figure 4.5.



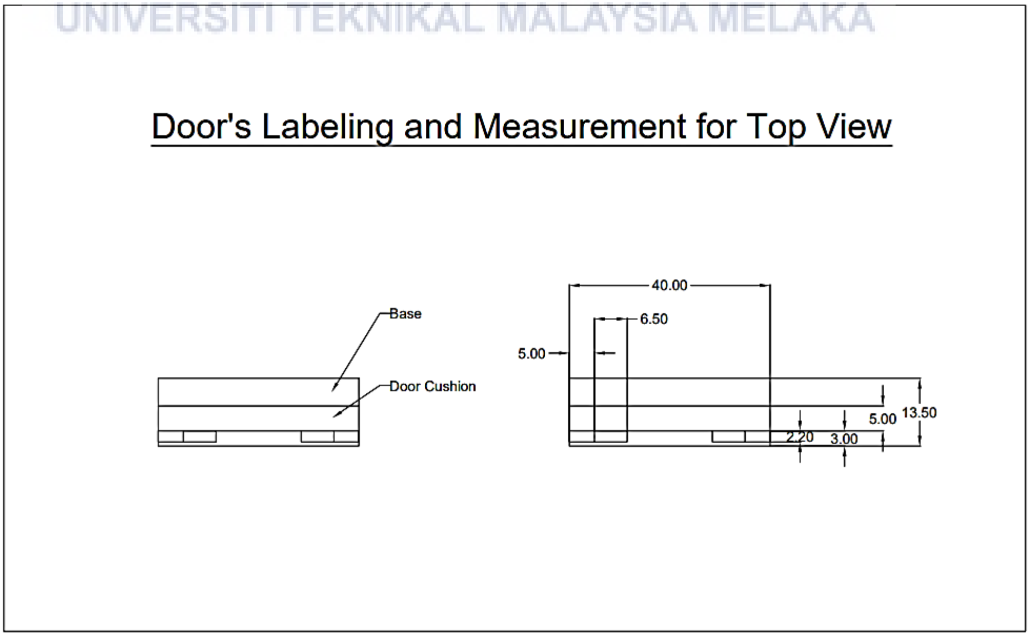



Figure 4.5 Door drawing at top view

#### 4.2.1.2 Deadbolt

Side view drawing of deadbolt attached at a door illustrated in Figure 4.6 that consist of servo motor positioned horizontally to thumb turn lock. There has a gripper attached to the thumb turn lock in order to turn the lock easily, using maximum area of the thumb turn lock requires less torque applied. Its measurement shown in Figure 4.7.

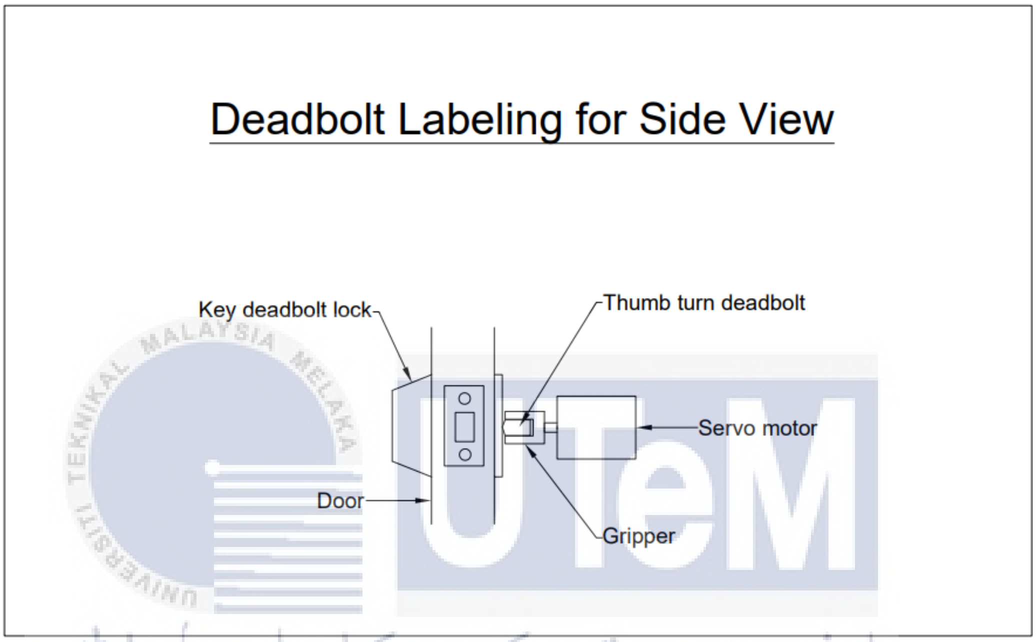



Figure 4.6 Labelled deadbolt drawing for side view



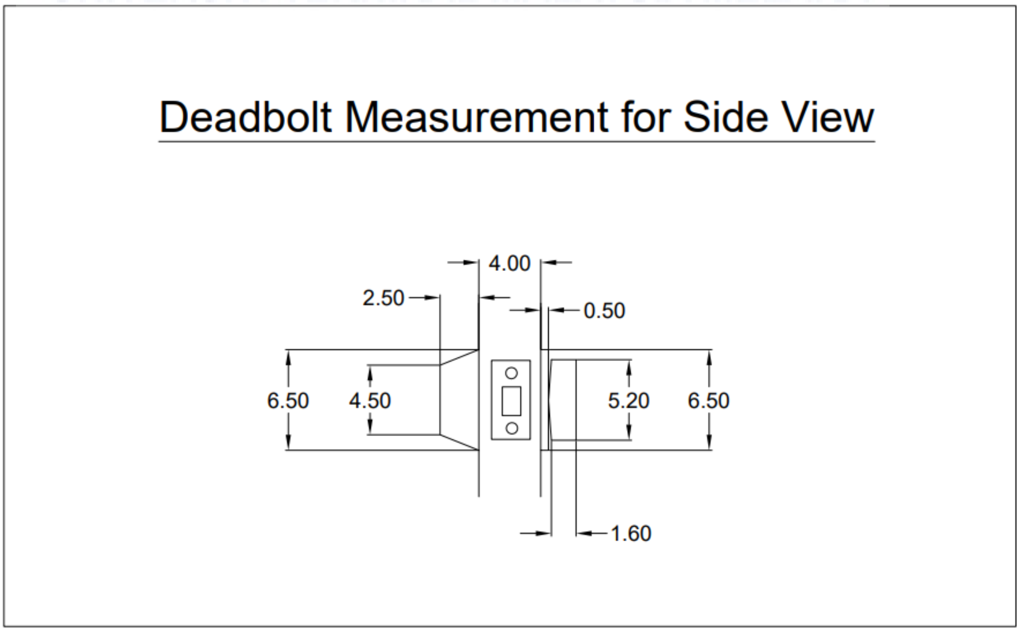



Figure 4.7 Deadbolt measurement drawing for side view

### 4.2.2 3D Drawing Results

In order to develop a prototype for the door lock casing, it is necessary to generate 3D drawings for each component using Autodesk Fusion 360 software before proceeding with the printing process. The casing part include body (base), cover, gripper and nut. The measurement used is in millimeter. This section exposes the standard drawings for each casing part, encompassing multiple views such as front, back, top, bottom, side, and isometric views.

#### 4.2.2.1 Body (Base)

According on the depicted Figure 4.8, this section encompasses the housing for hardware components, featuring designated slots for batteries, sensors, Arduino Nano, soldering plate, servo motor, and a slot for the deadbolt lock. In addition, there are slots provided for the Arduino Nano port and switches.

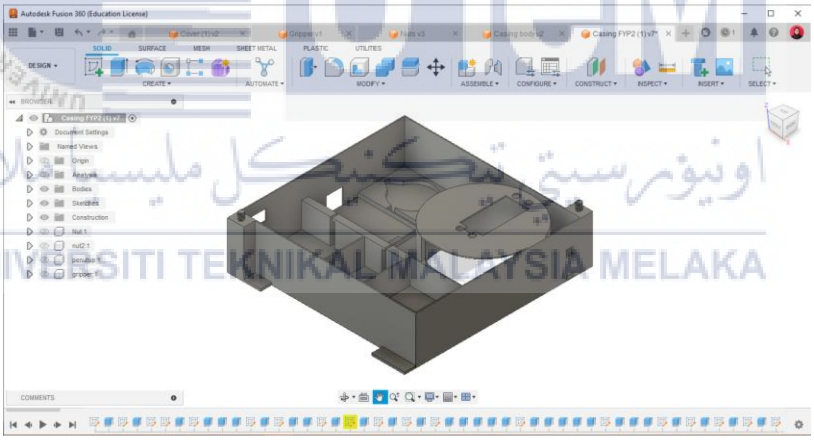



Figure 4.8 Body of casing drawing

The dimension of body casing is 160mm x 170mm x 43mm where it is indicated in the standard drawing shown in Figure 4.9 below.

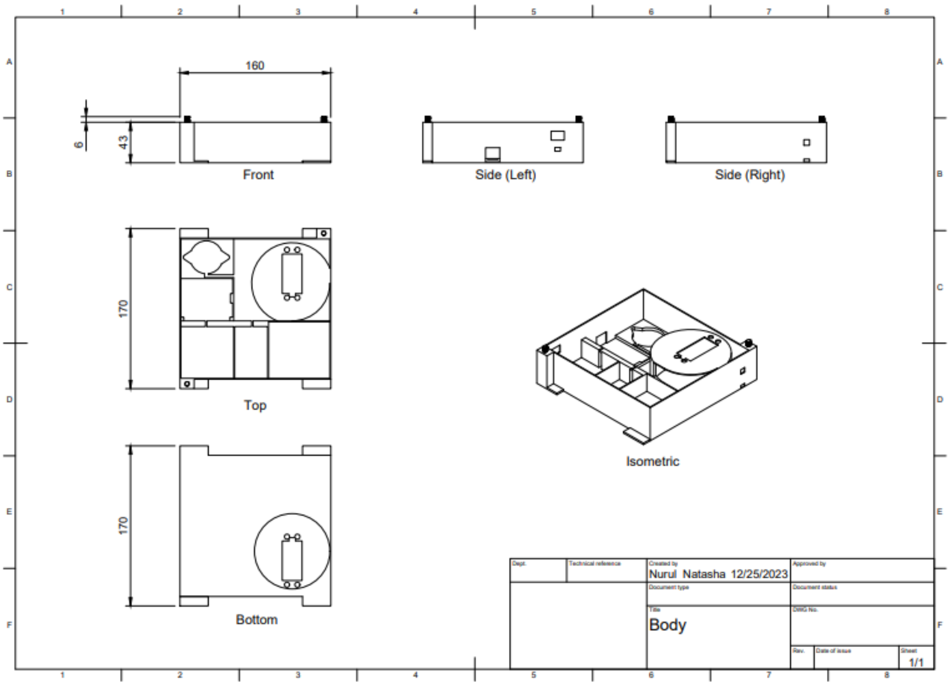



Figure 4.9 Standard drawing for casing body

### 4.2.2.2 Cover

The meticulously designed cover serves as a multifunctional component in the door lock system. Based on Figure 4.10 below, the cover incorporates specialized slots tailored for the secure accommodation of essential elements, including the servo motor, push button, and LEDs. The cover's thoughtful engineering extends to the incorporation of two strategically placed holes at the corners, ensuring seamless alignment and attachment to the system's body.

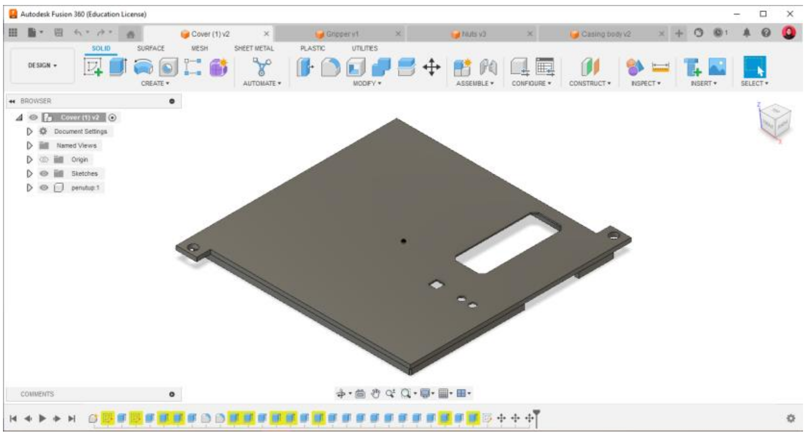



Figure 4.10 Cover of casing drawing

Cover's dimension also the same with previous body which is 160mm length x 170mm width x 0.8mm height. Figure 4.11 is illustrated the standard drawing for cover part.

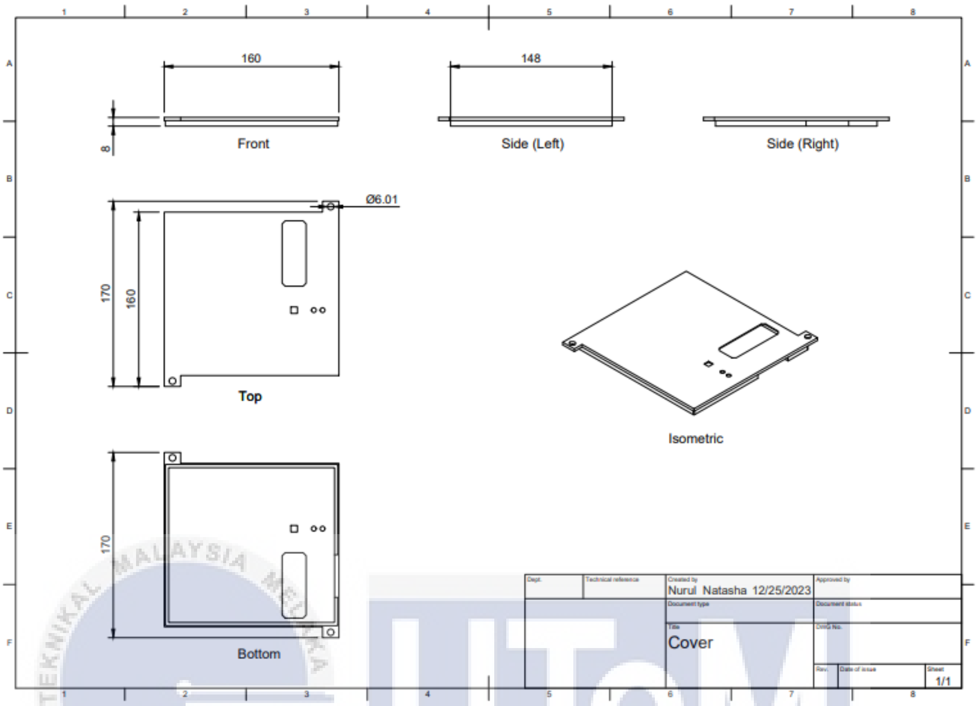



Figure 4.11 Standard drawing for casing cover

### 4.2.2.3 Gripper

Gripper is designed to connect between servo motor and the deadbolt lock, enabling the servo motor to exert force and move the lock in different direction. This involves incorporating two distinct slots: one for the deadbolt and the other for the servo motor, as illustrated in Figures 4.12 and 4.13.

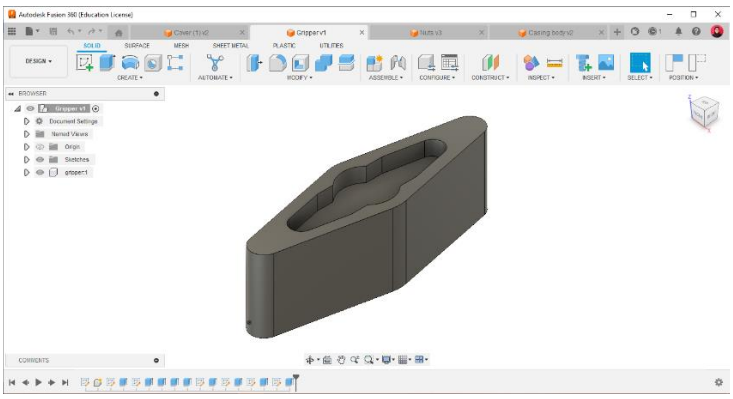


Figure 4.12 Top gripper drawing for servo motor slot

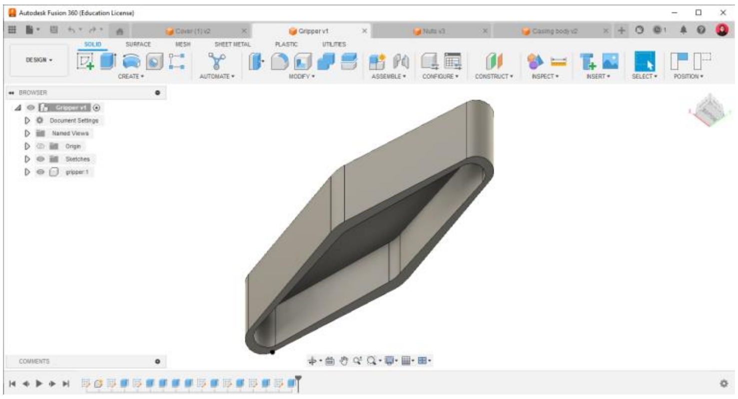


Figure 4.13 Bottom gripper drawing for deadbolt lock slot

The length of gripper is 64mm, width is 18.31mm and the height is 20mm. For the servo motor slot, the dimension is about 42mm x 13.2mm. The deadbolt lock dimension is 60mm x 14.5mm. Each slot is following the shape of both equipments and it is indicated in the standard drawing shown in Figure 4.14 below.



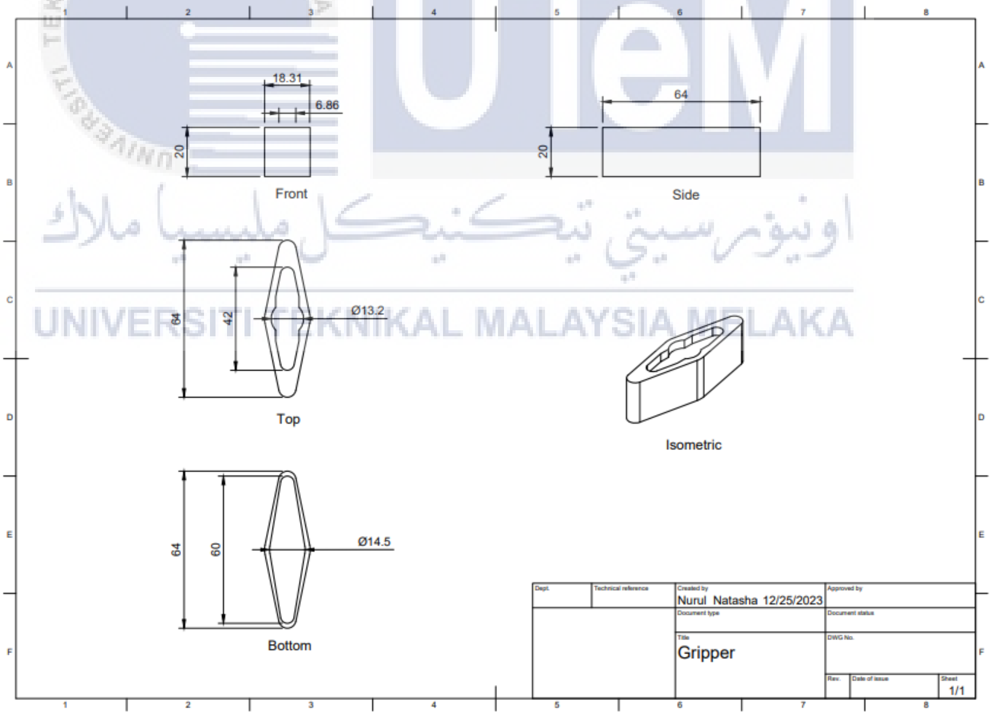



Figure 4.14 Standard drawing for gripper

#### 4.2.2.4 Nut

Two nuts are created and drawn as shown in Figure 4.15, for screwing as well as securing the cover firmly onto the casing's body part. This ensures a snug and stable attachment, contributing to the overall integrity and functionality of the door lock system's components.

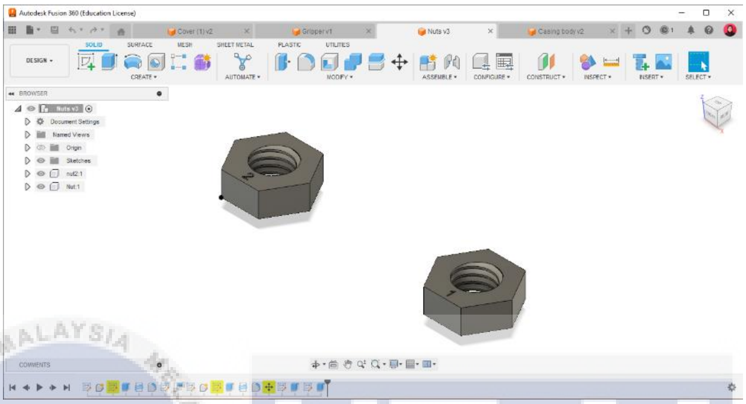


Figure 4.15 Nut drawing

Nut’s dimension is shown in Figure 4.16 where the length is 8mm, width is 9.24mm and height is 3mm.



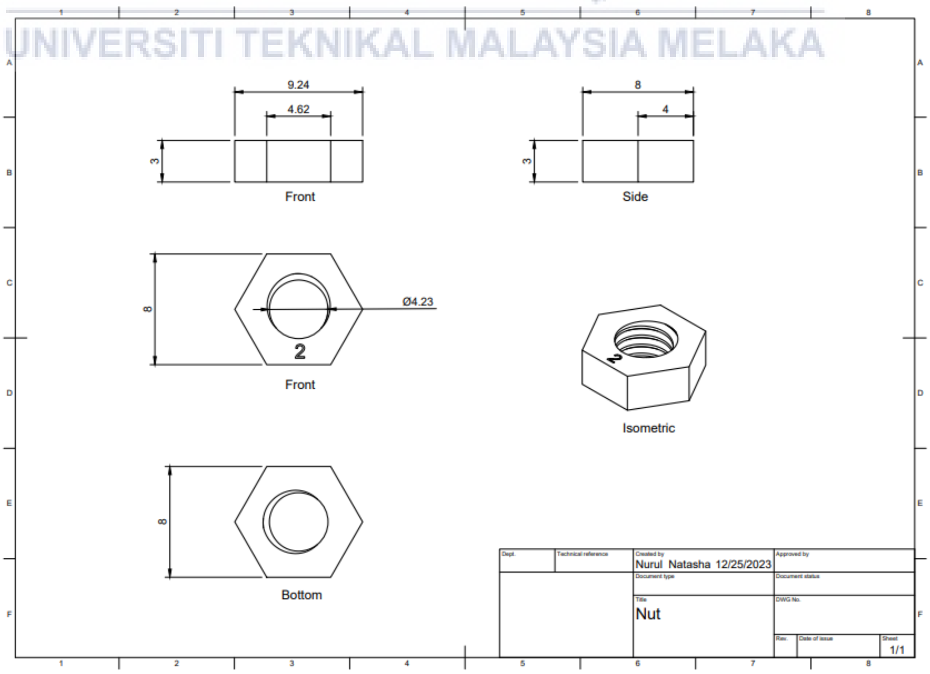



Figure 4.16 Standard drawing of nut

#### 4.2.2.5 Exploded View Casing Drawing

Exploded view of the casing provides an illustration of how each part is assembled. The cover and nuts are joined together and connected with the body from the top while the gripper is needed to be placed from the bottom of the body. The drawing is shown in Figure 4.13 below.

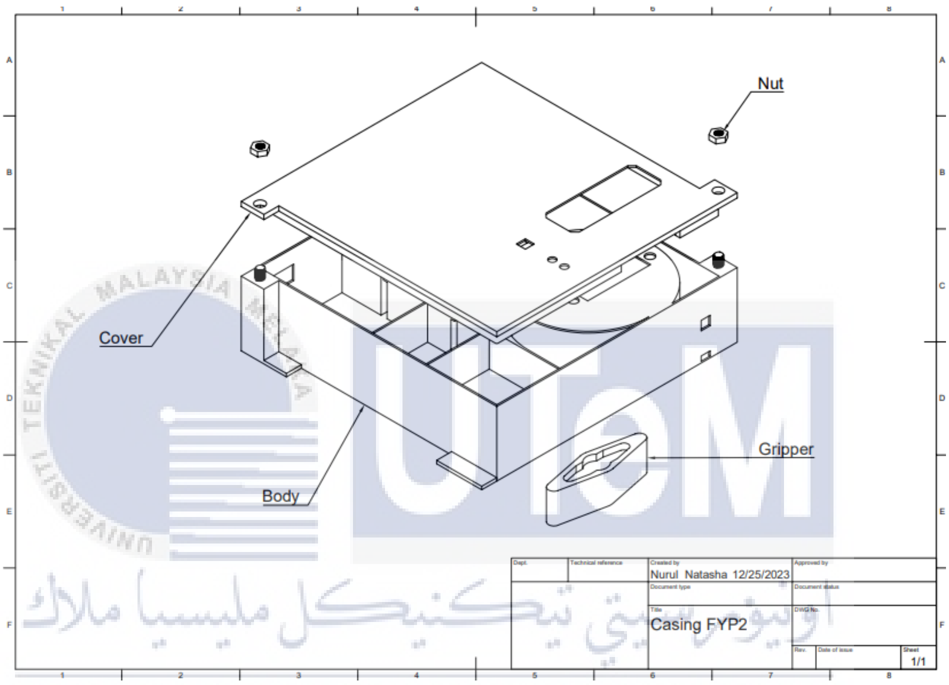





Figure 4.17 Exploded view drawing for casing

The 2D and 3D drawings are needed in order to perform the first objective of this project, design and develop the door lock system. The design then be printed using 3D printer. The printing process was taken about a week due to the edge gap error, sizing problem and unaware of the component's size. The sizing depends on the maximum size of 3D printer that can accommodate. It is crucial to ensure that the drawn size aligns with the provided door size, avoiding it being too large or too small. The casing should accommodate all components seamlessly.

## 4.3 Obtain the responses of vibration sensor activated by a knock sequence

There are few components testing involved in this experiment in order to get the step by step circuit connection. The testing mostly were performed using Arduino Uno and Arduino IDE. The testing involved are servo motor with program control and push button control, piezoelectric sensor, push button lock, push button program and complete circuit connection. The readings and responses were observed in the Arduino IDE through Serial Monitor and Serial Plotter.

### 4.3.1 Testing Result of Servo Motor with Program Control

In this experiment, a servo motor testing is made to measure the accuracy and percentage error of the actuator based on the angle rotation. Figure 4.18 shows the Arduino Uno and servo motor at 0 degree position. The desired angle are inserted directly on the code of the program which consist of 0°, 10°, 30°, 60°, and 90°. The actual servo motor direction are measured using protractor as shown in Figure 4.19.



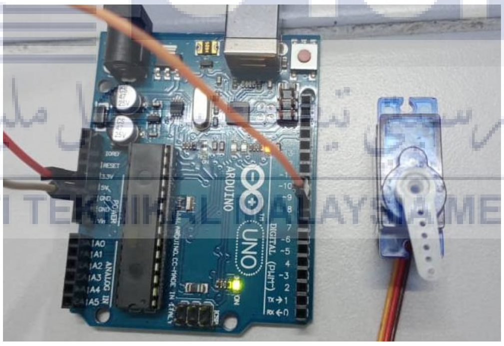



Figure 4.18 Servo motor measurement using protractor

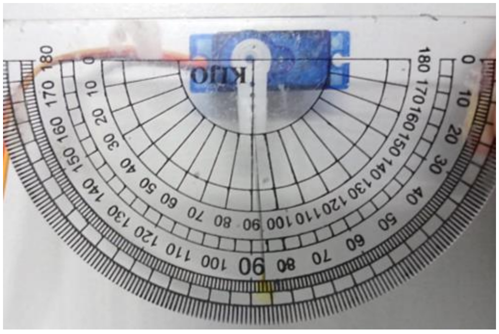


Figure 4.19 Servo motor at 0 degree

The experiment is run for about five times in order to get the average value of servo motor angle. The experimental results are recorded in Table 4.1. Equation (4.1) is the formula of the percentage error as follows;

$$\boldsymbol{Percentage\ Error}\ (\%) = \frac{\boldsymbol{measurement\ value - actual\ value}}{\boldsymbol{actual\ value}} \times \boldsymbol{100} \qquad (4\text{-}1)$$

Table 4-1 Actual angle of motor rotation for 5 different angles

| Desired Angle (°) | Actual Angle (°) | | | | | | Percentage Error (%) |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | Average | |
| 0 | 8 | 8 | 8 | 8 | 7 | 7.8 | - |
| 10 | 18 | 18 | 18 | 17 | 17 | 17.6 | 76.00 |
| 30 | 38 | 38 | 37 | 38 | 37 | 37.6 | 25.33 |
| 60 | 67 | 67 | 68 | 67 | 66 | 67 | 11.67 |
| 90 | 93 | 94 | 93 | 93 | 93 | 93.2 | 3.56 |

Based on Table 4.1 above, the actual value of angle with the desired angle are slightly different. The desired angle as initial position at 0 degree, there has average value of 7.8 degree which is at high value. While the measurement value of 93.2 degree is slightly similar to the desired angle with 3.56% of error. The ideal result should has zero percentage error. The result is true compared to the theory as only 0 and 90 degree can be used from this experiment because the percentage error of other angles are higher exclude 0 and 90 degree. The servo motor can only operate accurately at 0, 90 and 180 degree. Thus, 0 and 90 degree are selected to be used for the door lock mechanims.

Next, the angle of 0 and 90 degree are inserted into the program to analyze the direction of servo motor that can be relate to the door status. The door status for both angle at 0 degree rotation and 90 degree rotation can be seen from serial monitor as illustrated in Figure 4.20 and Figure 4.21 respectively. The result of motor movement and door status for both angles are recorded in Table 4.2 below.

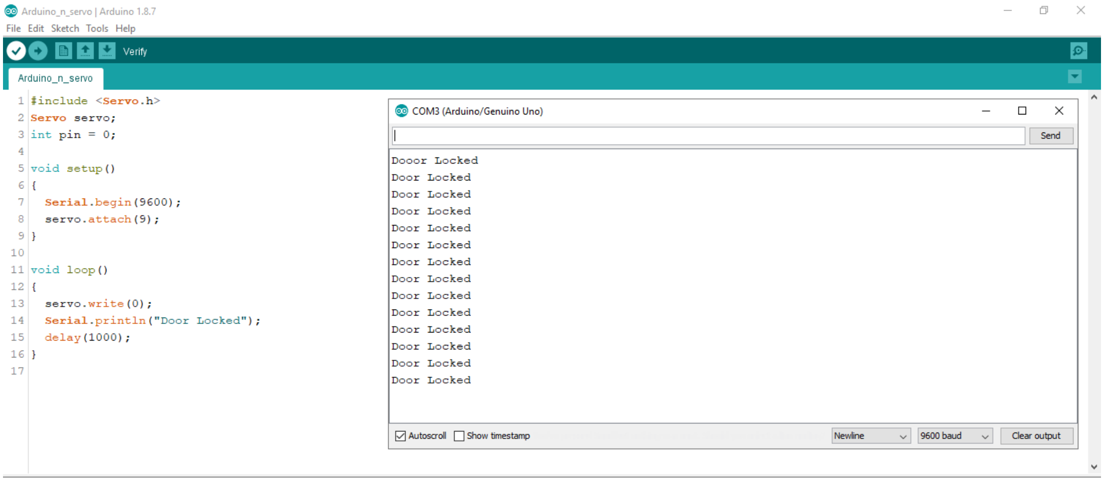



Figure 4.20 Serial monitor result for servo motor movement at 0 degree rotation

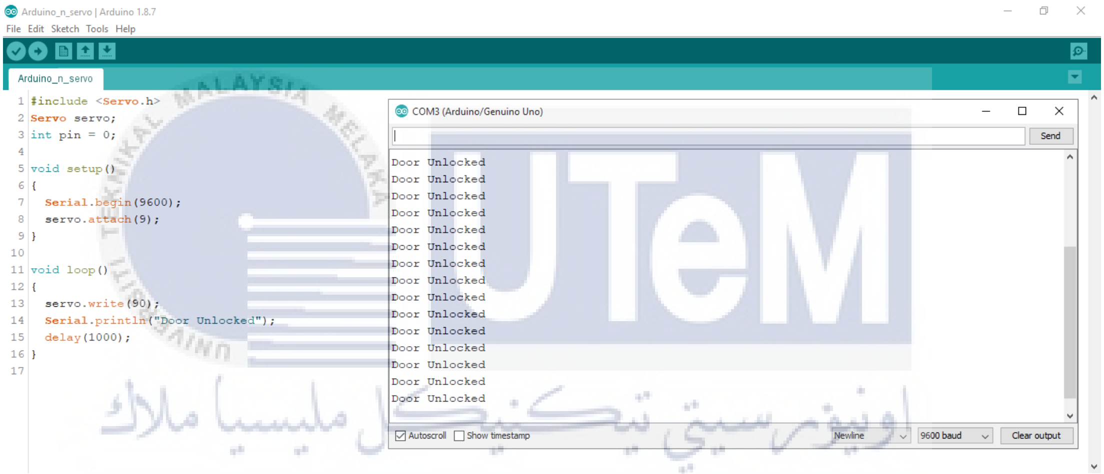





Figure 4.21 Serial monitor result for servo motor movement at 90 degree rotation

Table 4-2 Motor movement and its status for two different angle

| Desired Angle (°) | Motor Movement | Status |
|---|---|---|
| 0 | Clockwise | Door Locked |
| 90 | Anticlockwise | Door Unlocked |

According to the result obtained, since the coding is written as servo.write(0), the 0 degree of rotation give the clockwise movement indicates the door of the house is in lock condition. While, the angle of 90 degree indicates the door as unlock condition as servo motor rotates counter clockwise. The servo motor directly rotate at 90 degree rotation when the code is written as servo.write(90). The door status is appeared on the serial monitor when the code is written as Seral.prinln ("Door Locked") or Seral.prinln ("Door Unlocked").

### 4.3.2 Testing Result of Servo Motor with Push Button Control

This experiment is based on the servo motor controlled using two push buttons. Figure 4.22 shows the servo motor movement with push button control at 0 degree position. While Figure 4.23 shows the servo motor movement with push button control at 90 degree position.



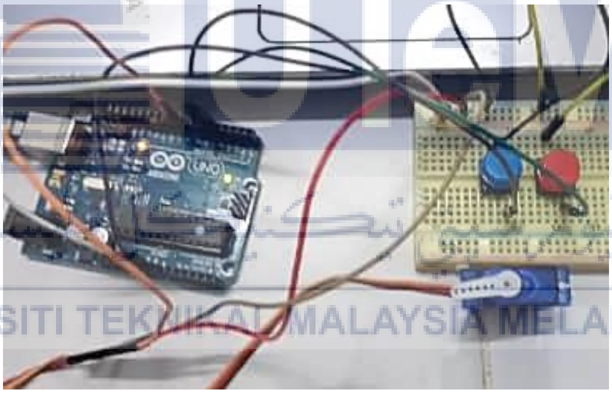


Figure 4.22 Servo motor movement with push button control at 0 degree

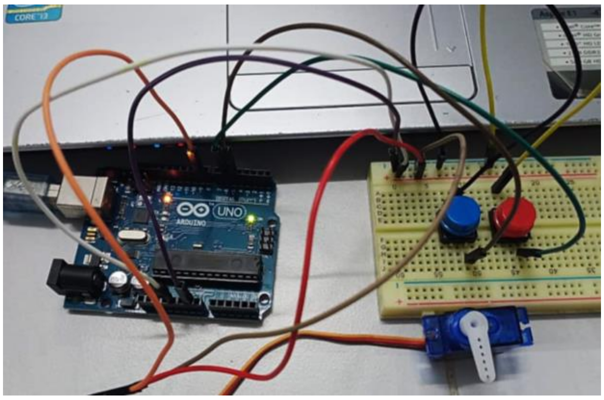


Figure 4.23 Servo motor movement with push button control at 90 degree

The results are based on the way of controlling a servo motor with Arduino Uno microcontroller by understanding its fundamental. Table 4.3 below shows the result of motor movement and door status using switching process.

Table 4-3 Motor movement and its status for two different switches

| Switching Pressed | Desired Angle (°) | Motor Movement | Status |
|---|---|---|---|
| Switch 1 (Blue) | 90 | Anticlockwise | Door Unlocked |
| Switch 2 (Red) | 0 | Clockwise | Door Locked |

The door condition or status and motor movement are the same with the previous experiment servo motor with program control. There has several assumption be considered in this experiment where servo motor is controlled through two push button. The blue push button is for open or unlock condition while red push button is for close or lock condition of the door. In this case, the servo motor rotates at counter clockwise with 90 degree when the push button blue is pressed. It is considered to be unlock position. The servo motor rotates at clockwise direction with 90 degree when the push button red is pressed. Thus, servo motor can be controlled in many ways such as directly from the code implemented in the program and controlled via additional peripheral like push button and sensors.

### 4.3.3 Piezoelectric Sensor Test

In this experiment, the primary objective is to analyze the sensor reading responses over time. Continuous data acquisition involves ongoing monitoring and collection of sensor measurements. Whenever a knock occurs, it generates a distinctive pulse or spike in the graph. The sensor's reactions to applied knocks are visually represented in the accompanying graphs. Figure 4.24 illustrates the scenario when no knock is applied, showcasing the baseline sensor response in the absence of external stimuli. The result shows sensor read up to 1 numerical value with continuous square wave output, since the sensor generate a binary signal (0 or 1). This attributed to the characteristics of the sensor signal or the way it is being processed, may occurs due to the several factors such as signal processing, sampling rate, amplication or filtering. For instance, if the signal is digitized using a sampling technique, it may appear as a square waveform or similar to it.


Figure 4.24 Graph of sensor reading over time at rest condition



As mentioned earlier, the output waveform exhibits impulses or spikes when the sensor detects and measures the applied knocks. Initially, random knocks were applied to the sensor, resulting in an output as depicted in Figure 4.25. It illustrates an example of the sensor reading responses over time based on the presence of applied knocks.

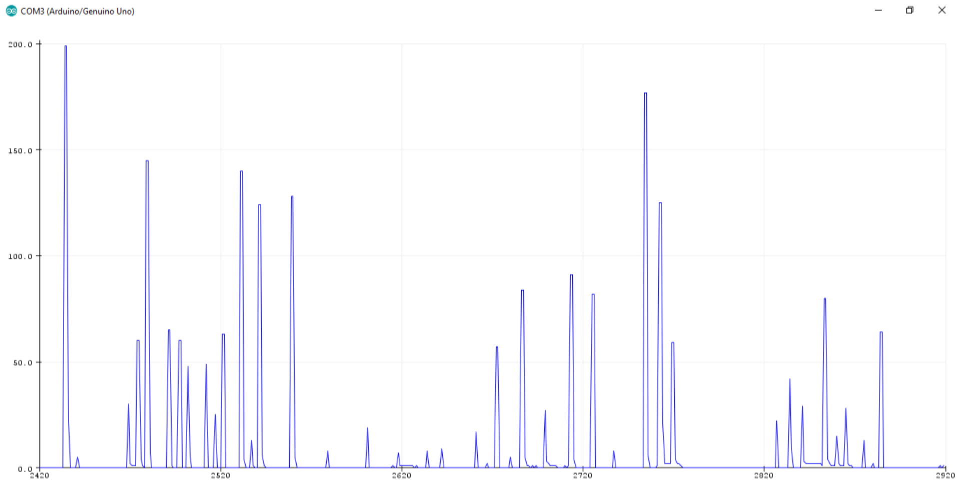


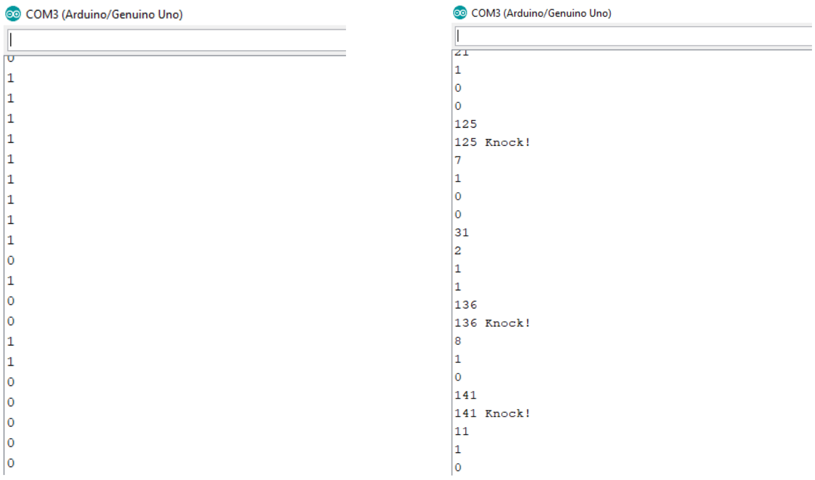

Figure 4.25 Graph of sensor reading over time when have knock

In Figure 4.26, by applying a hard knock onto the surface, it will register the maximum value that the sensor can read, approximately around 440. This process is conducted to determine the sensor's capability to read input and to assess the highest value it can generate.




Figure 4.26 Graph of sensor reading over time with highest impulse response

Since the graph only represents the waveform without displaying the values for each impulse in the serial plotter, the values can be obtained using the serial monitor, which indicates the sensor readings. Both the serial monitor and serial plotter cannot be opened simultaneously. Due to this limitation, the values between them differ in this section. Figure 4.27 serves as an example, displaying sensor values exclusively in the serial monitor.




a) b)

Figure 4.27 Example of sensor values in serial monitor, a) no knock and b) has knocks

The result is tabulated in Table 4.4 below for maximum piezoelectric sensor reading in numerical value according to the applied knock.

Table 4-4 Maximum sensor reading by a knocking action

| Knock applied | Maximum Sensor Reading (Numerical Value) |
|---|---|
| No | 1 |
| Yes | 440 |



In this experiment, the sensor's output values exhibited a range between 0 and 440. When sensor is at rest, no external force is applied, it tends to display values of 0 and 1. Theoretically, a piezoelectric sensor can produce values within the range of 0 to 1023. The piezoelectric sensor detection depends on the threshold value set in the coding. Through observation, it has been determined that a suitable threshold value for this project is 55 that serve as a baseline to ensure only substantial and intentional knocks are recognized, while eliminate false positives from minor vibrations or ambient noise. Therefore, any vibration or knock with a value above this threshold is considered a valid knock and it can be seen in Figure 4.27b). Fine-tuning the threshold is a critical aspect of the experiment, ensuring the sensor's responsiveness aligns effectively with the desired sensitivity for detecting knocks in the door lock system.

### 4.3.4 Push Button Program Test

This experiment of push button is used to program new knock pattern. Its role is pivotal in enabling users to input and configure a unique sequence of knocks for the door lock system. Figure 4.28 shows the example of serial monitor when new knock pattern is applied to the system. A genuine knock is considered valid when it surpasses the designated threshold. In an example of the test, two knocks are applied. If no additional knocks are registered within a specified time, the system concludes the knock input process and stored.

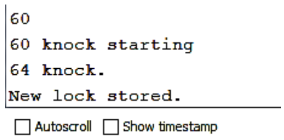



Figure 4.28 Serial monitor when new knock pattern is applied

Table 4.5 shows the output of the system when the push button is pressed. The system initially employs a default pattern defined in the code. To program a new pattern, users must press and hold the push button while inputting the desired knocks. The system then records this pattern. Subsequently, each time a knock is applied, the sensor references this new pattern for validation.



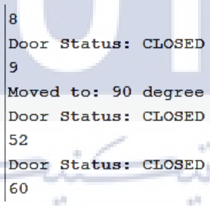
Table 4-5 System output in response to push button pressing

| Push button Program | Knock applied | Piezoelectric sensor | Knock pattern saved | Description |
|---|---|---|---|---|
| Not pressed | - | - | - | - |
| Pressed | No | Not activate | - | The system use default knock value |
| Pressed | Yes | Activated | Yes | Red and green LED blink simultaneously as same as knock applied. The system use new knock pattern |

Thus, by engaging the push button, user can set a personalized pattern that will be recognized by the system, enhancing security and customization features. This functionality allows for the dynamic adaptation of the door lock system to user preferences, providing a versatile and user-friendly interface for programming knock patterns.

### 4.3.5 Push Button Lock Test

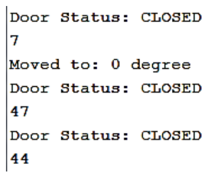
The push button testing differs from the previous push button lock test but shares similarities with the second test in Chapter 4. This particular test concentrates on observing the servo motor's movement triggered by a single push button. The servo motor's output is monitored through the serial monitor, as illustrated in Figures 4.29 and 4.30 below. Upon the initial press of the push button, the servo motor moves from 0 to a 90-degree rotation. As push button pressed again, it rotates in the opposite direction.



```
8
Door Status: CLOSED
9
Moved to: 90 degree
Door Status: CLOSED
52
Door Status: CLOSED
60
```

Figure 4.29 Serial monitor output for first press





```
Door Status: CLOSED
7
Moved to: 0 degree
Door Status: CLOSED
47
Door Status: CLOSED
44
```

Figure 4.30 Serial monitor output for second press

The details of the observation output are presented in Table 4.6 where it consist of push button lock, current condition, movement and new condition of the motor. The servo motor's movement is relies on its previous position which allowing it to determine the subsequent rotation direction.

Table 4-6 Servo motor condition in response to a pressing signal presence

| Push button Lock | Current condition servo motor | Servo Motor movement | New condition servo motor |
|---|---|---|---|
| Not pressed | - | Not move | - |
| Pressed | Lock (0 degree) | Rotate at 90degree clockwise | Unlock |
| Pressed | Unlock (90 degree) | Rotate at 90degree counter clockwise | Lock |

The push button used acts as a momentary switch, registering a signal when pressed and held, and ceasing to receive a signal upon release. The choice of a single push button of final decision in the project aims at conserving space and minimizing component usage. This strategic selection aligns with the goal of optimizing resource utilization. Consequently, through meticulous testing, the motor exhibits seamless movement in accordance with the intended input. The utilization of a single push button not only streamlines the design but also contributes to a more efficient and compact system.

### 4.3.6 Complete Circuit Composition

In this section, the final circuit testing including the combination of all circuits that has been tested before. The complete circuit was installed inside the casing, as illustrated in Figure 4.31 underneath.



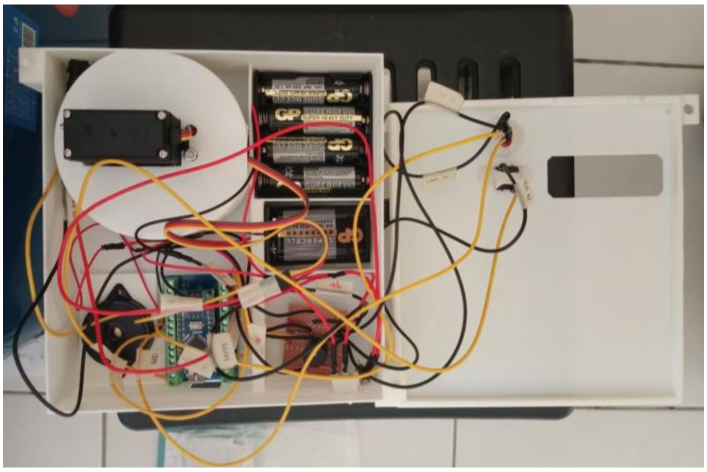


Figure 4.31 Connection of complete circuit

There have several condition obtain when the case of the knock is wrong and true. As in Figure 4.32, the output represent the wrong knocking by user.

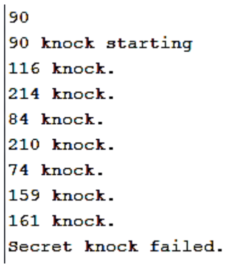

```
90
90 knock starting
116 knock.
214 knock.
84 knock.
210 knock.
74 knock.
159 knock.
161 knock.
Secret knock failed.
```

Figure 4.32 Serial monitor of wrong knock

For authenticating a legitimate knock, the door lock's locking and unlocking procedures are showcased in Figure 4.33 and Figure 4.34. Despite having an identical pattern for both locking and unlocking, the system effectively discerns between these actions. Figure 4.33 displays sensor detection with four sensor values, forming the knock rhythm in four sequences. As the rhythm is valid and the values exceed the threshold, it can be concluded that the door is locked. This corresponds to the servo motor moving from 90 degree to 0 degree.

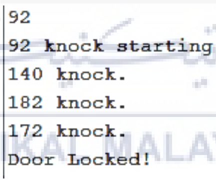

```
92
92 knock starting
140 knock.
182 knock.
172 knock.
Door Locked!
```



Figure 4.33 Serial monitor for locking process

The output validation is similar also in Figure 4.34, but the system considers it as the door being unlocked, as the servo motor moves from 0 degree to 90 degree.

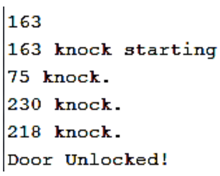

```
163
163 knock starting
75 knock.
230 knock.
218 knock.
Door Unlocked!
```

Figure 4.34 Serial monitor for unlocking process

The door lock system's results are summarized in Table 4.7, showcasing the combined actions of each component, including the buzzer, LED, and servo motor rotation.

Table 4.7 Complete door lock system output

| Knock applied | Knock true/false | Piezoelectric sensor | Buzzer | LED | Servo Motor |
|---|---|---|---|---|---|
| No knock | - | Not detect | Not active | - | - |
| Knock lock | True | Detect | Not active | RED ON for 3s | Rotate 90 degree clockwise |
| | False | Detect | Not active | RED blink for 4 time | - |
| Knock unlock | True | Detect | Active for 3 time | GREEN blink for 5 time | Rotate 90 degree anti-clockwise |
| | False | Detect | Not active | RED blink for 4 time | - |

There are three knock conditions as no applied knock, applied knock for locking, and applied knock for unlocking. When no knock is registered, no detection occurs, leading to no action for the buzzer and servo motor. In the second condition, the sensor detects whether the knocking is correct or incorrect. If it's correct, the servo motor rotates 90 degrees clockwise to lock the door, and the red LED turns on for approximately 3 seconds. In the third condition, when a knock is applied to unlock the door and is verified as correct, the buzzer activates and sounds three times, the green LED blinks five times, and the servo motor rotates 90 degrees counterclockwise. If the applied knock is incorrect and doesn't match the stored reference for both conditions, the LEDs provide feedback to the user, with the red LED blinking four times. This feedback mechanism ensures that users are informed when an unauthorized or incorrect knocking pattern is detected, enhancing the security features of the door lock system. In essence, the combination of sensor detection, LED indicators, and servo motor actions contributes to a comprehensive and responsive door lock system that effectively distinguishes between correct and incorrect knocking patterns.

## 4.4 Analyze the knock performance based on the presence of sound

In this experiment, the system must be install to the door so that the knock pattern can be applied to the door directly and can adjust the threshold value. Since the previous threshold is 55. After installation, the sensor can not read the knock with that threshold. Therefore, the threshold is changed as lowest as 10. Based on the observation, the sensor can detect the knock based on the surface material or door material and width. This characteristic in this experiment is ignored. So try and error the thresholding value to get the suitable value for basic knock applied by human.

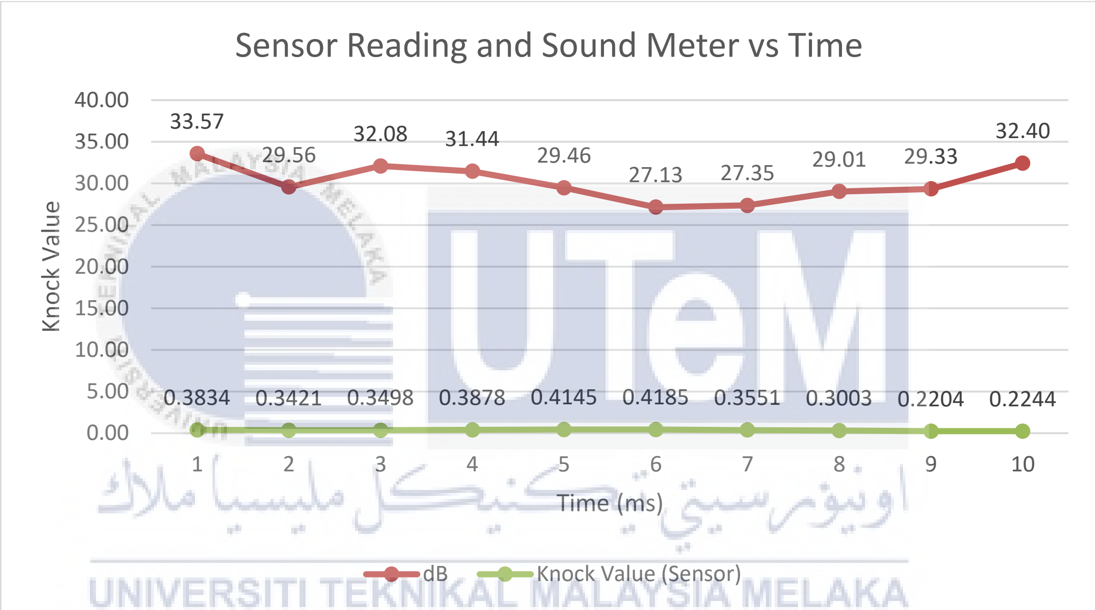



Figure 4.35 Graph of knock value from sensor reading and Sound Meter at initial state

Graph in Figure 4.35 illustered the initial state of knock value based on Sound Meter apps and sensor reading from serial monitor. The time taken is in milliseconds and takes samples of 10ms only. At the state where there has no knock apply to the door, the serial monitor mostly display average constant value 0. The average value of Sound Meter is around 30dB. Since the application used is Sound Meter that installed in smartphone, it is also detect the sound around it. In order to get the actual knock applied to the door, the measured value must be minus with 30dB.

This section contains two part by applying slow knock and hard knock to the door in order to determine the corresponding value in dB. In this experiment, the rhythms of knock used is in default setting, so the amount of knock is 5 knock to be detected. The table and graph depict the knock value measurements obtained using a piezoelectric sensor and a Sound Meter application. From the Table 4-7 below, it is observed that the sensor readings are consistent across all three tests, resulting in an average knock value of 12 for each test number. In contrast, the Sound Meter measurements vary slightly but show an increasing trend from Test 1 to Test 3.

Table 4-7 Knock value measurement using piezoelectric sensor and Sound Meter for default knock pattern

| No. | Sensor Readings | | | | Sound Meter Measurement (dB) | | | |
|---|---|---|---|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | Average | Test 1 | Test 2 | Test 3 | Average |
| 1 | 13 | 10 | 13 | 12 | 77.75 | 76.55 | 78.60 | 77.63 |
| 2 | 13 | 16 | 13 | 14 | 64.06 | 80.46 | 77.73 | 74.08 |
| 3 | 14 | 13 | 11 | 13 | 75.64 | 79.64 | 74.98 | 76.75 |
| 4 | 14 | 11 | 10 | 12 | 78.64 | 76.65 | 65.39 | 73.56 |
| 5 | 11 | 11 | 12 | 11 | 66.27 | 74.41 | 76.63 | 72.44 |

All data are illustrated in the form of graph for knock value over amount of knock applied in Figure 4.36, Figure 4.37 and Figure 4.38. The graph in Figure 4.36 illustrates the response between knock value and amount of knock based on default knock pattern for testing 1. The blue line represents data from the piezoelectric sensor, while the red line represents data from the Sound Meter application in decibel (dB). According to the Figure 4.36 below, this knock pattern started with 13 to 11 of numerical value from sensor reading while resulting 77.75 to 66.27dB respectively. Both lines exhibit an increasing trend as the amount of knock increases, indicating a positive correlation between these two variables.

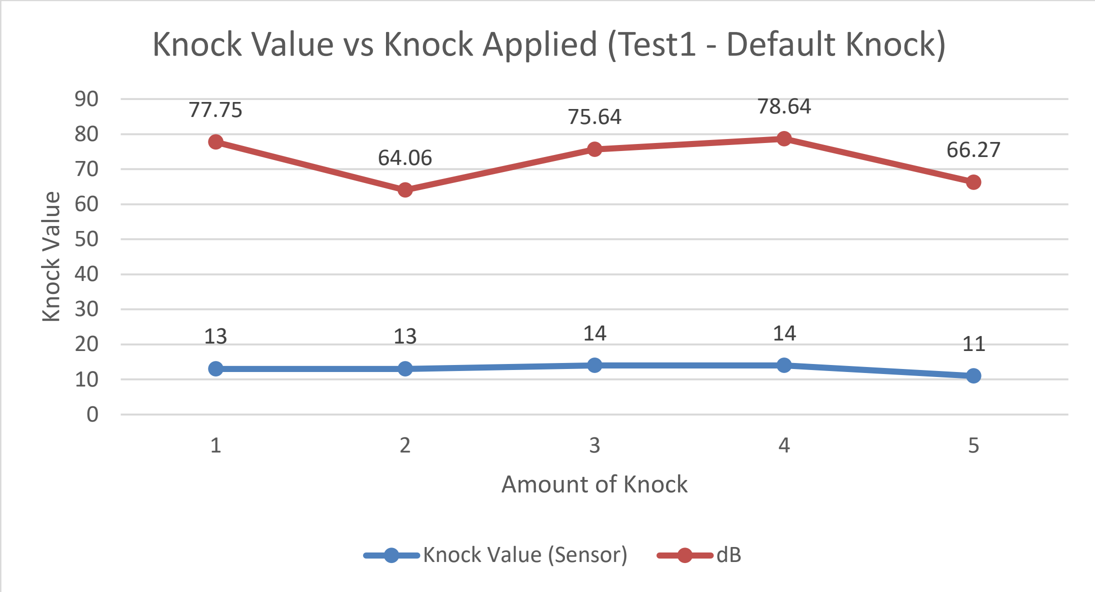



Figure 4.36 Graph of knock value over amount of knock based on default knock pattern for testing 1

Figure 4.37 shows the response between knock value and amount of knock based on default knock pattern for testing 2. The blue line represents the "Knock Value (Sensor)" and it remains relatively constant across different amounts of knock applied, with slight variations. It starts at a value of around 10 for an amount of knock equal to 1, increases slightly to reach its peak value at around 16 for an amount of knock equal to 2, then gradually decreases down to about 11 for an amount of knock equal to 5. On the other hand, the red line represents data in decibels (dB) and shows more significant variations compared to the blue line. It starts at approximately a value of around 76.55 for an amount of knock equal to one, peaks at about 80.46 when the amount of knock is increased to two, then fluctuates before stabilizing around a value close to mid-70s towards higher amounts of knocks.

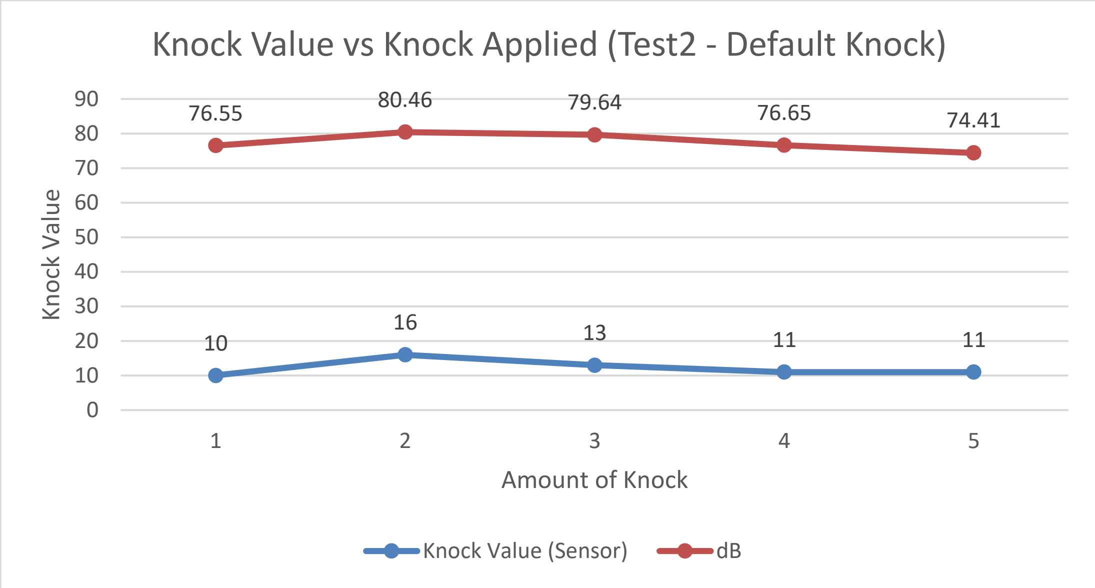



Figure 4.37 Graph of knock value over amount of knock based on default knock pattern for testing 2

The result for testing 3 is shown in Figure 4.38 below. The knock value and dB are not exactly proportional in this testing. For example, at knock amount 2, the knock value is about 77.73dB for 13. But at knock amount 4, the knock value is about 65.39dB for 10. This means that the sensor and the sound meter have different sensitivities or scales for measuring the knock.



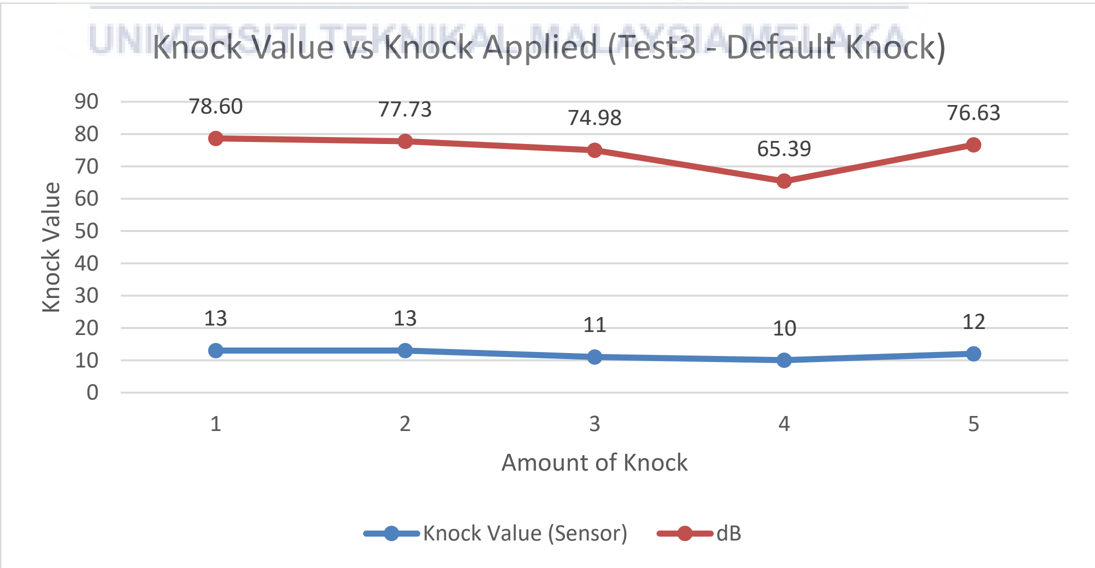



Figure 4.38 Graph of knock value over amount of knock based on default knock pattern for testing 3

The average value of knock from sensor and Sound Meter are obtained and illustrated in Figure 4.39. Analyzing the sensor readings, it is evident that the predominant knock count is 12, accompanied by a corresponding sound level ranging from 73.56 to 77.63. This slower knocks, the sensor registers a maximum value of 14.

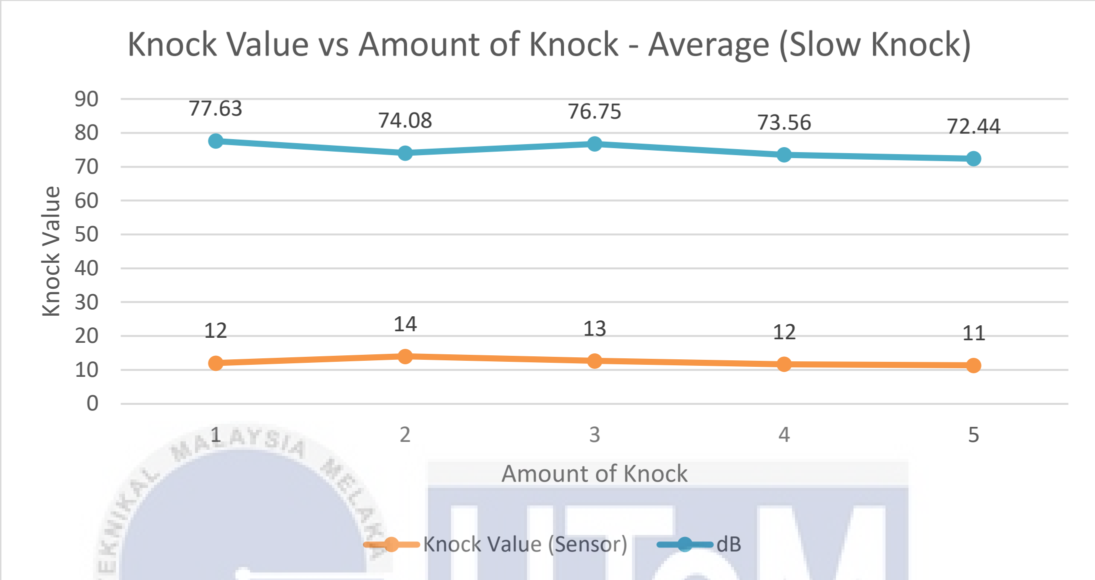



Figure 4.39 Graph of knock value over amount of knock based on default knock pattern for average value



Based on the results obtained when slow knock is applied, the piezoelectric sensor is capable of detecting knocks and providing values within the range of 10 to 16, although occurrences of 16 are infrequent. An inconsistency is noted, where the knock sensor does not consistently align with the sound level, for instance, the numerical value of 14 corresponds to a sound level of 74.08 dB, which is less than the 76.75 dB recorded for 13. This discrepancy may be attributed to factors such as ambient noise and variations in sensitivity.

Next experiment is by applying hard knock to the door in order to get the highest knock value. The knock pattern used also the same as previous which using default program, the difference is only the forces of applied knocks. From Table 4-8 below, there has three test for each sensor reading and sound meter measurement. Throughout the three tests, sensor readings were resulting a major knock value of 18.

Table 4-8 Knock value measurement using piezoelectric sensor and Sound Meter by applying hard knock

| No. | Sensor Readings | | | | Sound Meter Measurement (dB) | | | |
|---|---|---|---|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | Average | Test 1 | Test 2 | Test 3 | Average |
| 1 | 18 | 43 | 19 | 27 | 80.03 | 90.25 | 90.31 | 86.86 |
| 2 | 20 | 14 | 10 | 15 | 89.10 | 65.95 | 64.64 | 73.23 |
| 3 | 17 | 20 | 16 | 18 | 88.94 | 89.03 | 88.89 | 88.95 |
| 4 | 10 | 15 | 15 | 13 | 69.44 | 71.74 | 88.86 | 76.68 |
| 5 | 22 | 19 | 13 | 18 | 89.16 | 83.64 | 73.99 | 82.26 |

The data by giving the hard knocks from table above are presented through graphs depicting the knock value against the quantity of knocks administered, showcased in Figure 4.40 for testing 1, Figure 4.41 for testing 2, and Figure 4.42 for testing 3. According to the Figure 4.40 below, the knock pattern initiates with numerical values ranging from 10 to 22 in sensor readings, corresponding to sound levels of 60.44 to 89.16 dB respectively.

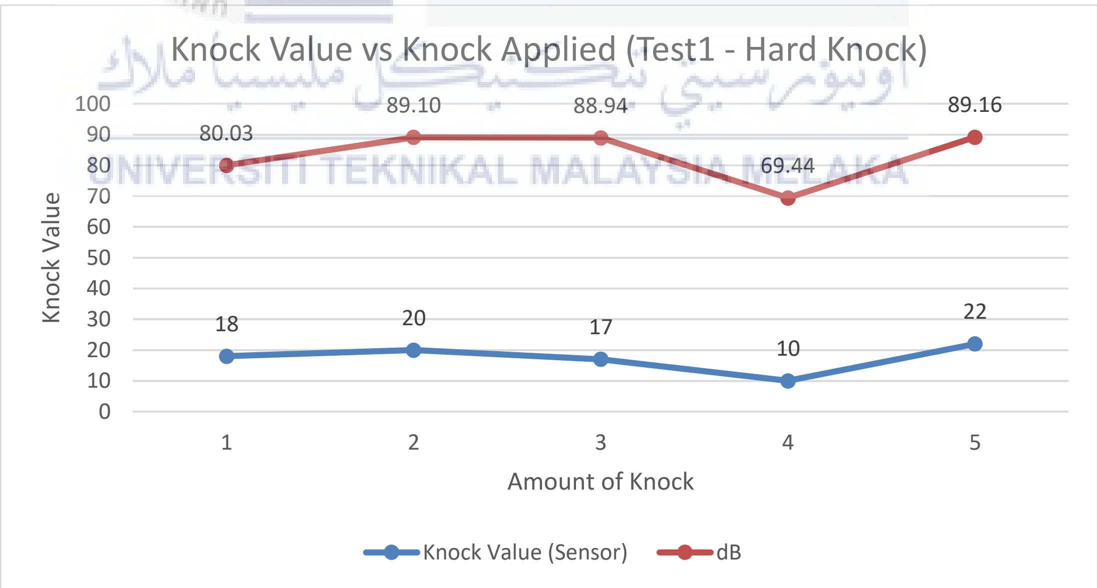



Figure 4.40 Graph of knock value over amount of hard knock for testing 1

For testing 2, the Figure 4.41 below shows response between knock value and amount of knock based on default knock pattern. The knock value is represented by a blue line on the graph, and it ranges from 43 until 19 at the fifth knock. The decibels of noise increase as more hard knocks are applied. This indicates the knocks produce more sound as they become harder. The decibels are represented by a red line on the graph, and range from 90.25 to 83.64dB. The highest value is 90.25dB while the lowest value is 65.95dB for this testing 2.

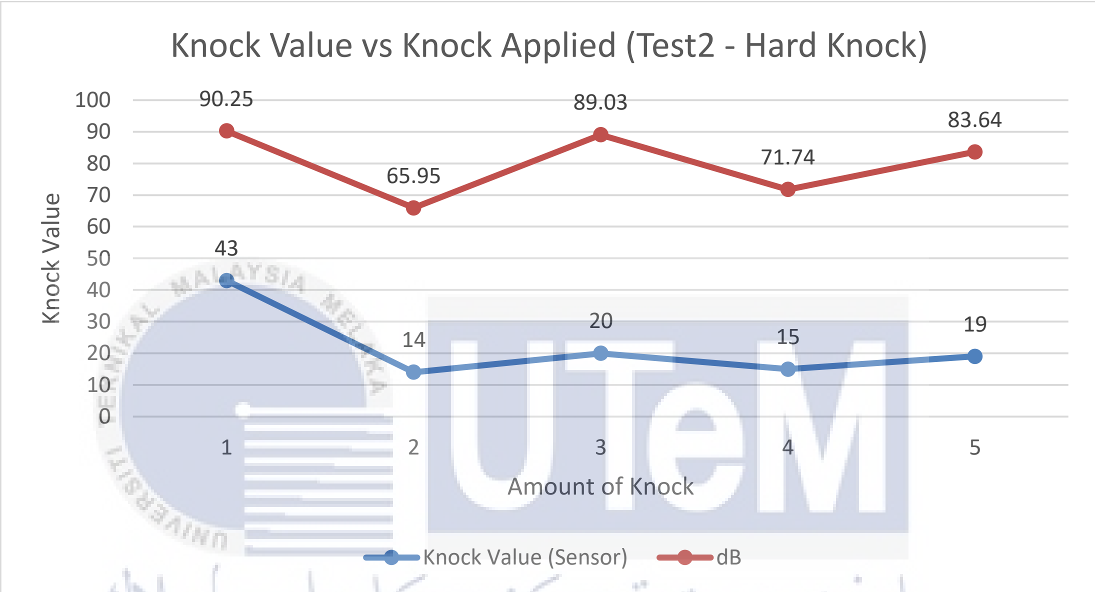



Figure 4.41 Graph of knock value over amount of hard knock for testing 2



The results from the third testing iteration are graphically presented in Figure 4.42 below. The correlation between knock value and decibels (dB) in this test is directly proportional, although there is a slight variance between the two variables. From the first knock to the fifth knock, the values from the sensor range from 19 to 13, corresponding to decibel levels of 90.31 to 73.99 dB respectively. This alignment in the trend demonstrates a consistent and proportional relationship between the knock values obtained from the sensor and the accompanying decibel levels.

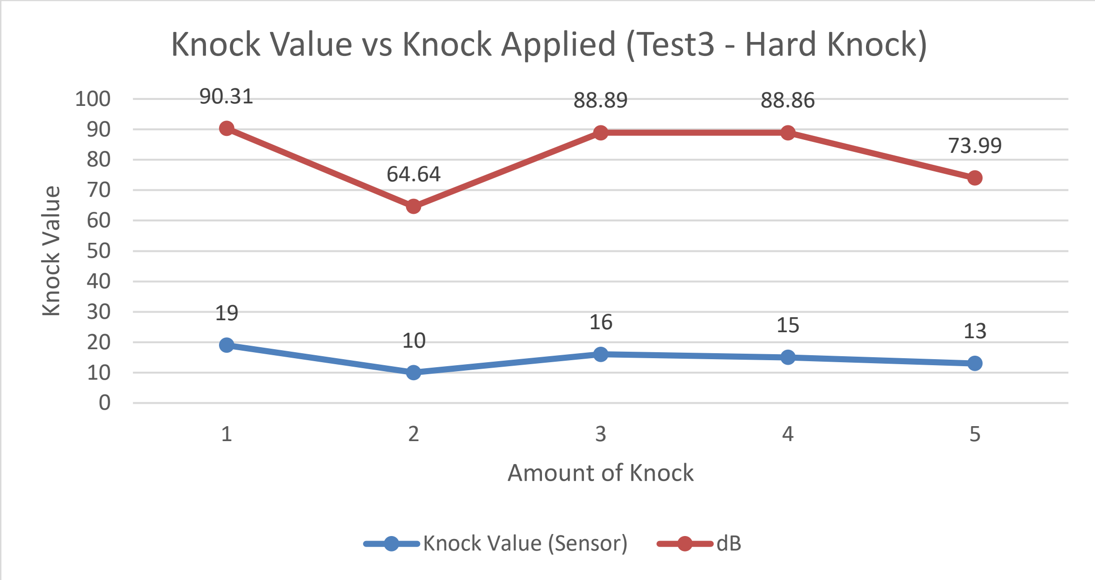



Figure 4.42 Graph of knock value over amount of hard knock for testing 3

The average knock values derived from both the sensor and Sound Meter are depicted in Figure 4.43. Upon the sensor readings, the knock value start at 27 up to 18, aligning with sound levels ranging from 86.86 to 82.26. During harder knocks, the sensor records a peak value of 27.



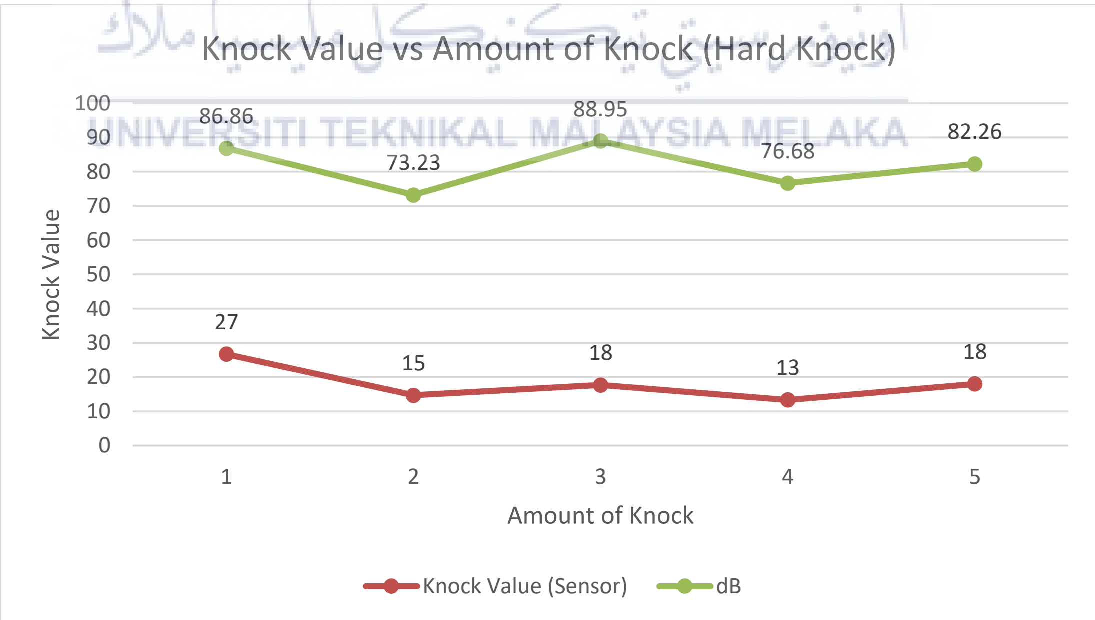



Figure 4.43 Graph of knock value over amount of knock based on hard knock in average value

According to the observation from harder knock applied, piezoelectric sensor is capable of detecting knocks and providing values within the range of 10 to 43, although occurrences of 43 are infrequent. The average knock detected is 18. Similar to the earlier sections, discrepancies between the sensor readings and sound level measurements may exist, suggesting potential errors. For instance, a numerical value of 27 corresponds to a sound level of 86.86 dB, which is less than the 88.95 dB recorded for 18. This discrepancy may be attributed to factors such as ambient noise and sensitivity, device position and control. After conducting both slow and hard knocks on the door, the summarized findings are presented in Table 4-9, detailing the minimum and maximum values from the overall observation.

Table 4-9 Maximum and Minimum of knock value for sensor reading and sound meter measurement based on applied knock

| Knock Value | Sensor Readings | Sound Meter Measurement (dB) | Actual Sound Meter Measurement (dB) |
|---|---|---|---|
| Initial | 0 | 30 | 0 |
| Minimum | 10 | 64.64 | ≈35 |
| Maximum | 43 | 90.25 | ≈60 |



The sound meter readings on the door should ideally register as 0 dB when there are no knocks, signifying the absence of any sound level due to no vibrations. Therefore, in this experiment, the minimum detectable knock produces a reading of around 35 dB, while the maximum is approximately 60 dB. The minimum knock value that can be detected depends on the threshold set in code.

The difference in knock values when subjected to slow or hard knocks yields minimal changes. There is not much variation, but the values remain consistently high. This may be attributed to the device used, as it is an application installed on a phone. The device is highly sensitive to ambient sounds in its surroundings. In contrast, the door system is sensitive primarily to vibrations or forces applied to it.

Relationship between variables sensor reading and decibel, the graphs show a positive correlation between the decibels and the amount of knock, meaning that as one increases, the other also increases. The graph does not show a clear relationship between the knock value and the decibels, as they do not move in the same direction or at the same rate. The variable selected to sample the knocks is the amount of knock, representing the number of knocks the sensor can detect based on the provided threshold value.

## 4.5 Summary

This chapter discusses the findings of an experiment that aims to achieve the objectives of the project as to design and develop a prototype of an efficient door lock system based on knocking rhythms, obtain the responses of vibration sensor activated by a knock sequence, and analyzed the relationship between sensor readings and sound level measurement. Design the prototype of the system was produced by considering factors such as casing placement, the mechanism for turning the lock, and determining the appropriate size for the casing. This is also achieved by conducting some testing for each hardware components like push button, servo motor and sensor to ensure their functionality before proceeding to the primary objectives. The responses as well as the performance of the piezoelectric sensor toward the knocking rhythms are evaluated. Lastly, as using the default codes of knock, an analysis is performed to establish the knock performance with considering the relationship between the knock value in decimal and corresponding decibel values. This helps determine the sensor's ability to detect the strength of the applied knocking.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

In conclusion, the first objective is to design and develop a prototype of efficient smart door based on knocking rhythms. The designed system successfully integrates various components, including a piezoelectric sensor, Arduino Nano, servo motor, push button and other hardware elements. The meticulous design of the casing, cover, and gripper ensures secure accommodation of essential components. The design emphasizes space-saving and efficient component usage.

The second objective is to obtain the responses of vibration sensor activated by a knock sequence. Extensive testing has been conducted to obtain responses from the piezoelectric sensor, which is activated by a sequence of rhythmic knocks. The system effectively captures and interprets knocking patterns, demonstrating its ability to recognize and authenticate knocks. The system's ability to detect and recognize knocking patterns through extensive testing validates its functionality. The servo motor effectively responds to authenticated knocks and demonstrating the door locking and unlocking process. The integration of a push button for programming new knock patterns adds flexibility to the system.

Lastly, the third objective which is to analyze the performance of knock based on the presence of sound which obtained between sensor readings and sound level measurement has been achieved in this project. The project has explored the relationship between sensor readings from piezoelectric sensor and manual sound level measurements using a Sound Meter. The system's response to both slow and hard knocks gives a comprehensive understanding of its performance.

The findings indicate that, despite some variations, there is a positive correlation between the sensor's knock value and the corresponding sound level, with the system displaying sensitivity to both slow and hard knocks. Thus, the developed smart door system exhibits reliability and responsiveness that meet the objectives of the design and development process.

## 5.2 Future Works and Recommendations

For future improvements, to make the Smart Door Lock Using Rhythmic Knocks to reach goals and be more accurate and precise by focusing on analysis of force or vibration sensor according to the knocks applied. It will consider the suitable forces that should be implemented using hand knocks and prevent being knocks from using others object. In addition, the sensitivity of sensors will be explored according to the distance between knock applied to the sensor location. Since this project only provide one set of program for both lock and unlock door, it is recommended to have the implementation of double registered pattern will be analyze for the use of unlock pattern and the lock pattern separately. The performance of door lock mechanism might be enhanced by providing an appropriate localization of actuator on the door lock. Next, the precision of sound level analysis can be enhanced by employing suitable devices and device positioning to accurately capture the actual sound level resulting from the applied knocks. Lastly, the use of mobile application for security purpose to accompany the smart door lock system might be conduct as real-time notification with remote control capabilities to accurately identify and differentiate between different knock patterns, increasing its reliability and reducing false positives.

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## APPENDICES

### APPENDIX A LIST OF PAST RESEARCH ARTICELS

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 1 | 2019 | Unlock A Device with Pressure and Rhythm Based Password | Keystroke dynamics | Traditional and keystroke dynamins will increase the security level of unlocking system | Not most reliable identification method alone | - | The highest value between the values is the actual value of the stroke. |
| 2 | 2019 | Arduino based safeguarding system by using sound | Using knock pattern | Extensible software, and hardware simple<br><br>Programming environment cross platform and inexpensive characteristics | - | - | Motor runs if knock sequence matches the knock sequence<br><br>Infrared sensor detects any obstacle, the LED glows<br><br>If one bit false from given knock bit sequence, the door not be opened |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 3 | 2022 | HandKey: Knocking-triggered Robust Vibration Signature for Keyless Unlocking | User-specific vibration signatures<br><br>The uniqueness of vibration signatures to represent corresponding user identities | - | - | Scattered<br><br>Owning a large size<br><br>Conjunctive mechanism needs careful consideration. | Incorrectly verifies the identity of users at a low ratio.<br><br>Door materials almost don't affect unlocking performance |
| 4 | 2020 | Knock-Knock Door Lock: Unlocking your door with a secret knock sequence | Simple TDOA knock localization | Easier method than TDOA with geometrical constraints<br><br>Increases security significantly | Much less accurate | Only measured which sensor was activated first, a significant amount of information was left out. | Correctly identified in 34/35 cases<br><br>Rhythm detection software analyzed door vibrations continuously over time |
| 5 | 2021 | IOT Based Digital Door Lock | Authenticate their fingerprint through the mobile application<br><br>Tapping the door with the pre-recorded pattern, changed as per user's satisfaction | More versatile with increased security<br><br>Ease, lead upper class lifestyle<br><br>Life much simpler, finer, accessible and more steady | - | - | Enter secured pin, then only the user will direct to lock interface<br><br>User click the unlock button, door unlocked |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 6 | 2022 | Knock sensing and imaging from structural bending waves | Piezo sensor array is used | - | Higher frequency signals<br><br>Increase the sidelobe level in the back ground area<br><br>Difficult to identify the knock position. | - | Performance of reconstructed image was evaluated considering beam peak, beamwidth, and sidelobe level. |
| 7 | 2014 | Perancangan Pintu Otomatis Menggunakan Pola Ketukan Berbasis Arduino | Push button used for new knock recording<br><br>Knocking is made for opening the door which depends on the numbers of knocks, duration and vibration sensitivities | - | - | Depends on knocks time and knocks number | Difference result which it is not the same rythmics with initial value, therefore the knocks is unreadable |
| 8 | 2019 | Perancangan Sistem Pintu Pintar Untuk Tuna Netra Dengan Knock Pattern | Comparison made between recorded knocks and present knocks, include duration, number of knocks and the knock force level, using fingerprint sensor | - | - | The fingerprint sensor only can record up to 100 fingerprint | Knocking slow for amplitude 10, knocking hard for amplitude is 20<br><br>Slow knock for 3-100 threshold, hard knock for 101-1023 threshold |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 9 | 2016 | Pintu Morse: Kode Ketukan Pada Pintu Berbasis Mikrokontroler Sebagai Sistem Penguncian, Bel Pintu, Dan Notifikasi Melalui Pesan Singkat | Using knock pattern to open and close door lock,<br><br>Produce bell ring and send short notification presence of guests | - | - | - | If knocking is true then the lock is open<br><br>If false, GSM module send notification to the owner |
| 10 | 2015 | Rancangan Bangun Sistem Pengunci Pintu Otomatis Menggunakan Pendeteksi Getaran Ketukan | Using code beats | - | - | - | System related to the number of beats and value of time interval or distance between every beats and stored in array<br><br>When the rhythm / rhythm beats in accordance with the previously saved, the system locking / opening the door will be active |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 11 | 2022 | Security Door System Using Knock Sensor Based On Arduino Uno | Using piezoelectric to detect knocks<br><br>Measure of the time between knocks | - | - | - | - |
| 12 | 2018 | Security System Based on Knock Pattern Using Ardino and GSM Communication | Based on LabVIEW using wireless sensor network system. | - | - | Knocking pattern to be implemented only at certain place for lock to open and known only to owner<br><br>Only way to change the secret pattern is by unlocking it first through the secret knock | Maximum interval is 10 interval means that there is 11 knocks in the maximum |
| 13 | 2021 | Sistem Keamanan Rumah Berbasis Knocksensor & Fingerprint | Open the door using knock sensor and also fingerprint sensor<br><br>Compare beats saved with a recent tap tapped | - | Delay on realtime data | Fingerprint only installed infront of door while when user want to go out from house, must use a push button | Knock is readable if tolerance value is not more or less than 15ms and vice versa |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 14 | 2021 | Smart Knock Detecting Door Lock Using Arduino | Installed on the door and will detect any discrepancy or unknown pattern if recorded. | Reasonable cost<br><br>Enhanced security<br><br>Small size | - | - | Efficiency for detecting the knock has been increased |
| 15 | 2021 | Knock based Security Console with Fingerprint Sensor | Built with 2 vibration sensors placed at particular distances | Knock pattern and fingerprint sensor most secured, low cost, user friendly locking system | - | - | If the received fingerprint impression matches with the corresponding id present in the IDE, then the LCD prompts 'Welcome' and also the Arduino Nano commands the servo to rotate to its adjacent 90 degrees from its initial position, thus, opening the door |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 16 | 2021 | Sound Based Door Locking System Using Arduino | Piezo sensor on consumer knocks is used<br><br>The narrowband Time Division Multiple Access (TDMA) strategy is used by GSM to relay signals. | - | - | - | Determines the order in which the unlock areas are knocked on after identifying the unlock areas.<br><br>GSM, which sends a text message warning to an authorized user in the event of an assault. |
| 17 | 2018 | Acoustic Smart Sensor Based Integrated System for Smart Homes | Detect one or multiple knocks on a wall, with resource to environmental information gathering, and share the information with a central gateway, which can be a smartphone, a microprocessor or a laptop, as long as it has Bluetooth connectivity | Ability to control any integrated part of an automated home | - | - | The use of only one of this two sensors is not viable because in a room loud noises or accidental touches on the wall could trigger the system<br><br>Values of the registers varied from 0 to 1023. Until the value of 200, it is programmed by software for nothing to happen |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 18 | 2021 | Design and Construction of Additional Security Device for House Door Using Arduino Uno Based on Short Message Service | Data Analysis Method<br><br>Assembling or assembling the components needs to be analyzed whether it is in accordance with the initial description of the tools and programs used | - | - | - | When aperture sensor detects door open, buzzer sound. The buzzer off when GSM receives certain SMS, send notification that someone is trying to enter.<br><br>Door open, vibration sensor not work. |
| 19 | 2019 | Door Surveillance with Smart Bell | Capturing images of unknown peoples taking videos announcing their names after they scan their fingers through scanner<br><br>Fingerprint help the user to identify the person is known to him or the person is not known | - | - | - | If fingerprint match, raspberry pie announce message through speaker stored in the database beside visitor's name<br><br>Notification send to user's mobile application. If user discards notification within one minute, nothing happen or image of that visitor will be send to user. |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 20 | 2021 | Intelligent Door Knocking Security System Using IOT | Method of 'lock and key'<br><br>Door lock is controlled by IOT and Bylynk app. | If any intruder trying to enter with wrong thumping, then alert will be sent to the client through their mobile phone. | If the door broken then no signal will be transmitted to the client. The client not aware of this incident | - | If data was an authenticated data, then flag will be set to open the door.<br><br>Door status continuously monitored by client. If unauthenticated person try open the door, alert given to client mobile |
| 21 | 2022 | Design of Intelligent Low power Micro Vibration Gating System | Uses the knock frequency as the password, uses the vibration sensor to detect the number and time interval of user's knock and open the door if the password is correct | High security<br><br>Easy operation | - | - | 9 different passwords are set for testing to verify accuracy<br><br>Error warning when it is set to 0s. If the time limit is exceeded, the door cannot be opened. |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 22 | 2019 | Intelligent Lock Applied for Smart Door | Intelligent lock system<br><br>Using piezo and fingerprint sensor with bluetooth module | Can access house with special knock<br><br>Can open door using fingerprint and bluetooth if forget the knocks pattern<br><br>Easy to update new features | | | Open door if knock true, stay closed if false<br><br>Unlock/lock by press of icon<br><br>Receive notification |
| 23 | 2022 | Knock pattern based door lock with Amazon Alexa on Rasberry Pi | Using custom Alexa Skill<br><br>AWS IoT Core (main MQTT server) | a low-cost smart door lock solution | - | - | User knock within 10 seconds. If started, the knock pattern is being recorded until two-second delay is encountered after the last knock.<br><br>New knock pattern valid and is set if it recorded more than three knocks |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 24 | 2020 | Sistem Membuka Pintu Dengan Ketukan Bernada Menggunakan Mikrokontrolle r Atmega328 | Knock on it, identification until the verification of each knock pattern is recognized. | - | - | - | Low knock value not detected, minimum no. of knock is 2 while the maximum knock is 21<br><br>Read the number of knock is 21 but must not more than 2s of each knocks and not less than 30ms. |
| 25 | 2021 | Conware: Automated Modeling of Hardware Peripherals | Modeling by first mapping the recordings of observed interactions (raw recordings) into directed graphs (one per peripheral), which are then converted into w-automata. | - | - | Only consider two patterns equal if they identical to ensure not lose any encoded information. | Unlock the door by a knock pattern, a personal identification number (PIN) entered on the IR remote, or by presenting a specific color |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 26 | 2015 | Design and Development of Sound Control Door Lock System | Using electronic component and locally available materials, wire and plastic box for the casing of the electronic circuit | - | - | Can only be used in a light weight door (<25kg)<br><br>Only be applied to swing door<br><br>Degree of opening angle is (0<a<95) | Maximum distance the sound sensor can detect a sound is 7meters, it worked well both in ac and dc voltages, lastly it was not affected by weather or environmental noise |
| 27 | 2021 | Secret Knock Detecting Dor Lock | Detection by Piezo Electric Sensor | Easily satisfied<br><br>User friendly to open the door to every user.<br><br>Cost less and easily understandable to every user without knowledge. | - | - | Inputs of data which stored in the Arduino UNO and the system which reads by authorizing the number of knocks and opens the door lock. |

| No | Year | Title | Methodology | Advantages | Disadvantages | Limitation | Result |
|---|---|---|---|---|---|---|---|
| 28 | 2017 | Door Lock System via Web Application | Using a web application combine with conventional door lock system | - | - | - | User identification, door status checking, lock or unlock, user adding and right management, send passcode to temporary user via email, transaction recording functions are 100% work properly |
| 29 | 2021 | "Branket" Design as a Safe Deposit Box Security System using Arduino Based Tap Sensor | Determine the shortcomings that exist both from the needs of components and the working system of the components | - | - | - | If the tap pattern is wrong, it will be marked with a red LED light flash. if the tap pattern is correct, it will be marked with a green/yellow LED light that lights up and simultaneously the solenoid will open |

## APPENDIX B GANTT CHART OF FINAL YEAR PROJECT 1

| Description | Week | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| FYP1 briefing | | | | | | | | | | | | | | |
| Title selection | | | | | | | | | | | | | | |
| Meeting with SV | | | | | | | | | | | | | | |
| Title registration and declaration form submission | | | | | | | | | | | | | | |
| Search for related journals | | | | | | | | | | | | | | |
| Background project, motivation, problem statement, objective, and scope | | | | | | | | | | | | | | |
| Literature Review | | | | | | | | | | | | | | |
| Methodology | | | | | | | | | | | | | | |
| Design | | | | | | | | | | | | | | |
| Prototype testing | | | | | | | | | | | | | | |
| Submission of Draft Report | | | | | | | | | | | | | | |
| Attend Seminar for FYP1 | | | | | | | | | | | | | | |
| Finalize Progress Report | | | | | | | | | | | | | | |
| Submission of Progress Report | | | | | | | | | | | | | | |

## APPENDIX C GANTT CHART OF FINAL YEAR PROJECT 2

| Description | Week | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Buy Hardware | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| Hardware testing | | | | ■ | ■ | ■ | ■ | ■ | | | | | | |
| Circuit Design | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| Casing Design | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | |
| Built Complete Circuit and Hardware | | | | | | | ■ | ■ | ■ | ■ | ■ | | | |
| Run Complete Program | | | | | | | | ■ | ■ | ■ | ■ | | | |
| Experimental Work and Data Collection | | | | | | | | ■ | ■ | ■ | ■ | | | |
| Report Writing Progress | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | |
| Submission of Draft Report | | | | | | | | | | | | ■ | | |
| Finalize Progress Report | | | | | | | | | | | | | ■ | |
| Attend Seminar for FYP2 | | | | | | | | | | | | | | ■ |
| Final Report Submission | | | | | | | | | | | | | | ■ |

## APPENDIX D CODING OF FINAL YEAR PROJECT 2

```
#include <Servo.h>

// Pin definitions
const int knockSensor = 0;          // Piezo sensor on pin 0.
const int programSwitch = 2;        // If this is high we program a new code.
const int lockMotor = 3;            // Gear motor used to turn the lock.
const int redLED = 5;               // Status LED
const int greenLED = 4;             // Status LED
const int buzzer = 6;               // Buzzer used for unlock door sound.
const int doorSensor = 7;           // magnetic Switch Sensor to detect door open or
close
Servo knockServo;

#define lockButton 12               // Button for lock and unlock door from inside

// Servo motor
int angle = 0;                      // initial angle for servo
int angleStep = 90;
const int minAngle = 0;
const int maxAngle = 90;

// Tuning constants.
const int threshold = 10;               // Set the Minimum signal from the piezo to
register as a knock
const int rejectValue = 30;             // If an individual knock is off by this
percentage of a knock we don't unlock..
const int averageRejectValue = 20;      // If the average timing of the knocks is off by
this percent we don't unlock.
const int knockFadeTime = 150;          // milliseconds we allow a knock to fade before
we listen for another one. (Debounce timer.)
const int lockTurnTime = 650;           // milliseconds that we run the motor to get it to
go a half turn.

const int maximumKnocks = 10;           // Maximum number of knocks to listen for.
const int knockComplete = 1200;         // Longest time to wait for a knock before we
assume that it's finished.


// Variables.
int secretCode[maximumKnocks] = {100, 100, 100, 100, 0, 0, 0, 0, 0, 0};  // Initial
setup
int knockReadings[maximumKnocks];    // When someone knocks this array fills
with delays between knocks.
int knockSensorValue = 0;                    // Last reading of the knock sensor.
```

```
int lockState = false;
int buttonPushed = 0;
int programButtonPressed = false;    // Flag so we remember the programming button
setting at the end of the cycle.

void setup() {
  pinMode(lockMotor, OUTPUT);
  pinMode(redLED, OUTPUT);
  pinMode(greenLED, OUTPUT);
  pinMode(buzzer, OUTPUT);
  pinMode(programSwitch, INPUT);
  pinMode(lockButton, INPUT_PULLUP);
  pinMode(doorSensor, INPUT_PULLUP);


  knockServo.attach(3);
  knockServo.write(0);
  Serial.begin(9600);                     // Uncomment the Serial.bla lines for debugging.
  Serial.println("Program start.");     // but feel free to comment them out after it's
working right.

  digitalWrite(greenLED, HIGH);    // Green LED on, everything is go.
}

void loop() {
  // Listen for any knock at all.
  knockSensorValue = analogRead(knockSensor);
  Serial.println(knockSensorValue);

  if (digitalRead(programSwitch)== HIGH){      // is the program button pressed?
    programButtonPressed = true;               // Yes, so lets save that state
    digitalWrite(redLED, HIGH);                // and turn on the red light too so we
know we're programming.
  }
  else {
    programButtonPressed = false;
    digitalWrite(redLED, LOW);
  }

  if (knockSensorValue >= threshold){
    listenToSecretKnock();
  }

  //Detection when lock button pressed
  if(digitalRead(lockButton) == LOW){
    buttonPushed = 1;
  }
   if( buttonPushed ){
    // change the angle for next time through the loop:
    angle = angle + angleStep;
```

```
    // reverse the direction of the moving at the ends of the angle:
    if (angle <= minAngle || angle >= maxAngle) {
      angleStep = -angleStep;
      buttonPushed = 0;
    }
    knockServo.write(angle); // move the servo to desired angle
      Serial.print("Moved to: ");
      Serial.print(angle);   // print the angle
      Serial.println(" degree");
    delay(100); // waits for the servo to get there
   }
}

// Records the timing of knocks.
void listenToSecretKnock(){
  Serial.print(knockSensorValue);
  Serial.println(" knock starting");

  int i = 0;
  // First lets reset the listening array.
  for (i=0; i<maximumKnocks; i++){
    knockReadings[i]=0;
  }

  int currentKnockNumber=0;                  // Incrementer for the array.
  int startTime = millis();                  // Reference for when this knock started.
  int now = millis();

  digitalWrite(greenLED, LOW);               // we blink the LED for a bit as a visual
indicator of the knock.
  if (programButtonPressed == true){
     digitalWrite(redLED, LOW);              // and the red one too if we're
programming a new knock.
  }
  delay(knockFadeTime);                      // wait for this peak to fade before we
listen to the next one.
  digitalWrite(greenLED, HIGH);
  if (programButtonPressed == true){
     digitalWrite(redLED, HIGH);
  }
  do {
    //listen for the next knock or wait for it to timeout.
    knockSensorValue = analogRead(knockSensor);

    if (knockSensorValue >= threshold){       //got another knock...
      //record the delay time.
      Serial.print(knockSensorValue);
      Serial.println(" knock.");
      now = millis();
```

```
      knockReadings[currentKnockNumber] = now - startTime;
      currentKnockNumber ++;                  //increment the counter
      startTime = now;

      // and reset our timer for the next knock
      digitalWrite(greenLED, LOW);
      if (programButtonPressed == true){
        digitalWrite(redLED, LOW);          // and the red one too if we're programming
a new knock.
      }
      delay(knockFadeTime);                 // again, a little delay to let the knock decay.
      digitalWrite(greenLED, HIGH);
      if (programButtonPressed == true){
        digitalWrite(redLED, HIGH);
      }
    }

    now = millis();

    //did we timeout or run out of knocks?
  } while ((now - startTime < knockComplete) && (currentKnockNumber <
maximumKnocks));

  //we've got our knock recorded, lets see if it's valid
  if (programButtonPressed == false){                  // only if we're not in
progrmaing mode.
    if (validateKnock() == true && lockState == true){
      triggerDoorUnlock();
      lockState =! lockState;
    }
    else if (validateKnock() == true && lockState == false){
      triggerDoorLock();
      lockState =! lockState;
    }
    else {
      Serial.println("Secret knock failed.");
      digitalWrite(greenLED, LOW);                      // We didn't unlock, so blink the
red LED as visual feedback.
      for (i=0;i<4;i++){
        digitalWrite(redLED, HIGH);
        delay(100);
        digitalWrite(redLED, LOW);
        delay(100);
      }
      digitalWrite(greenLED, HIGH);
    }
  } else { // if we're in programming mode we still validate the lock, we just don't do
anything with the lock
    validateKnock();
    // and we blink the green and red alternately to show that program is complete.
```

```
    Serial.println("New lock stored.");
    digitalWrite(redLED, LOW);
    digitalWrite(greenLED, HIGH);
    for (i=0;i<3;i++){
      delay(100);
      digitalWrite(redLED, HIGH);
      digitalWrite(greenLED, LOW);
      delay(100);
      digitalWrite(redLED, LOW);
      digitalWrite(greenLED, HIGH);
    }
  }
}


// Runs the servo motor to unlock the door.
void triggerDoorUnlock(){
  Serial.println("Door Unlocked!");
  int i = 0;

  tone(buzzer, 10800);      //tone(pin number, frequency, duration)
  delay(100);
  noTone(buzzer);
  delay(100);
  tone(buzzer, 10800);
  delay(100);
  noTone(buzzer);
  delay(100);
  tone(buzzer, 10800);
  delay(100);
  noTone(buzzer);
  delay(100);

  knockServo.write(0);

  // Blink the green LED a few times for more visual feedback.
  for (i=0; i < 5; i++){
      digitalWrite(greenLED, LOW);
      delay(100);
      digitalWrite(greenLED, HIGH);
      delay(100);
  }
}

// Runs the servo motor to lock the door.
void triggerDoorLock(){
  Serial.println("Door Locked!");
  knockServo.write(90);
  digitalWrite(greenLED, LOW);
  digitalWrite(redLED, HIGH);
```

```
  delay(3000); //Wait a bit.
  digitalWrite(greenLED, HIGH);
}

// Sees if our knock matches the secret.
// returns true if it's a good knock, false if it's not.
boolean validateKnock(){
  int i=0;

  // simplest check first: Did we get the right number of knocks?
  int currentKnockCount = 0;
  int secretKnockCount = 0;
  int maxKnockInterval = 0;               // We use this later to normalize the times.

  for (i=0; i<maximumKnocks; i++){
    if (knockReadings[i] > 0){
      currentKnockCount++;
    }
    if (secretCode[i] > 0){                   //todo: precalculate this.
      secretKnockCount++;
    }
    if (knockReadings[i] > maxKnockInterval){   // collect normalization data while
we're looping.
      maxKnockInterval = knockReadings[i];
    }
  }

  // If we're recording a new knock, save the info and get out of here.
  if (programButtonPressed == true){
      for (i=0; i<maximumKnocks; i++){ // normalize the times
        secretCode[i]= map(knockReadings[i],0, maxKnockInterval, 0, 100);
      }
      // And flash the lights in the recorded pattern to let us know it's been
programmed.
      digitalWrite(greenLED, LOW);
      digitalWrite(redLED, LOW);
      delay(1000);
      digitalWrite(greenLED, HIGH);
      digitalWrite(redLED, HIGH);
      delay(50);
      for (i = 0; i < maximumKnocks ; i++){
        digitalWrite(greenLED, LOW);
        digitalWrite(redLED, LOW);
        // only turn it on if there's a delay
        if (secretCode[i] > 0){
          delay( map(secretCode[i],0, 100, 0, maxKnockInterval)); // Expand the time
back out to what it was.  Roughly.
          digitalWrite(greenLED, HIGH);
          digitalWrite(redLED, HIGH);
        }
```

```
        delay(50);
      }
    return false;   // We don't unlock the door when we are recording a new knock.
  }

  if (currentKnockCount != secretKnockCount){
    return false;
  }

  /*  Now we compare the relative intervals of our knocks, not the absolute time
between them.
      (ie: if you do the same pattern slow or fast it should still open the door.)
  */
  int totaltimeDifferences=0;
  int timeDiff=0;
  for (i=0; i<maximumKnocks; i++){ // Normalize the times
    knockReadings[i]= map(knockReadings[i],0, maxKnockInterval, 0, 100);
    timeDiff = abs(knockReadings[i]-secretCode[i]);

    if (timeDiff > rejectValue){ // Individual value too far out of whack
      return false;
    }
    totaltimeDifferences += timeDiff;
  }
  // It can also fail if the whole thing is too inaccurate.
  if (totaltimeDifferences/secretKnockCount>averageRejectValue){
    return false;
  }

  return true;

}
```