Faculty of Electrical Engineering

DEVELOPMENT OF MASS DETECTION MODULE FOR LOW-COST SPORT COURT SYSTEM APPLICATION

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DEVELOPMENT OF MASS DETECTION MODULE FOR LOW-COST SPORT COURT APPLICATION

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DECLARATION

I declare that this report entitled "Development of Mass Detection Module for Low-Cost Sport Court System Application" is the results of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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I hereby declare that I have read through this report entitled "Development of Mass Detection Module for Low-Cost Sport Court System Application" and in my opinion this report is sufficient in terms of scope and quality as a partial fulfilment of Bachelor of Electrical Engineering (Control, Instrumentation & Automation).

Signature	:	....
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Date	:	....

ABSTRACT

The purpose of this project is to implement a mass detection module which is a detection sensor module underneath a sports court floor. The existing sports electronic officiating system (or line-calling technology) have flaws which required human supervision and are not fully accurate due to certain influencing factors. Therefore, the concept of a sports officiating system is applied into the sensor module which aimed to detect the impact of a ball on the boundary line of a sports court floor. The sensor module is based on the conductive silicone rubber keypad, where it serves to determine whether the detected impact lands inside or outside of a boundary line. In addition, a printed circuit board (PCB) containing the design of keypad switches is made to allow the keypad to rest on top of it. A software algorithm is created, as to be integrated with the hardware, where microcontroller such as Arduino Mega 2560 is used. Once there is a presence of detection due to impact on the boundary line of the sport court, the result is shown by the system as ‘1’ (one), whereas ‘0’ (zero) if no impact is detected. Next, a liquid crystal display (LCD) is used to display the output position of the detected impact, as ‘IN!’ or ‘OUT!’.

ABSTRAK

Tujuan projek ini adalah untuk melaksanakan modul pengesanan jisim yang merupakan modul pengesanan di bawah lantai gelanggang sukan. Sistem perasmian elektronik (atau teknologi panggilan barisan) mempunyai kelemahan iaitu memerlukan pengawasan manusia ataupun ketepatan yang tidak sepenuhnya disebabkan oleh faktor-faktor tertentu. Oleh itu, konsep sistem perasmian sukan tersebut telah diaplikasikan ke dalam modul pengesanan yang bertujuan mengesan impak bola di atas garisan sempadan lantai gelanggang sukan. Modul pengesanan ini adalah berdasarkan pada pad kekunci getah silicon konduktif, di mana ia menentukan sama ada pengesanan tersebut dikesan di dalam ataupun di luar garisan sempadan pada gelanggang tenis tersebut. Di samping itu, papan litar bercetak (PCB) yang mengandungi reka bentuk suis papan kekunci telah direka untuk membolehkan papan kekunci untuk berehat di atasnya. Satu algoritma perisian juga telah diwujudkan, untuk mengintegrasikannya dengan perkakasan, di mana pengawal mikro seperti Arduino Mega 2560 digunakan. Apabila terdapat kehadiran pengesanan yang disebabkan oleh impak yang terjadi ke atas garis sempadan gelanggang sukan, hasilnya ditunjukkan oleh sistem sebagai '1' (satu), manakala '0' (sifar) jika tiada pengesanan dikesan. Seterusnya, paparan kristal cecair (LCD) juga digunakan untuk memaparkan keputusan kedudukan pengesanan yang dikesan, sebagai ‘IN!’ atau ‘OUT!’.

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CHAPTER 1

INTRODUCTION

This chapter is intended to provide a rationale for the research by highlighting the importance, depth, content, structure and complexity of the research. This chapter includes research background, motivation, problem statement, objectives and scope and limitations.

1.1 Research Background

The term “Sport” originated from desport, an ancient French word meaning relaxation, which denotes “anything humans find amusing or entertaining” with the old definition in English from around 1300 [1]. The characterization of sports accordingly to the International Sports Federations, SportAccord, is “a sport should have an element of competition, be in no way harmful to any living creature, not rely on equipment provided by a single supplier and no rely on any luck element specifically designed into the sports”. The sports within SportAccord can be known as “primarily physical, primarily mind, primarily motorized, primarily co-ordination, or primarily animal-supported” [2].

Generally, a sports court is also known as a multi-sport game court, typically constructed outdoors and indoors [3]. The sports court concept was popularized by Sport Court, a listed brand of Connor Sport Court International. It is served to recognize the genuine segmental sports surfaces developed and continuously upgraded since they were founded in 1974. The courtyard game court idea was then introduced, bringing families and children to gather for healthy and safe recreational place. Sport Court’s main highlight was the courtyard game court, where a diversity of outdoor sports and recreational games can be played. For example, basketball, volleyball, badminton, tennis, shuffleboard, and roller hockey [4].

Every sport has sporting event that requires a sports referee. A sports referee is a person of jurisdiction, who is accountable for presiding over competitive sporting events from a neutral point of view to help maintain the standards of play [5]. The key duty of sports referees is to make instant decisions and ensure that a match is conducted accordingly to the rules and regulations of the competition. If there were to be violations, a sports referee will signal the participants and other officials to regulate the play [6]. Besides referee, there are other titles, including umpire, touch judge, linesman, sports official or technical official depending on the sport itself [5].

In certain sports, such as tennis, basketball and football, uses ball which has masses as a part of the equipment of the sport. In physics, mass is a property of a physical body and the quantity of matter an object has. Accordingly, to Newton’s Second Law of Motion, it is the measure of resistance to a change in its state of motion when a force is applied [7]. Meanwhile, detection meant the act of detecting [8], where the word detects means discover or investigate the presence or existence of something [9]. In addition, each of a set of standardized portions or independent component that can be used to construct a more composite structure are known as a module. In terms of software, a module is a fragment of a program that contains one or several procedures while a module is a self-contained component based on hardware terms [10]. Besides, a device that detect and measure any physical property and then records or respond to it is called a sensor. The quantity to be measured is then converted from analogue signal into a digital signal, where the data can be read, displayed or stored in a way that a computer could understand [11].

In this project, a mass detection module would be developed which act as a detection sensor underneath the boundary line of a sport court floor. The module will be made up of custom designed sensory module.

1.2 Motivation

The world of sport is constantly evolving over the years, and the use of technology has caused an influence on many sports. One of the downsides of the use of technology is that it can hold up the flow of the game, while in contrast, making it a more pleasurable view for the spectators to see the precise decisions being made. Most sports have previously utilized immediate replay and other high technology assistances to aid referees make the correct decision.

Since the early 1970s, technology of officiating and judging of calls in sports was introduced. The first electronic line judge device for tennis was invented in 1974 while in the 2000s, the use of video camera-based technology called Hawk-Eye has revolutionized the world of sports [12]. The Hawk-Eye system uses cameras to trace the trajectory of a ball and the images collected is then sent to a virtual-reality machine. In tennis, the Hawk-Eye allows players to challenge the umpire's decisions and provides video replays to the audience and commentators [13]. Up until very recently, soccer has always resisted the use of high technology assistance. The video replays applied in soccer could resolve decisions concerning off-sides, whether a ball passes over the goal line, and clarify penalty decisions. This technology has been a great help in assisting the referees.

Most of the sports, mainly cricket, tennis, football, and lately, badminton have embraced the technology of officiating into their games and matches. It became a decision-aid to the officials when sometimes it may be too difficult for the officials to analyze the game due to the limits of human perception.

Even though recent technology was well-accepted by players, fans or officials, the system is imperfect. Thus, this paper is proposed to enhance the officiating system by using sensory modules. This project could be used by all the sport courts throughout the world, mainly indoors.

1.3 Problem Statement

Despite the advantages of the system, rulings by Hawk-Eye has shown that they are only correct about 46% of the time, of the challenges made by the players. The location of the tennis ball has a margin of error of “3.6 mm” as measured by the Hawk-Eye system, which was criticized as too large [13]. Therefore, any technology can be fallible. In the tennis final at Wimbledon 2008, a ball that seemed out was called “in” by “1 mm”, a distance which is smaller than the publicized margin of error [14]. Besides, the installation cost of the high-speed cameras of Hawk-Eye around the court can be very costly and because of that, it is only approved for use at tournament level [15]. Even though several high-speed cameras were used around the court, the detection might not be fully accurate as occlusion might occur in front of the cameras.

Therefore, there is a need for high performance system where the errors can be greatly reduced while increasing the detection accuracy of the system. Furthermore, this economical proposed system is practical to be implemented at any tournament level and beneficial for sport users. In this project, the proposed detection sensor module will be able to solve the arise problem, where only sensors are involved and no cameras will be used. This meant that any occlusions occurred would not affect the accuracy of the system. Moreover, the sensor module is designed at an affordable price for the market, thus can be used in almost any sport courts.

1.4 Objectives

There are a few objectives required to be fulfilled to achieve the relevancy of the project. The objectives of this project are to:

1. Identify the parameters required for the designation of sensor module
2. Design a sensor module with the integration of software algorithm
3. Develop a smart and cost-effective sports court system

1.5 Scope and Limitations

This project addresses the development of sensory modules in the cost-effective sports court system. The scope of this research is discussed.

The sensory modules to be developed will only be laid beneath the boundary line of a sports court floor. The sensor will only detect whether the detected impact is landed inside or outside of the boundary line. Only data such as position of the detected impact which is the impacted ball will be collected into the system.

The proposed system would be introduced only to practical sports court level. The current proposed system will be targeted only for tennis court. The Proteus ISIS Professional software is used to construct circuit design for simulation prior to testing of the project hardware, whereas Autodesk EAGLE is used to construct schematic diagram for the design of PCB layout. A microcontroller known as Arduino Mega 2560 with its programming software, Arduino IDE is used to develop a software algorithm and integrate it with the project hardware. The decision of the ball position will be displayed on the LCD as 'IN!' or 'OUT!'.

CHAPTER 2

LITERATURE REVIEW

This chapter serves to establish theoretical framework to identify the research area based on previous related works to support this research. Previous works are studied in terms of the tennis court, existing sports officiating system, type of detection, type of parameters, type of sensors, and the flow to design sensors.

2.1 Tennis Court

The sports of tennis are played on the surface of a tennis courts, a rectangular flat surface with a low net stretched across the center. Both singles and doubles matches are competed on the same surface. A tennis court can be created with different types of materials of court surfaces, mainly clay courts, grass courts, hard courts, and carpet courts. The playing style of the game is influenced by the surfaces, with each having its own characteristics. A governing body, the International Tennis Federation (ITF) has regulated the dimensions of a tennis court, and is written in the document of 'Rules of Tennis' [16].

The length of the tennis court is 23.77 meters. For double matches, the width of the court is 10.97 meters whereas for the single matches is 8.23 meters. The service line is 6.40 meters from the net. For players to reach overrun balls, extra clear area around the court is needed, which is a total of 18 meters wide and 37 meters long. A net is stretched across the full width of the tennis court, parallel with the baselines, dividing it into two equal ends. The net posts are located 0.91 meters outside of the doubles court and also outside of the singles court on each side, respectively. The height of the net at the posts is 1.07 meters while, in the center is 0.91 meters [17]. Figure 2.1 shows the dimensions of a tennis court.

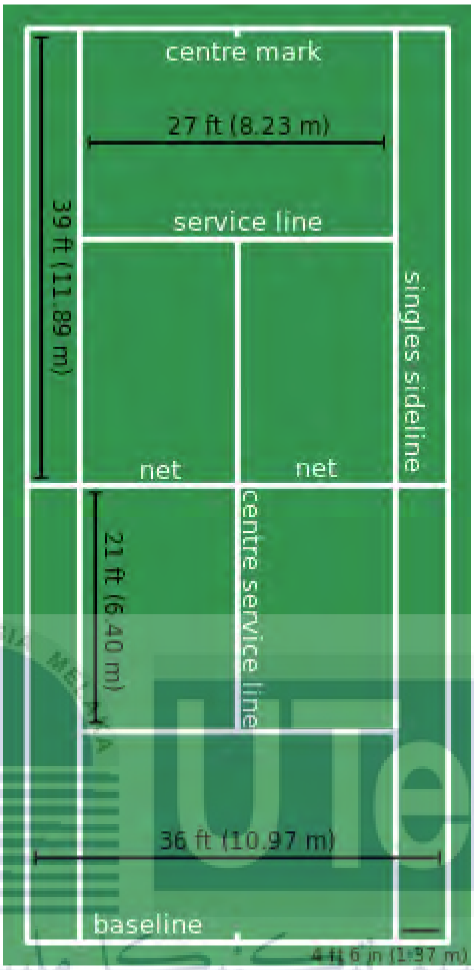

Figure 2.1: Dimensions of a Tennis Court

2.2 Sports Officiating System

Sports officiating system is a system of managing a sport, specifically on implementing the game rules and keeping order in the duration of the game. Primarily, the task of presiding over a sporting events was the role of a sports referee or officials. The existence of sports officiating system or line-calling technology nowadays, had become a decision-aid to the officials.

2.2.1 Electroline (Grant-Nicks System)

In 1974, the first computerized, electronic line judge device called as the Electroline was co-invented by Geoffrey Grant and Robert Nicks. Grant is a researcher and an enthusiastic tennis player, while Nicks is an engineer majoring in electronics. The Grant-Nicks device, Electroline made its public appearance in the tennis championship finals of both the 1974 Men's World Championship Tennis in Dallas and the 1975 Ladies' Virginia Slims tour in Los Angeles. The Electroline system, shown in Figure 2.2 was successfully demonstrated to provide automated "in" and "out" line calls, as to decide whether the ball landed within the boundaries of the playing zone [18].

The pressure-based system was comprised of thin Mylar conductive plastic pressure sensors, underneath a court surface [18], as can be seen in Figure 2.3. Besides, the system was wired to distinguish foot faults using directional microphones together with a timing circuit and automated service net-cord legal serve decisions by using piezoelectric sensor on the net. It is sensitive enough to be able to differentiate between a tennis ball and a player's foot [12]. The system was issued with a United States Patent and Trademark Office (USPTO) patent. However, the invention did not emerge as a commercial product.

Figure 2.2: The Electroline


Figure 2.3: Grant (left) and Nicks (right) with the Mylar sensors

2.2.2 David Lyle System

An electronic officiating system that was initiated in Edinburgh, Scotland, United Kingdom was autonomously developed by David Lyle, at a sponsored tennis match in 1977. The Lyle system was based on a combination of an electrically conductive tennis ball [19], a micro-computer network systems equipment for making and using automatic line-call decisions in tennis [20], along with an impact-detection apparatus for determining the location of a tennis ball, whether it landed in or out of the court surface [21]. Similarly, with Grant-Nicks system, the Lyle system was also never commercialized.

2.2.3 Cyclops

Cyclops is a computer system invented by Bill Carlton, the inventor of plastic shuttlecock used in badminton and an aeronautics engineer. It serves as an electronic line judge on the Association of Tennis Professionals and Women's Tennis Association professional tennis tours. The Cyclops system involves the usage of two boxes bolted into the side-lines of the tennis court surface. The pair of boxes are the transmitter and receiver boxes situated on either side of the net. Moreover, a horizontal array of five or six infrared beams is projected by the transmitter across the court to its counterpart receiver box [22] [23], as shown in Figure 2.4. A control box containing the receiver which is held by the service line umpire, must be triggered before a serve and disabled after each serve. The boxes are configured so that, the good side of the service box line is covered by one infrared beam, while the fault side is covered by the other four infrared beams. Whenever a served ball breaks the first beam positioned beyond the service line, the other four beams are switched off. If the served ball breaks one of the four other beams, a loud audible beep will be heard, indicating the serve was long [22] [23] [24].

The Cyclops computer system was the first electronic officiating system ever commercialized. It was introduced to the Wimbledon Championships in 1980 and has been used ever since. Other major championships such as the U.S Open and Australian Open also adopted the use of Cyclops in their tennis matches. The system has been constantly being enhanced and is more resilient to being activated by bugs flying in front of the beams [23]. Still, Cyclops was detached from Wimbledon's Courts in 2007 [24], to permit the installation of the Hawk-Eye system which was initially presented at the U.S Open in 2006 [25].

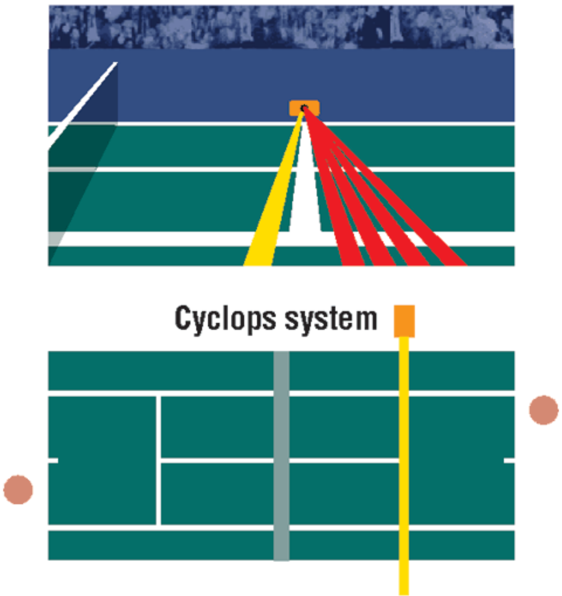

Figure 2.4: The Cyclops system

2.2.4 Hawk-Eye Technology

Hawk-Eye Technology invented by Dr. Paul Hawkins was firstly introduced in cricket, to intensify the TV before being adopted into tennis since 2002. Since then, it has advanced into a device that is now being utilized for officiating in a range of sports, including tennis, soccer, cricket, hurling, baseball, snooker and Australian rules football. A tennis officiating system of Hawk-Eye has received authorization by the International Tennis Federation (ITF) to be the first and only ball tracking technology which passed testing measures [13].

Hawk-Eye is a complex video processing system uniting several cameras and a host computer to accumulate and process the information. It is now widely used in numerous sports to visually track the trajectory of ball and predicting the most likely path of the ball by analyzing the pixels in each frame of each camera feed. Hawk-Eye relies on six to seven computer-linked high-performance video cameras situated around the field-of-play [13]. The video produced by all the separated six cameras are combined to synthesize a 3D representation of the path of the ball using triangulation method [14], which is accurate up to within 5mm. The example of video replay by Hawk-Eye can be seen from Figure 2.5. The video data recorded are sent in real-time to the computer for processing and data analysis, and to track the path of the tennis ball on each camera [13].

Figure 2.5: The Hawk-Eye Video Replay

2.3 Type of Detection

Many projects research had been carried out to detect and identify the presence of objects on top of a floor surface by using designated sensors beneath the floor.

2.3.1 Magic Carpet

J. Paradiso et al. proposed the Magic Carpet, an interactive environment system comprising of a pair of Doppler radars and a grid of piezoelectric wires hidden under a carpet. The Doppler radars measures upper-body kinematics whereas the piezoelectric wires are used to monitor dynamic foot position and sense foot pressure. The insulation of the piezoelectric wires is made from a type of usually obtainable piezoelectric material, Polyvinyl Dene Fluoride (PVDF) polymer. A voltage will be produced when the carpet is pressured or bent anywhere along the length of the wire. The Magic Carpet is a very responsive system, since the PVDF wire displays a much higher dynamic range in response of pressure and is much more sturdy [26].

2.3.2 Z-tiles

A system quite similar with the Magic Carpet, called the Z-tiles was proposed by B. Richardson et al. A pressure-sensing area of changeable size and form are developed by connecting the integrated nodes together, forming a modular floor spaces. The Z-tiles floor spaces are comprised of an array of force-sensitive resistors (FSR) on its surface used to read pressure values. There are twenty hexagonal-shaped force sensitive resistors on each node, leaving no space for senseless area and can network. The pressure sensors that made up a single Z-Tile have a distinctive shape, permitting them to interlock with each other in an organized pattern and to hold their position in place. Calculation of center-of-pressure area and radii of the circles or ellipses were matched to the pressure data collected from the Z-Tiles for a very lightweight form of blob-detection system. The user's pressure pattern recorded on the tiles are then used to detect their position [27].

2.3.3 Pressure Sensing Floor

P. Srinivasan et al. proposed a reconfigurable large-area high-resolution pressure sensing floor for interactive media applications. The interaction of a user with the system produces pressure and the exertion on the floor produces distributed forces. Both of which are then measured to study the human dance movement. The system design composed of several sensor mats with each mat having a total of 2,016 pressure sensors assembled together to form a cluster that sends real-time data to the host computer. To do so, all the mats were networked with microcontrollers, Rabbit Ethernet-enabled controllers and Windows based application program. The sensor elements of the mat were made up of a pressure sensitive polymer between conductive traces on sheets of Mylar [28].

2.3.4 UnMousePad

The UnMousePad is an interpolating multi-touch force-sensing input pad, proposed by I. Rosenberg et al. It serves as a multi-touch interactive pad with pressure-sensing and pressure acquisition abilities. The UnMousePad uses the custom-built principle of Interpolating Force Sensitive Resistors (IFSR) to capture images of pressure upon a surface. An IFSR can mimic the multi-resolution properties of human skin, where the position of a touch can be identified at a better scale compared to discrimination of multiple touches. The advantages of UnMousePad is flexible, inexpensive, unobtrusive, durable and require less bandwidth to process [29].

2.3.5 tacTiles

J. Anlauff et al. proposed tacTiles, a low-cost approach to a tactile sensing prototype of a spatially resolved force sensing floor surface. The pressure sensors used are based on conductive paper and then grouped into modules forming tacTiles. The conductive paper in this case is made up of black art paper. Then, a grid of paper-based force-sensing resistors (FSRs) was produced and regarded as the sensing element of the system. In the process, 64 custom FSRs were used. The resistance of the sensing elements is measured by a microcontroller on each tile module. Connection from the tacTiles to a host computer or to a master via a shared bus are required to accumulates the measurement values before sending the data to a host computer. The aim of the system is to measure quasi-static forces. The benefits of the proposed tacTiles are it could avoid visual occlusion and bad lighting conditions as no camera were used in the system. Moreover, the tiles are cheap and more versatile [30].

2.3.6 Smart-Mat

M. Sundholm et al. proposed the Smart-Mat, a gym mat which uses resistive pressure sensor matrix made to recognize and count gym exercises. The matrix contains a thin layer of conductive polymer fiber sheet. This gym mat is capable of robustly count the number of performed exercises within real-life data. When the fiber sheet is pressed, the volume resistance produced decreases locally. The Smart-Mat is a thin, soft and low-cost mat. Besides, it can easily replace traditional gym mats [31].

2.3.7 General-purpose Sensing Floor Architecture

R. Vezzani et al. proposed a complete and general-purpose architecture for human-environment interaction based on smart floors. From the system, human behaviors can be acquired and understood through a sensing floor. The pressure field generated by moving people is captured and analyzed. The whole system architecture acquires matrices of pressure points and converts them to grey-level images. The general-purpose sensing floor uses video camera and sensor module for its system whereby the sensing floors is cheap enough to allow wide areas coverage. Besides, the sensors can be integrated unobtrusively. Yet, the drawback of placement constraints and occlusions might occur causing inaccurate data [32].

2.4 Type of Parameters

This section would discuss about the parameters that will be used throughout the project. The study of each parameter are analyzed.

2.4.1 Force

The main parameters in this project is force. Commonly, a force can be described as the two-way interaction between an object and another object which results in a push or pull effect. In physics, the motion of an object will be changed when no opposition occurs during the any course of interaction, and this is known as force [33]. In short, the velocity of an object with mass will change its motion from state of rest to accelerate due to the act of force. A force is a vector quantity, as it has both the magnitude and direction. The SI units of force is measured in Newton (symbol N), which is defined by:

$$\text{Newton (N)} = \text{kg}\frac{\text{m}}{\text{s}^2} \tag{2.1}$$

and the symbol of force is represented in **F**.

In Newton's Second Law of Motion, as stated by Sir Isaac Newton, the rate of change of momentum of a body increases as the net force applied onto the body increases. The direction of the change in momentum is the same as the direction of the applied force. This equation is given by:

$$\vec{F} = \frac{d\vec{\rho}}{dt} \tag{2.2}$$

where $\vec{F}$ is the net force in vector quantity and $\vec{\rho}$ is the momentum of the system. The forces will be balanced out each other when there is no net force exist, which means the system is in equilibrium. On the other hand, the momentum of an object would change if the forces acted on the object are unbalanced.

$$\vec{\rho} = m\vec{v} \tag{2.3}$$

$$\therefore \vec{F} = \frac{d(m\vec{v})}{dt} = m\frac{d\vec{v}}{dt} \tag{2.4}$$

where m is the mass and $\vec{v}$ is the velocity. Subsequently, the equation is derived as below:

$$\vec{a} = \frac{d\vec{v}}{dt} \tag{2.5}$$

$$\therefore \vec{F} = m\vec{a} \tag{2.6}$$

where $\vec{a}$ is the acceleration. Besides, this law only work for system with constant mass.

2.4.2 Pressure

Secondly, the next parameter is pressure. In science, pressure happens when there is an applied force perpendicularly to the surface of an object per unit area over which that force is dispersed [34]. In brief, pressure is "the amount of force acting per unit area". The symbol used for pressure is indicated by a letter **p** or **P**. Usually, the measurement of pressure is in Pascal (Pa), whereby it is the SI units for pressure and is defined by one newton per square meter as shown below:

$$\text{Pascal (Pa)} = \frac{N}{m^2} = \frac{kg}{ms^2} \tag{2.7}$$

Unlike force, pressure has no direction, and hence, is a scalar quantity. The formula of pressure is shown mathematically as below:

$$p = \frac{F}{A} \tag{2.8}$$

where p is the pressure, F is the amount of force applied and A is the area of the surface on contact.

2.4.3 Ohm's Law

Ohm's Law states that the voltage (potential difference) across two points of a conductor is proportional to the electric current flowing through it [35]. Mathematically, the law states that:

$$V = IR \tag{2.9}$$

where V is the voltage (or potential difference), I is the current, and R is the resistance. The voltage, V is measured in volts (V) while current, I is measured in Amperes (A) and resistance, R is measured in ohms (Ω). "Resistance", R is the constant of proportionality, as seen as the ratio of voltage to current.

$$R = \frac{V}{I} \tag{2.10}$$

2.5 Type of Sensors

The discussion about the type of sensors to be used will be made in this section prior to choose the suitable and cost-effective sensor to be designed.

2.5.1 Force-sensitive Resistor (FSR)

Firstly, force-sensing resistors or most commonly known force-sensitive resistors (FSR) are a type of resistor where the applied force or pressure detected on the surface of the sensor would changes the value of resistance within the sensor itself. It not only detects physical pressure and force, but also weight by pressing on or squeezing the resistor. The harder you pressed on the sensor, the lower it is the resistive value of the resistor. Basically, when the applied force on the active surface area of the sensor increases, the FSRs will display a decrease in electrical resistance. In fact, the technology FSRs was designed by Franklin Eventoff in 1977. Later, Eventoff founded Interlink Electronics Company, Camarillo, USA in 1985. Eventually, Eventoff became the founder of a new company, Sensitronics after leaving Interlink Electronics [36].

FSRs are very simple to use, and therefore there are fairly low-cost sensor. Still, the accuracy of FSRs are undeniably inaccurate where the measurements may differ by 10%, and hence, not suggested for use in precision industries. Also, the FSRs from Interlink Electronics are made from polymer thick film (PTF), where the surface of the active area is screen-printed with carbon-based ink. The figure below shows a photo of a force-sensitive resistor from Interlink Electronics, FSR-402 [37].

Figure 2.6: Interlink FSR-402

2.5.2 Pressure-sensitive Conductive Sheet

A pressure-sensitive conductive sheet is a piezo-resistive material made of polymeric foil which consisted of polyolefines. This packaging material should be electrically conductive, and thus, it was infused with carbon black. Comparable with FSRs, when the surface area of the pressure-sensitive conductive sheet is pressured, the electrical resistance of the sheet decreases. It is capable of detecting position and resistance over a certain distance, making it suitable to be used as a pressure and flexible sensor [38].

Since the characteristics of the conductive sheet, whereby its resistance can be changed by either pressing or flexing, has caused it to become a trend among hobbyists for making low-priced sensors for multi-purposed experiments involving microcontroller. An example can be seen from a YouTube video uploaded by Adafruit Industries which utilized a pressure-sensitive conductive sheet into a pair of sneakers [39]. Whenever the wearer of the sneakers takes a step, the Velostat step sensor triggers the LEDs strip to light up. Moreover, Adafruit Industries is an open-source hardware company based in New York City [40].

There are two brands popular for its pressure-sensitive conductive sheet [41], namely Velostat and Linqstat. The Velostat was previously developed by Custom Materials, and then factory-made by a material manufacturer company, 3M but now, is a part of Desco Industries Inc. Meanwhile, the Linqstat was mass-produced by another company, Caplinq. As can be seen from the figure below, the Velostat is an opaque, conductively layered, carbon-based polymeric foil and black-colored sheet [38].

Figure 2.7: Velostat

2.5.3 Conductive Silicone Rubber

The grouping of silicon together with carbon, hydrogen, and oxygen form a polymer, called silicone. The rubber-like material that is made up from that silicone is known as silicone rubber, which is an elastomer. It is a synthetic rubber compound containing properties of both the organic and inorganic materials. Silicone rubber that is electrically conductive can be produced by adding of any conductive substance such as carbon as a powdered filler, without affecting most of its mechanical properties. Nowadays, it is used for flexible contacts in devices such as calculators, remote control and computer keyboards. The reason is due to its elasticity on being pressed, causing the flexible contacts to closes [42].

Conductive rubber keypads and switches are a form of molded rubber, regarded as any rubberized material that was manufactured to can conduct electricity whenever being pressed. Examples of conductive rubber keypads are shown in Figure 2.8 below. Meanwhile, a conductive elastomer can work as a pressure sensor. This is due to the properties of the conductive rubber as being pressure-sensitive, causes their conductivity to be varied with the amount of pressure applied onto it. The electrical conductivity within the rubber allowing the electromagnetic interference (EMI) and radio frequency interference (RFI) or simply known as noise, that is frequently related with electronics, to be lowered or even be removed [43].

Figure 2.8: Silicone Rubber Keypad

2.6 Flow to Design Sensor

This section will discuss and review on the procedures used to develop sensors by several past related works.

2.6.1 Paper-based Force-sensitive Resistor (FSR)

The type of detection system as said earlier, the tacTiles, were using the paper-based force-sensitive resistors (FSRs), which was firstly introduced by Koehy et al. [44]. J. Anlauff et al. decided to developed their own customized sensors. Carbon particles that is electrically conductive were colored onto some types of black art paper. This type of conductive paper act as the resistive element, can be used to produce custom-made FSRs. Sensors made by using custom paper FSRs can be built into almost any shape and the costs is reasonably low. The principle of the paper FSR is shown in Figure 2.9.

There are some variations of conductive paper, of which each has different resistances. Resistance in the low mega ohm (MΩ) range of paper was used as the sensing layer, whereas the connector layer used a paper with resistance in the kilo ohm (kΩ) range. Both paper was referred to as MΩ paper and kΩ paper [30]. The increasing value of the applied pressure resulted in an increase in the quality of contact between the resistive and conductive layers, and an increase in the conductance. The conductive adhesive contained in the pieces of copper tape were stuck onto the paper and wires were soldered onto the copper tape to connect the sensor to the electronics [30]. The tacTiles sensing element is as shown in Figure 2.10.

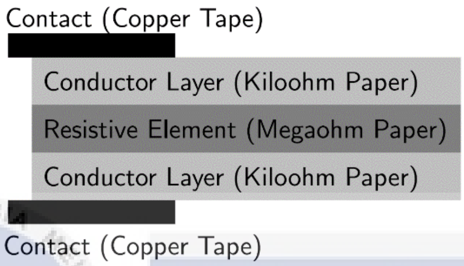

Figure 2.9: Layers of Paper FSR

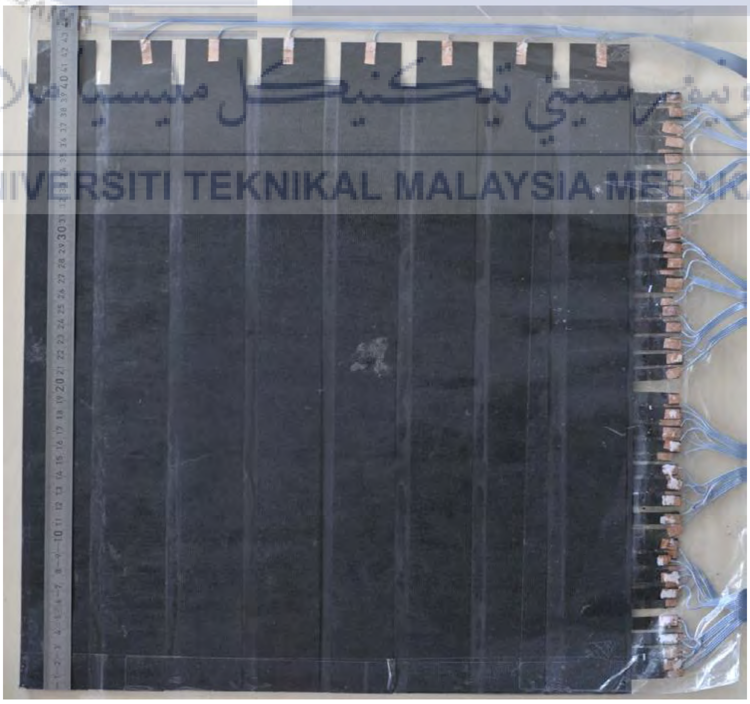

Figure 2.10: Sensing Element, tacTiles

2.6.2 Tactile Sensor Sheet

Mizushima et al. proposed the flexible and capacitive tactile sensor sheet. The movable electrode in the sensors is formed on a conductive silicone rubber. In the meantime, a flexible thin poly (ethylene terephthalate) or PET film with silver paste is used as the fixed electrodes. The fabrication of the fixed electrode is done through the techniques of screen-printing. The sensors fabricated are capable of detecting directions and distributions of the force. The force sensing cells on the sensor sheet are arranged in an array form, making it suitable to be used as a flexible tactile imager [45].

At the row-column intersections, the force-sensing elements are formed between the movable electrodes, printed horizontally using conductive silicone rubber paste onto the molded silicone rubber sheet. Whereas, the fixed electrodes are printed vertically onto the thin PET film. The connection and arrangement of eight pieces of octagonal shaped electrodes to a row electrode are made onto the non-conductive rubber sheet. All the ten lines of the row electrodes are secluded from each other. Next, on the thin PET film, ten pieces of diamond shaped electrodes are connected and then arranged to the column electrode. Similarly, with the row electrodes, the eight lines of the column electrodes separated from each other. Then, the force sensing elements are built from eighty pieces of the variable capacitors, after the rubber sheet and the PET film is stuck together [45]. The layout of the sensor sheet can be referred in Figure 2.11(a) and Figure 2.11(b).

The force sensitive capacitor is formed between the two electrodes with two dielectric layers of air and PET. When a force is applied on it, the capacitance increase. This is due to the deformation of the movable electrode toward the fixed electrode, when it is being pressed. The changes in the capacitance of the arranged sensing elements in array form, allowed the distribution of the applied force to be detected [45]. This can be seen from Figure 2.12(a) and Figure 2.12(b).

Screen-printing of the fixed electrodes and the lead lines are completed into the PET film with silver paste. The through-holes were fabricated to allow electric feed-through to connect the row electrodes to the lead lines on the PET film, and then filled in with printing of contact pads to the row electrodes. The molding and forming of the non-conductive silicone rubber sheet were made for the movable electrodes. For the row electrodes, conductive silicon paste containing silver and carbon filler were used, and then the electrodes undergo screen-printing process. Later, the PET film and the rubber sheet were bonded with silicone rubber adhesive [45]. The process of fabrication is as shown in Figure 2.13.

From Figure 2.14(a) and Figure 2.14(b), the distance is well kept between the sensing elements of the fixed electrodes and the movable electrodes. It has high flexibility to be able to be bent and hence, can be used on cylindrical surfaces [45].

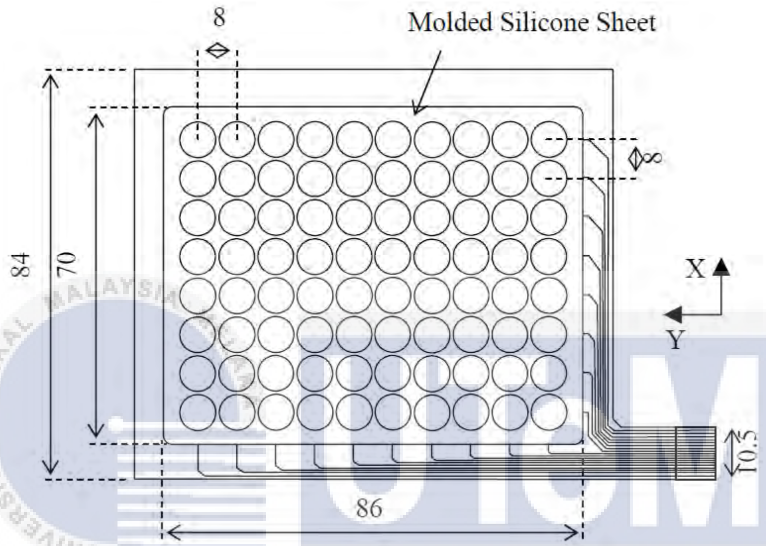

Figure 2.11(a): Top View of the Sensor Sheet Structure

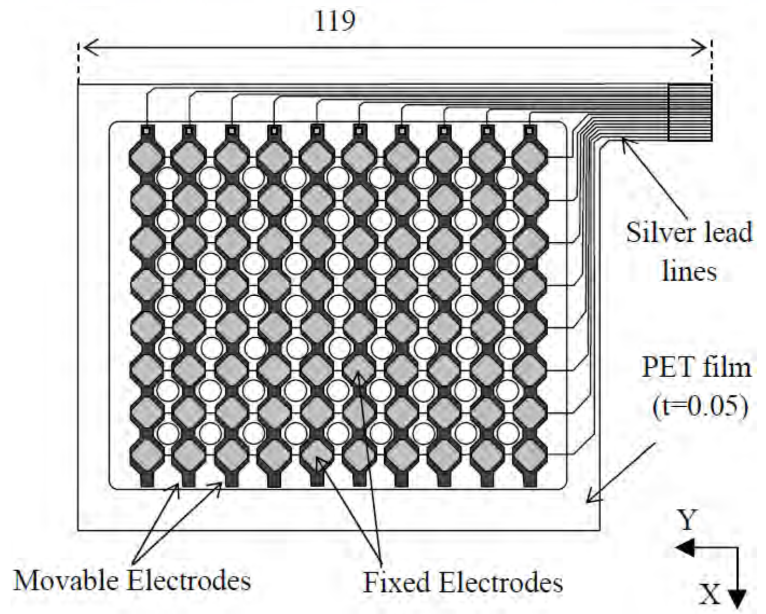

Figure 2.11(b): Bottom View of the Sensor Sheet Structure

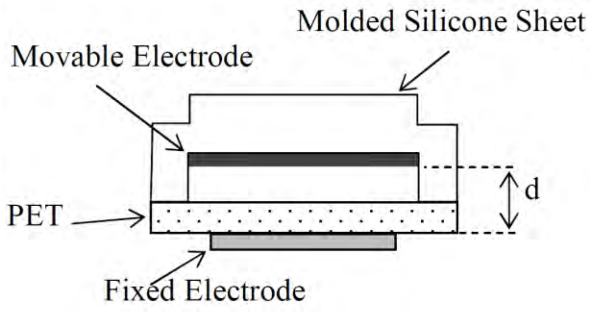

Figure 2.12(a): Initial State of Sensing Element

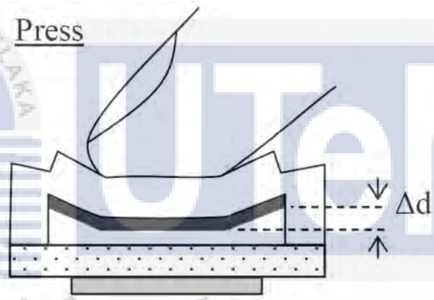

Figure 2.12(b): Active State of Sensing Element

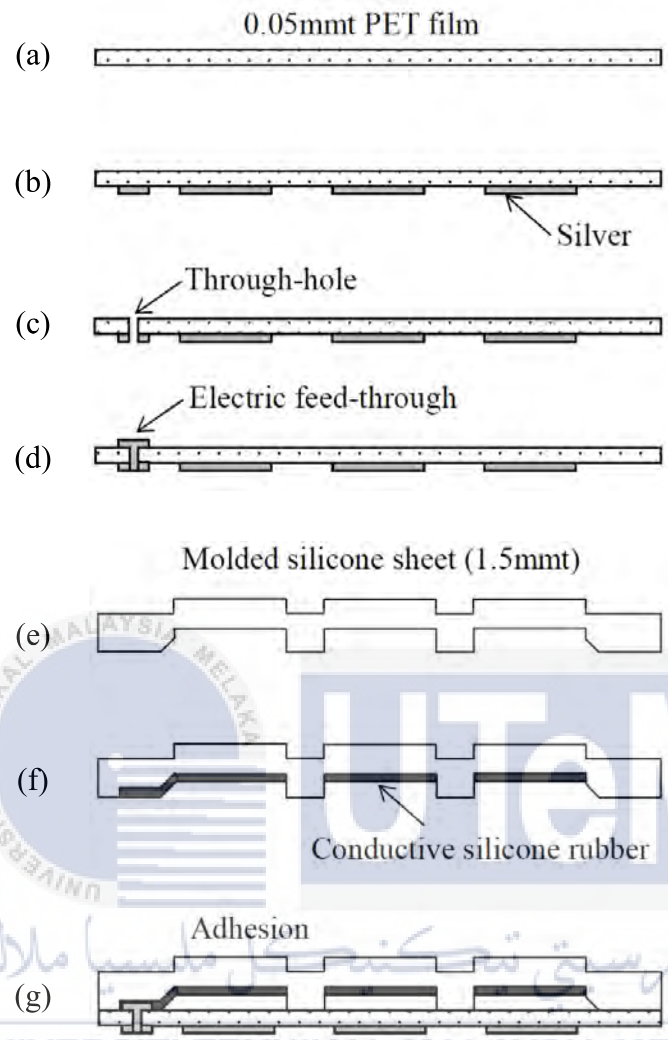

Figure 2.13: Process of Fabrication of the Sensor Sheet

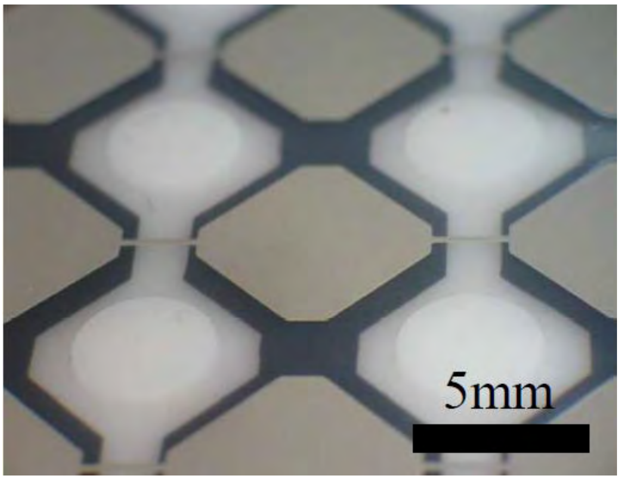

Figure 2.14(a): Bottom View of the Fabricated Sensor Sheet

Figure 2.14(b): Bending State of the Fabricated Sensor Sheet

2.7 Summary of Review

All the sports officiating systems above proved that the technology has been constantly revolving, assisting sports referees or umpires to make decisions in a sporting event. Nonetheless, most of the systems were unable to achieve almost perfect accuracies, causing inappropriate judgement in a sporting event, between referees or the system itself. Thus, in this project, the concept of sports officiating system would be utilized into the sensory module, while increasing the system accuracy of detection.

After reviewing the detection systems proposed earlier, every system have its own pros and cons and their main resolution. The similarities are that they all uses sensors for their detection purposes, while a few of them uses camera. Therefore, the literature review of those systems is studied as reference for this project.

The studies of each sensor have allowed the comparison and analysis of the sensors to be made, to choose the appropriate sensor to be used throughout this project. In conclusion, the conductive silicone rubber keypad has been selected for my sensor development. However, due to the force-sensitive resistor are readily available and easier to be used, pre-testing of circuit will be carried out by using the FSR. Afterwards, the conductive silicone rubber keypad will be used to be designed as a sensor and modification will be made, so that the sensor is suitable for use and can fulfil the project specifications.

Both design procedures of sensors are reviewed and studied. It can be referred as guidance and reference prior to sensor designing.

CHAPTER 3

METHODOLOGY

This chapter introduces the parameter model, procedures to design sensor, system configuration, development of the system in terms of software and hardware, experimental setup and lastly, project implementation.

3.1 Parameter Model

In this project, the main parameter is force. The sensory module to be designed on the boundary line of a sports court would detect forces whenever there is a force exerted onto the boundary line. The force exerted might be from a falling ball or from a player's footstep.

Whenever a ball is hit onto the floor by a player's racket, the ball is in contact with the racket. The energy exists within the ball is transferred from potential energy into kinetic energy. The potential energy is due to the velocity of the ball being zero when it contacted the racket, and subsequently the energy changes into kinetic energy when the ball hits the ground. During this process, the Law of Conservation of Energy is applied. The Law of Conservation of Energy states that, "energy can neither be created nor destroyed; rather, it transforms from one form to another". In general, it states that, the net energy is constant in any closed system.

In accordance to the parameter model, two approaches will be considered in this section. The first approach is the kinematics approach, and the other one is the energy approach, and lastly, the momentum approach.

3.1.1 Kinematics Approach

As the ball is under constant acceleration, the velocity of the ball at any point in time can be modelled by the equation:

$$v = v_0 + at \tag{3.1}$$

where v is the velocity at any point in time, v_0 is the initial velocity, a is acceleration, and t is the time elapsed. Since the ball contacted the racket, and started falling from it maximum height, the initial velocity of the ball is zero. Thus, the equation becomes:

$$v = at \tag{3.2}$$

The acceleration of the ball can be referred from the gravitational acceleration g, where $a = -g$, as this is due to the direction of gravitational force is downwards. But, in most cases, by altering the direction of motion, the equation of acceleration can be, $a = g$. The equation is then modified and becomes:

$$v = gt \tag{3.3}$$

Next, to obtain the value of time elapsed to hit the ground, the displacement of the ball should be found. The equation of displacement, s is as shown:

$$s = \frac{1}{2}t(v_0 + v) \tag{3.4}$$

Here, since we know, $v_0 = 0$, and to solve for t, the equation becomes:

$$t = \frac{2s}{v} \tag{3.5}$$

Next, the equation of time elapsed, t is then substituted into equation (3.3),

$$v = g\left(\frac{2s}{v}\right) \tag{3.6}$$

$$v^2 = 2gs \tag{3.7}$$

$$v = \sqrt{2gs} \tag{3.8}$$

And finally, the velocity of the ball under constant acceleration, at any point in time, can be calculated by using formula from equation (3.8).

3.1.2 Energy Approach

When the ball is at its maximum height, the gravitational potential energy of the ball is given by:

$$E = mgh \tag{3.9}$$

where E is the gravitational potential energy, m is the mass of the ball, g is the gravitational acceleration, and h is the height. The ball is in contact with the ground, indicating the height, h is primarily zero. When the ball hits the ground, the kinetic energy can be measured by:

$$E = \frac{1}{2}mv^2 \tag{3.10}$$

Accordingly, to the Law of Conservation of Energy, the energy of the ball is conserved in the process. Therefore, to solve for velocity of the ball, the equation (3.9) and (3.10) are equated as shown:

$$mgh = \frac{1}{2}mv^2 \tag{3.11}$$

$$gh = \frac{1}{2}v^2 \tag{3.12}$$

$$v^2 = 2gh \tag{3.13}$$

$$v = \sqrt{2gh} \tag{3.14}$$

3.1.3 Momentum Approach

The Law of Conservation of Momentum states that, the total momentum before and after the collision of two objects in an isolated system are equal. This law is correlated with the Newton's Third Law of Motion, it stated that, in every interaction, there is an equal and opposite pair of forces exerting on the two interacting objects. By referring to the momentum principle,

$$F_{net} = \frac{\Delta P}{\Delta t} \tag{3.15}$$

$$\Delta P = F_{net} \times \Delta t \tag{3.16}$$

$$P_{final} - P_{initial} = F_{net} \times \Delta t \tag{3.17}$$

where ΔP is the rate of change of momentum, P_{final} is the final momentum, $P_{initial}$ is the initial momentum, F_{net} is the net force applied, and Δt is the rate of change of time. Since the initial velocity, v is zero, hence, $P_{initial} = 0$, so:

$$P_{final} = F_{net}\Delta t \tag{3.18}$$

Momentum is the product of mass and velocity, whereas force is the product of mass and acceleration, as shown below:

$$P = mv \tag{3.19}$$

$$F_{net}\Delta t = mv_{final} \tag{3.20}$$

$$F_{net} = ma \tag{3.21}$$

Thus, by substituting equation (3.21) into equation (3.20),

$$(ma)\Delta t = mv_{final} \tag{3.22}$$

$$v_{final} = a\Delta t \tag{3.23}$$

Moreover, velocity, v is the rate of change of displacement, s. It is expressed as displacement per unit of time as shown:

$$v = \frac{s}{\Delta t} \tag{3.24}$$

By equating equation (3.23) and equation (3.24),

$$\frac{s}{\Delta t} = a\Delta t \tag{3.25}$$

$$s = a(\Delta t)^2 \tag{3.26}$$

$$\Delta t = \sqrt{\frac{s}{a}} \tag{3.27}$$

Besides, v is the derivative of s, so:

$$v = \frac{d}{dt}s = \frac{d}{dt}a(\Delta t)^2 = 2a\Delta t \tag{3.28}$$

3.2 Design of Sensor

This section will discuss on the brief procedure of sensor designing, including the materials to be used. Specific details of procedure and specification will be discussed.

The sensor to be used to design is conductive silicone rubber keypad. Firstly, to obtain the material, the first process is molding. Molding is a process used in manufacturing by shaping the liquid or raw materials into a model of the final object by using a mold. In this case, the silicone rubber will be molded in a mold to obtain the silicone rubber sheet in the shape of a keypad.

Next, the process is fabrication. One of the fabrication techniques that could be used is screen-printing. Screen-printing is a printing technique used to transfer the ink onto a substrate. The force-sensing elements will be screen-printed onto the silicone rubber keypad by using carbon-based ink. By doing this, the silicone rubber keypad will be now electrically conductive.

Alternatively, the conductive silicone rubber keypad can also be bought from suppliers or any other valid sources. Still, modification should be made onto the keypad, so that the sensor is suitable for the project requirements. Figure below shows an image of a basic construction of silicone rubber key for reference.

The sensors are obtained from a calculator's keypad bought in the market. It is very affordable and easily obtainable. Figure 3.2, 3.3, and 3.4 show the calculator bought in the market and its keypad taken out from the calculator itself.

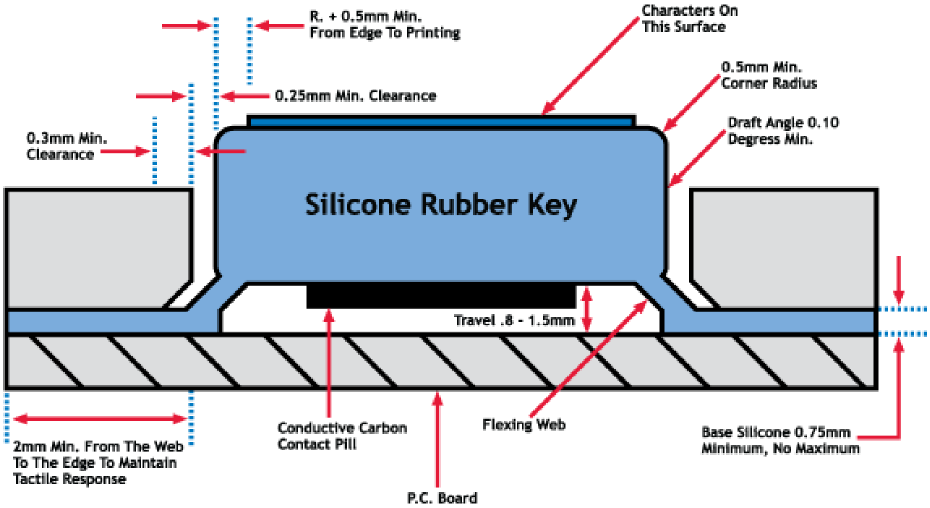

Figure 3.1: Basic Construction of Silicone Rubber Key

Figure 3.2: Calculator Bought in Market

Figure 3.3: Top View of Keypad

Figure 3.4: Bottom View of Keypad

3.3 System Configuration

This section covers the configuration to be made to build the system for this project. The configuration of the system consists of a few modules. The modules are shown in the figure below.

Figure 3.5: System Configuration

3.3.1 Design of Sensor Module

The sensor module as discussed earlier, is designed by using conductive silicone rubber keypad. The force-sensing elements contained in the conductive silicone rubber keypad are able to sense and detect any force exerted on it. It is aimed to detect the impact of the ball. The designed sensor module is organized underneath the boundary line of a tennis sports court floor. Required parameters is tested to obtain a fully compatible sensor module.

3.3.2 Develop Software Algorithm

Efficient software algorithm is created is created by using Arduino IDE to aid the differentiating process whether impacted ball lands inside or outside of the boundary line on the sports court. Next, the algorithm developed using the Arduino IDE will be uploaded and tested on the microcontroller, Arduino Mega 2560.

3.3.3 Display Module

The display module used is a liquid-crystal display (LCD). The decision of the ball position is displayed on the LCD as 'IN!' or 'OUT!' as soon as the microcontroller, Arduino Mega 2560 analyzes the data collected. Upon successful testing, the redesigned detection sensor module, microcontroller and display module are integrated and combined to produce a highly reliable prototype.

3.4 Development of The System

This section of the methodology chapter describes the development of the system which involves the use of software and hardware.

3.4.1 Software

The software used in this project consist of circuit simulation software, Autodesk EAGLE and programming software, Arduino IDE.

3.4.1.1 Autodesk EAGLE 8.1.1

Figure 3.6: Autodesk EAGLE Icon Image

Autodesk EAGLE is a type of scriptable Electronic Design Automation (EDA) tool which are used for schematic capture, auto-router, computer-aided manufacturing features and printed-circuit board (PCB) layout modules. The acronym of EAGLE is Easily Applicable Graphical Layout Editor, developed by CadSoft Computer GmbH. Later, it was acquired by Autodesk Inc. in 2016. The schematic capture of the software works for both the simulation of circuit designs and as the design phase of a PCB layout project. EAGLE is fully compatible with operating system of Windows, Linux, and Mac OS X. By using appropriate components into the schematic editor of the EAGLE, a designed circuit can be simulated. After testing and simulating the circuit, the finalized circuit will be transferred into a circuit of PCB layout. Next, the circuit of PCB layout is then printed on a tracing paper before transferring onto a printed-circuit board (PCB).

3.4.1.2 Arduino IDE 1.6.13

Figure 3.7: Arduino IDE Logo

The Arduino Integrated Development Environment (IDE) is an open-source software, provided by Arduino. It is very user-friendly as the coding can be written and uploaded into the Arduino board without any fuss. The programming languages used in Arduino IDE is C languages and it has a unique library. The software has another feature, the serial monitor. The serial monitor enables the data of any information to be displayed, per the coding of the Arduino IDE.

The main purpose of Arduino IDE in this project is to develop software algorithm for the system. The software algorithm is required to aid the differencing process between a ball and a player's foot.

3.4.2 Hardware

This section will discuss about the hardware and components that will be used in this project. Analysis and specifications of each component are made and reviewed.

3.4.2.1 SN74HC165N Shift Register

Figure 3.8: SN74HC165N Shift Register

A shift register is a form of sequential logic circuit that basically serves as digital data memory. They are a group of cascaded flip-flops, sharing a common clock. The output of each flip-flop is linked to the data input of the next flip-flop in the chain, and so, at each transition of the clock input, the circuit shifts by one position of the bit array stored in it.

SN74HC165N is a type of 8-bit Parallel-in/Serial-Out (PISO) Shift Register, an integrated circuit produced by Texas Instruments. A PISO Shift Register can convert data from a parallel format to a serial format. This means that the parallel data is loaded into the register simultaneously and is shifted out of the register serially one bit at a time under clock control. At first, the data is shifted toward the serial (Q_H) output whenever it is clocked. Access to each stage is provided by eight individual direct data (A – H) parallel inputs, which are enabled at the shift/load ($SH/\overline{LD}$) input. Shift registers are widely used in appliances, keyboards, video display systems, output expander and programmable logic controller. In this project, the SN74HC165N shift register used works best as a device that allows multiple inputs to be added to the microcontroller.

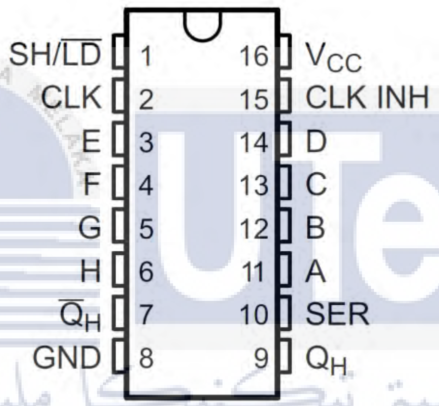

Figure 3.9: Pin Configuration of SN74HC165N

Table 3.1: Pin Functions of SN74HC165N

Pin		Input/ Output	Description
Name	**No.**		
A	11	Input	Parallel Input
B	12	Input	Parallel Input
C	13	Input	Parallel Input
CLK	2	Input	Clock Input
CLK INH	15	Input	Clock Inhibit; when High – No change in output
D	14	Input	Parallel Input
E	3	Input	Parallel Input
F	4	Input	Parallel Input
G	5	Input	Parallel Input
GND	8	–	Ground Pin
H	6	Input	Parallel Input
NC	–	–	Not Connected
Q_H	9	Output	Serial Output
$\overline{Q}_H$	7	Output	Complementary Serial Output
SER	10	Input	Serial Input
$SH/\overline{LD}$	1	Input	Shift or Load input; when High – Data is shifted, when Low – Data is loaded from parallel inputs
V_{CC}	16	–	Power pin

3.4.2.2 4-Pin Tactile Switch

Figure 3.10: 4-Pin Tactile Switch

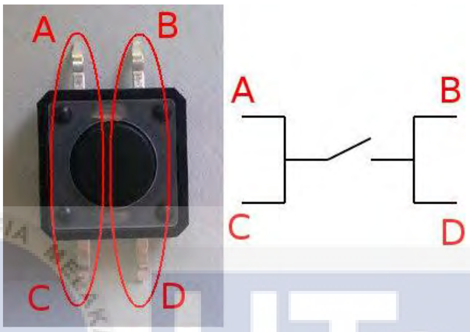

Figure 3.11: 4-Pin Tactile Switch and its Pin

A switch is an electrical component that can "make" or "break" an electrical circuit. It consists of at least two terminals, for the current to flow into and out from it. A switch can only exist in one of two states, open or closed. To change from one state to another, a switch must be actuated. Tactile switch is a kind of momentary switch, at which it only remains active for if it is actuated, whereas it remains off-state if not being depressed. The number of poles on a switch defines how many separate circuits the switch can control and a switch's throw count defines how many positions each of the switch's poles can be connected to. In this case, the 4-pin tactile switch is a single pole, single throw (SPST) switch. Thus, the switch has an output and an input, suitable for on-off switching. In this project, 64 of these switches are used for pre-testing purposes of the prototype circuit before the conductive silicone rubber keypad is used in the hardware prototype.

3.4.2.3 Arduino Mega 2560

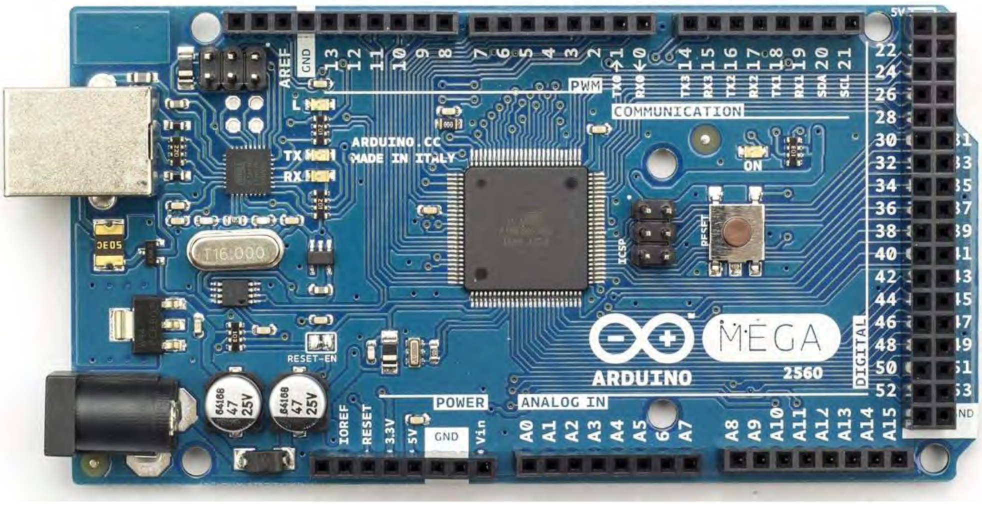

Figure 3.12: Arduino Mega 2560

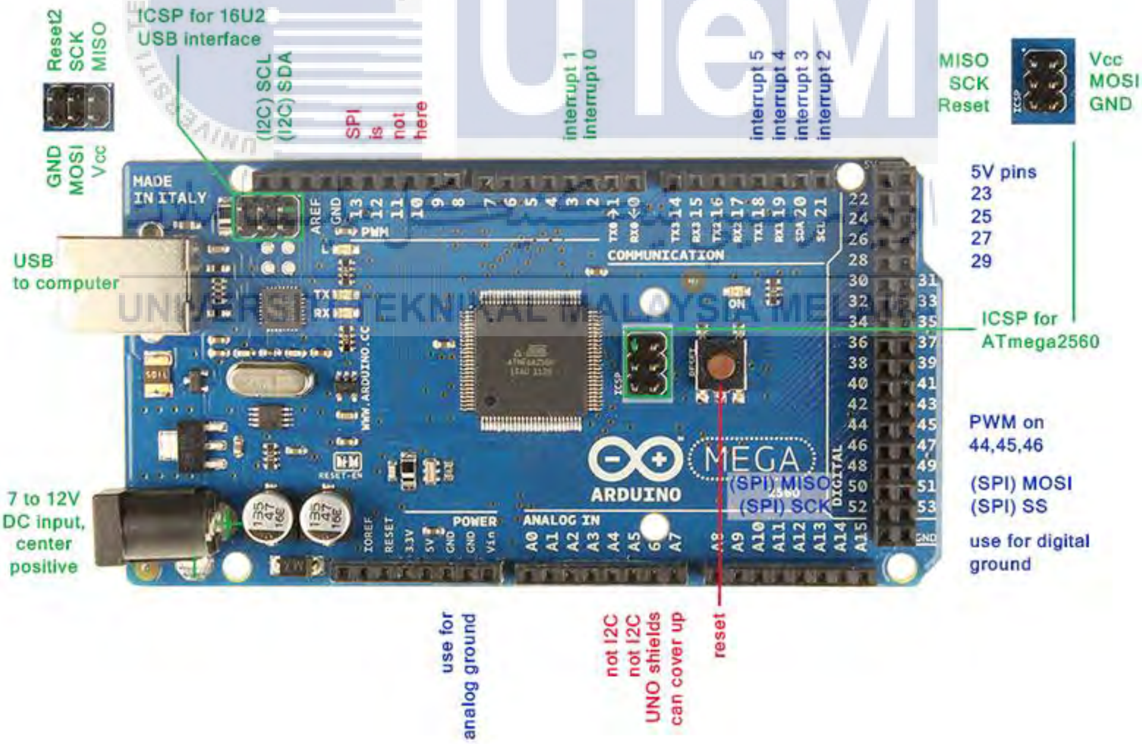

Figure 3.13 Arduino Mega 2560 and its label

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It contains a reset button, a Universal Serial Bus (USB) port connection, a power jack and an In-Circuit Serial Programming (ICSP) header. Besides, there are four hardware serial ports or in specific, the Universal Asynchronous Receivers/Transmitters (UART). The Arduino Mega 2560 also comprised of a 16 MHz crystal oscillator, 16 analog inputs, and 54 digital input/output pins. From the 54-digital input/output pins, there are 15 of which it can be used as pulse-width modulation (PWM) outputs. The ATmega2560 on the Arduino Mega 2560 comes preprogrammed with a bootloader that allows new code to be uploaded into the board without the use of an external hardware programmer.

In this project, the Arduino Mega 2560 is used as the microcontroller alongside with the sensors. The data obtained from the sensor will be collected and analyzed by the microcontroller before proceeding with the decision process. Next, the decisions of ball position will be displayed on LCD screen, which is connected to the Arduino Mega 2560.

Table 3.2: Technical Specifications of Arduino Mega 2560

SPECIFICATIONS	RATING
Microcontroller	ATmega2560
Operating Voltage	5 V
Input Voltage (recommended)	7 – 12 V
Input Voltage (limit)	6 – 20 V
Digital I/O Pins	54 (of which 15 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	20 mA
DC Current for 3.3 V pin	50 mA
Flash Memory	256 kB of which 8 kB used by bootloader
SRAM (Static Random-Access Memory)	8 kB
EEPROM	4 kB
Clock Speed	16 MHz
LED_BUILTIN	13
Length	101.52 mm
Width	53.3 mm
Weight	37 g

3.4.2.4 16×2 Liquid Crystal Display (LCD)

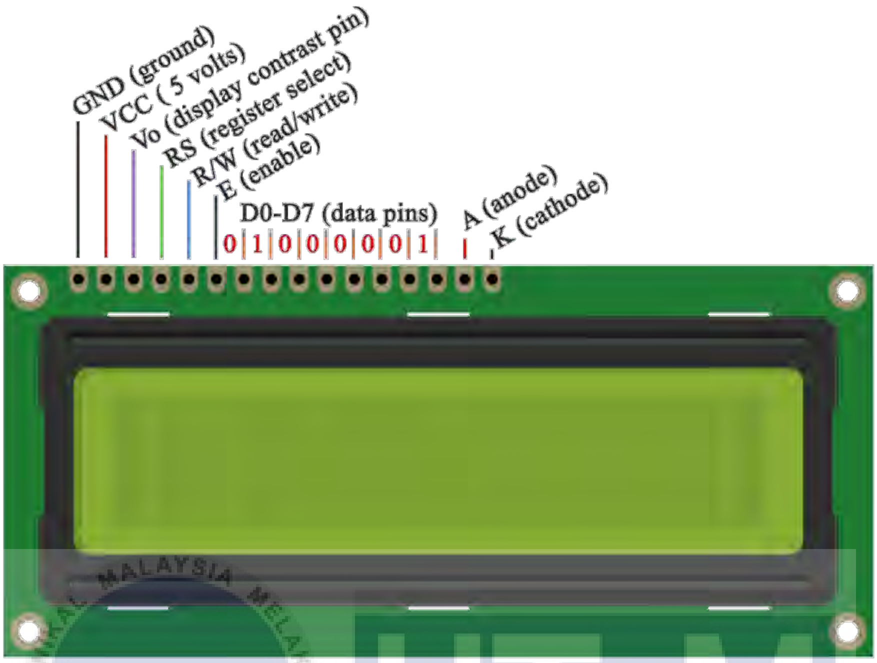

Figure 3.14: 16×2 LCD Display and its Pin

A 16×2 Liquid Crystal Display (LCD) screen is an electronic display module and can be found in a wide range of applications, as it is very usually used in devices and circuits. The features of 16×2 LCD are it is a built-in controller and has 5×8 dots with cursor. The display consists of 2 lines, which could occupy up to 16 characters per line. The LCD also contained display mode and backlight variations. Moreover, the LCD has two registers, which are Command and Data. The command register stores the command instructions given to the LCD. Meanwhile, the data register stores the data to be displayed on the LCD in the form of ASCII value of the character. In the project, 16×2 Liquid Crystal Display (LCD) is used to display the 'IN!' and 'OUT!' decisions of the ball position.

Table 3.3: Pin Description of 16×2 LCD

Pin No.	Name	Function
1	Ground	Ground (0 V)
2	V_{CC}	Supply Voltage; 5 V (4.7 V – 5.3 V)
3	V_{EE}	Contrast adjustment; through a variable resistor
4	Register Select	Selects command register when low; and data register when high
5	Read/ Write	Low to write to the register; High to read from the register
6	Enable	Sends data to data pins when a high to low pulse is given
7	DB0	8-bit data pins
8	DB1	
9	DB2	
10	DB3	
11	DB4	
12	DB5	
13	DB6	
14	DB7	
15	Led+	Backlight V_{CC} (5V)
16	Led–	Backlight Ground (0V)

3.4.2.5 Printed-Circuit Board (PCB)

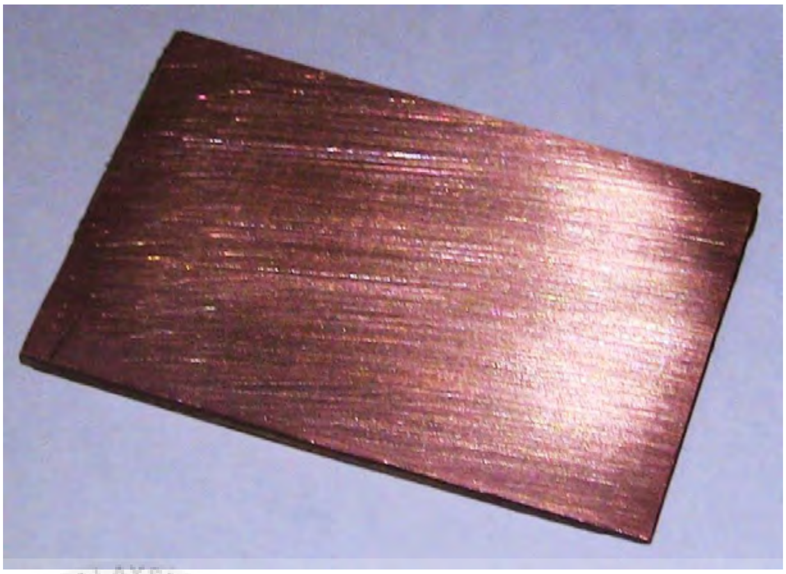

Figure 3.15: Bare Printed-Circuit Board (PCB)

A printed-circuit board (PCB) is a board base used for physically supporting and wiring the surface-mounted and socketed components in most electronics. PCBs route signals and power through electronic devices, providing both mechanical and electrical connections. Conductive tracks are etched from copper sheets, laminated onto a non-conductive substrate to provide the basic layout of PCBs. There are three main types of PCB construction, namely, single-sided, double-sided, and multi-layered.

Single-sided boards have the components on one side of the substrate while double-sided may be used when the number of components becomes too much for a single-sided board. The electrical connections between the circuits on each side are made by drilling holes through the substrate in appropriate locations and plating the inside of the holes with a conducting material. Next, a multi-layered board, has a substrate made up of layers of printed circuits separated by layers of insulation. The components on the surface connect through plated holes drilled down to the appropriate circuit layer.

In this project, the layout of the constructed circuit will be printed onto the PCB and the conductive silicone rubber keypad will be attached on top of the board.

3.5 Experimental Setup

This section discussed about the experimental setup of the project, including the design of schematic diagram for PCB layout design, and the making of PCB such as the process of developing, etching, drilling, components placing, and soldering.

3.5.1 Design of Schematic Diagram

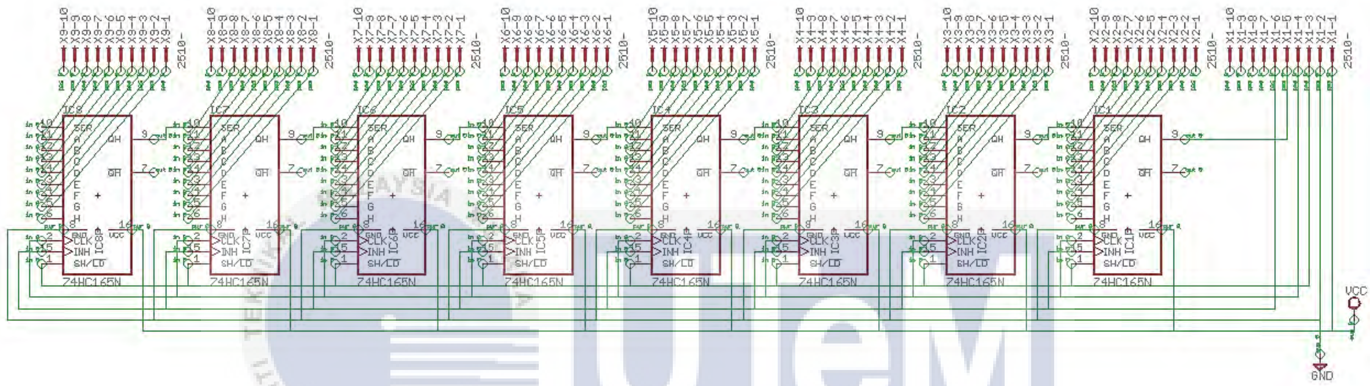

Figure 3.16: Schematic Diagram of Shift Registers Circuit

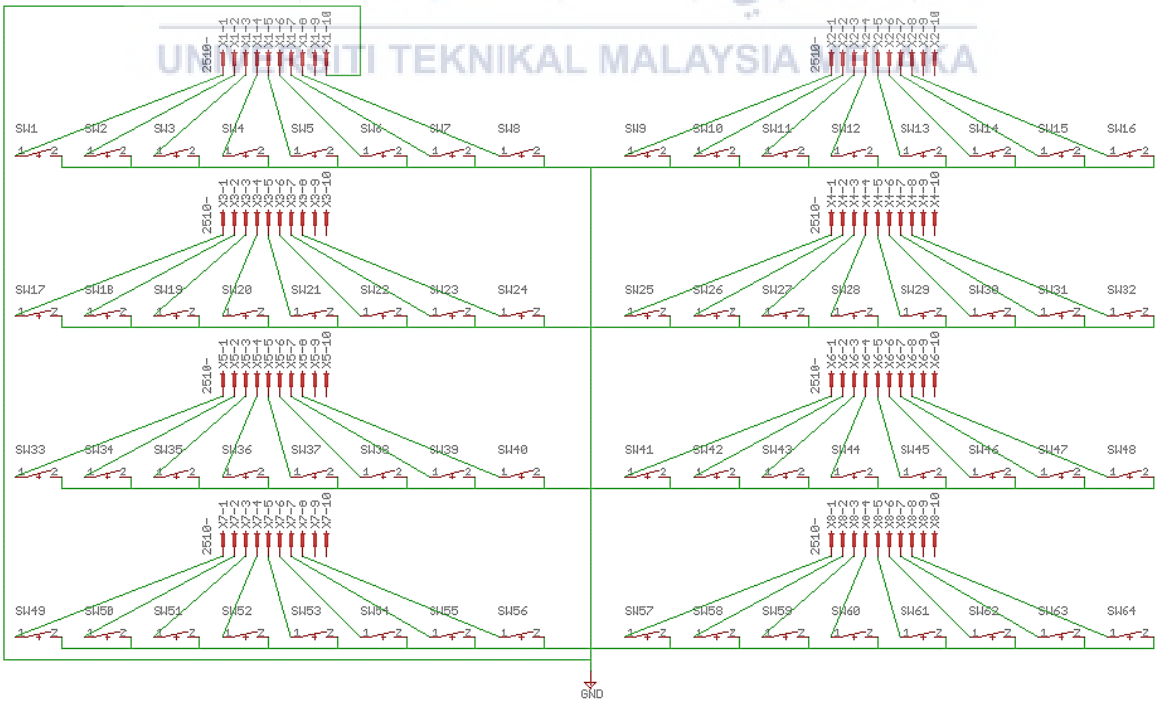

Figure 3.17: Schematic Diagram of Keypad Switches Circuit

Figure 3.16 above shows the schematic diagram consisting of eight shift registers (IC1~IC8), with each of them connected to a 10-pin shrouded male header (X1~X9). Except for the first shift register (IC1) as it is connected to two headers (X1 & X2), where the first header (X1) will be made to connect with the microcontroller, Arduino Mega 2560. Then, the rest of the headers will have connection with the headers from the keypad switches circuit.

Figure 3.17 above shows the schematic diagram consisting of 64 keypad switches (SW1~SW64), with every eight of the keypad switches is connected to one of the 10-pin shrouded male header (X1~X8). The keypad switches have two terminals, one of which is connected to the header pin and the other one is connected to the ground pin (GND).

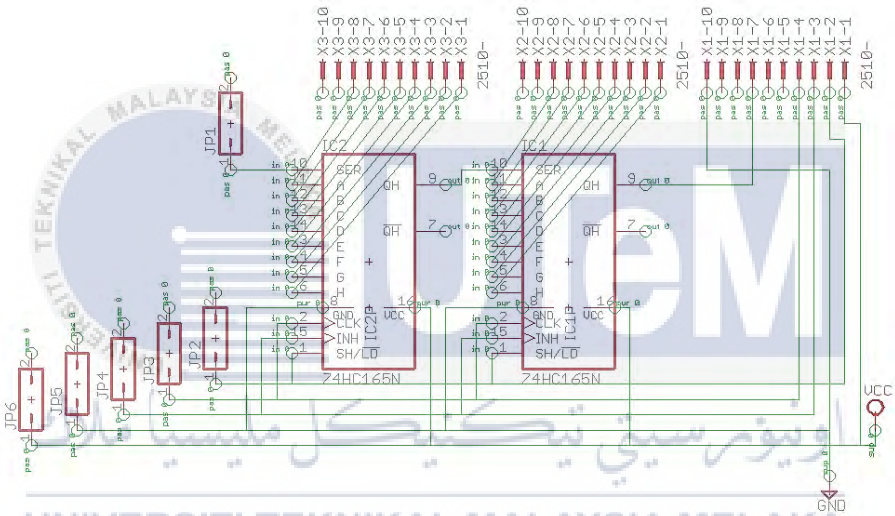

Figure 3.18: Schematic Diagram of First Two Shift Registers – IC1 & IC2

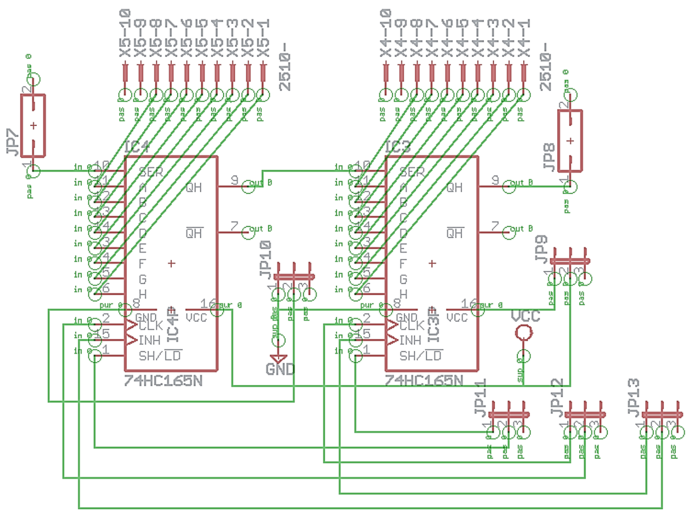

Figure 3.19: Schematic Diagram of 3rd and 4th Shift Registers – IC3 & IC4

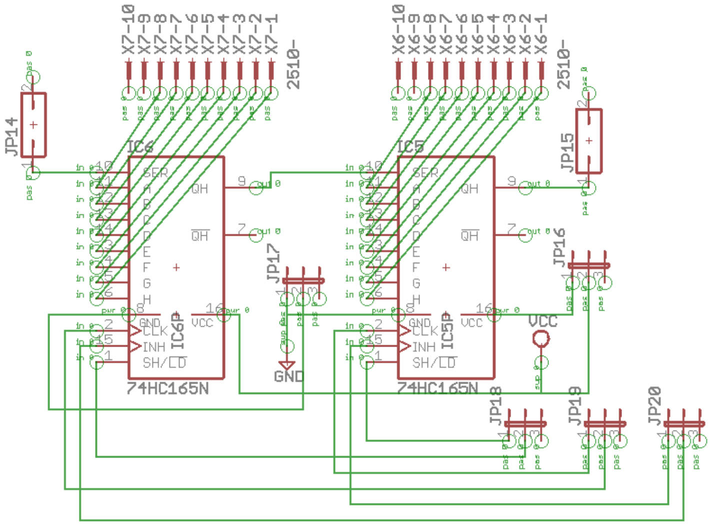

Figure 3.20: Schematic Diagram of 5th and 6th Shift Registers – IC5 & IC6

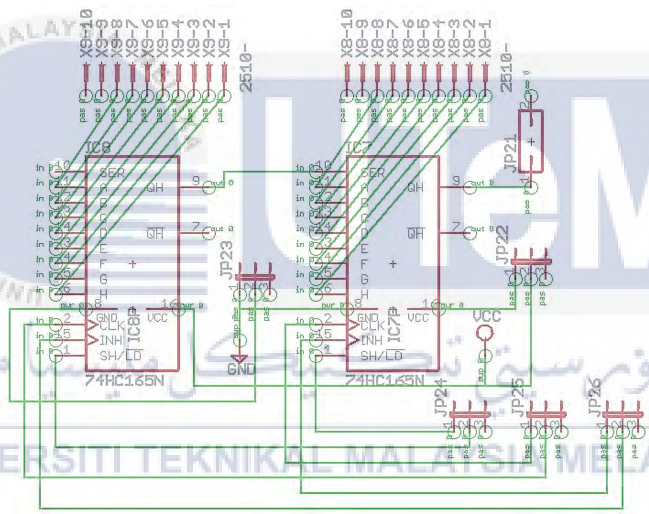

Figure 3.21: Schematic Diagram of 7th and 8th Shift Registers – IC7 & IC8

Figure 3.18, 3.19, 3.20 and 3.21 above show the schematic diagram where each of them consisted of two shift registers separated from the full schematic diagram of shift registers shown earlier in Figure 3.16. This is because to create the PCB layout design, the separated circuit would have more flexibility and simpler to be made, and therefore, reducing the error that could occur during the process of etching and soldering. Jumpers (JP1~JP26) were added to each circuit to ease the connection between these shift registers circuit after the PCB is made.

3.5.2 PCB Layout Design

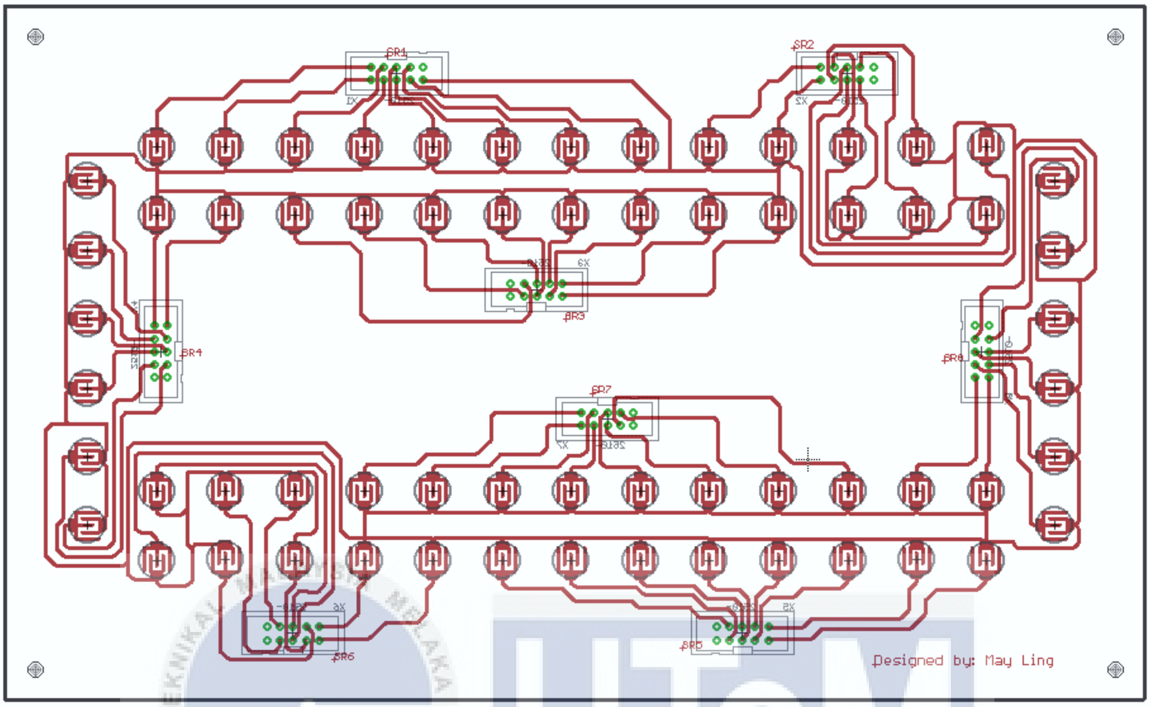

Figure 3.22: PCB Layout of Keypad Switches Circuit

Figure 3.22 above shows the PCB layout of the keypad switches circuit transferred from the schematic diagram that was made earlier. The dimension of the keypad switches was designed by referring to the actual sizing of the conductive silicone rubber keypad. There are 64 interconnected keypad switches, with every eight of them is connected to a header (X1~X8). The keypad switches have two terminals, one of which is connected to the header pin and the other one is connected to the ground pin (GND). Then, connections will be done by using rainbow cables to connect each of the headers from the keypad switches circuit to the headers on the schematic diagram circuits.

Figure 3.23, 3.24, 3.25 and 3.26 below show the PCB layout of the shift registers circuits transferred from the schematic diagram that was done previously.

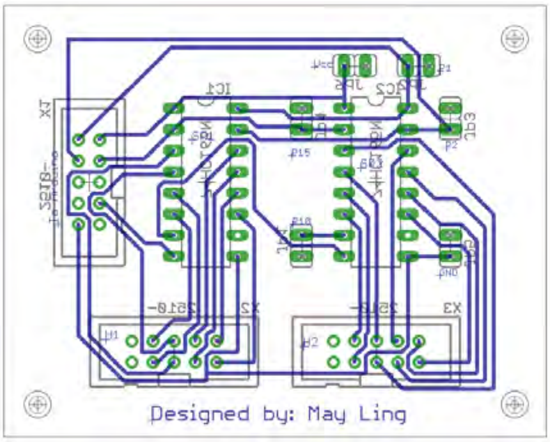

Figure 3.23: PCB Layout of First Two Shift Registers – SR1 & SR2

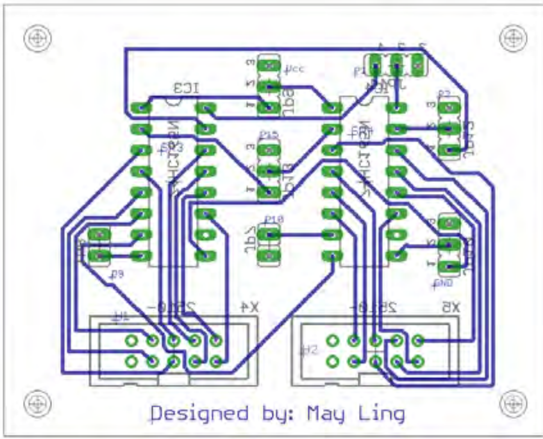

Figure 3.24: PCB Layout of 3rd and 4th Shift Registers – SR3 & SR4

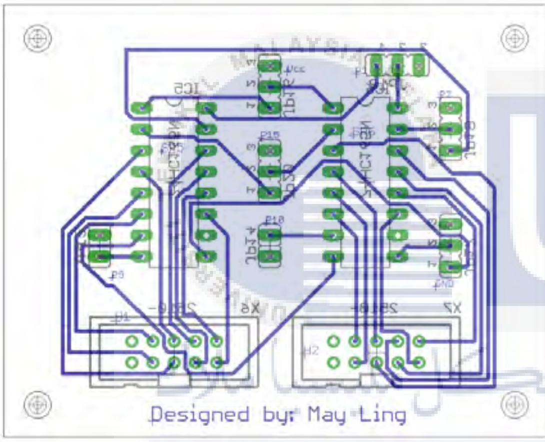

Figure 3.25: PCB Layout of 5th and 6th Shift Registers – SR5 & SR6

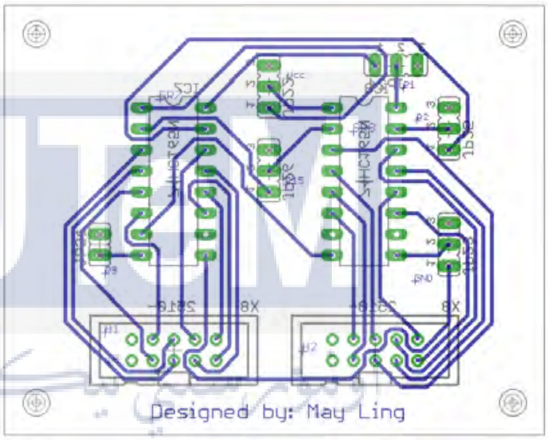

Figure 3.26: PCB Layout of 7th and 8th Shift Registers – SR6 & SR8

3.5.3 The Making of PCB

The making of PCB includes the process of developing, etching, drilling, components placing, and soldering. Figure 3.27 shows the PCB circuit of keypad switches that had done etching, while Figure 3.28 shows the PCB circuit of shift registers that had undergone both etching and drilling. The developing and etching process are done by using an acid PCB developer and a ferric chloride acid. For instance, the image of the acid PCB developer and ferric chloride acid are located at the Appendices.

Firstly, the PCB layout circuit of the shift registers and keypad switches are printed onto a tracing paper using a laser printer. The black tape stuck over the photo-sensitive etch resist on the PCB Ultra-violet (UV) board is then peeled off, to allow the tracing paper to sit on top of the PCB UV board. It is then promptly exposed under the blazing sunlight, to allow the circuit to be transferred onto the board. After exposure, a feint image of the circuit pattern can be seen in the photo-sensitive layer. In about one minute, the board is immersed into the solution mixture of water and acid PCB developer, to be developed. The ratio of acid to water is 2:3. The tracks eventually shows after a little while. The surface area of the board which is exposed to the sunlight, is dissolved into the solution, leaving only the unexposed to sunlight area of circuit patterns to remain.

The developed PCB is etched by using immersion etching, where the board is submerged in ferric chloride acid. This process took quite some time, approximately five to ten minutes. The layer of copper which is unexposed, slowly dissolves into the solution, leaving only the circuit copper tracks. After the PCB is etched, the board is washed with clear running water. Lastly, the board is put under the sunlight for a few minutes before immersing into the acid PCB developer to dissolve the photo-sensitive etch-resist layer on top of the circuit patterns. The only remaining layer is the copper tracks of the circuit.

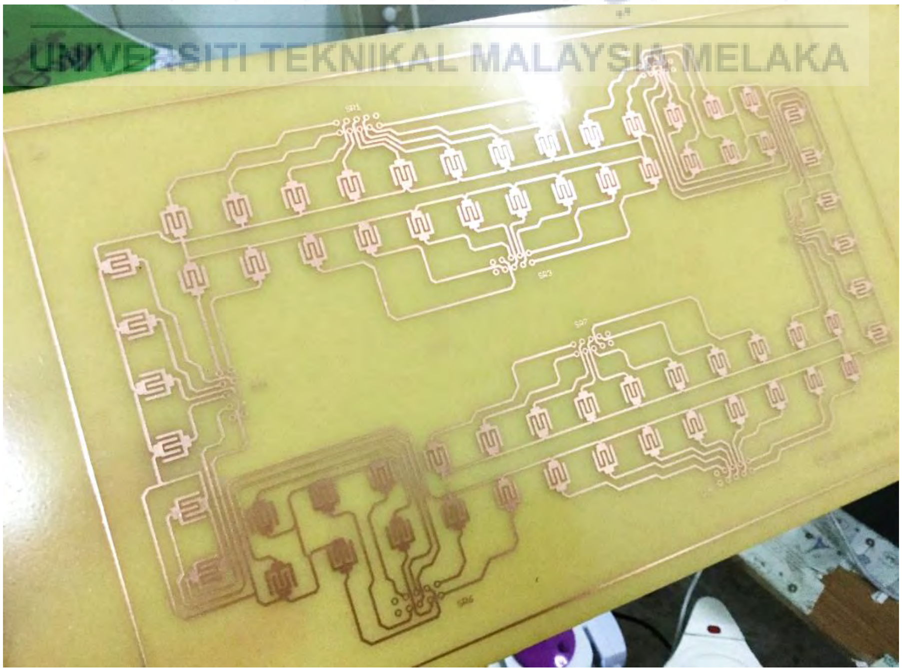

Figure 3.27: Etched PCB Circuit of Keypad Switches

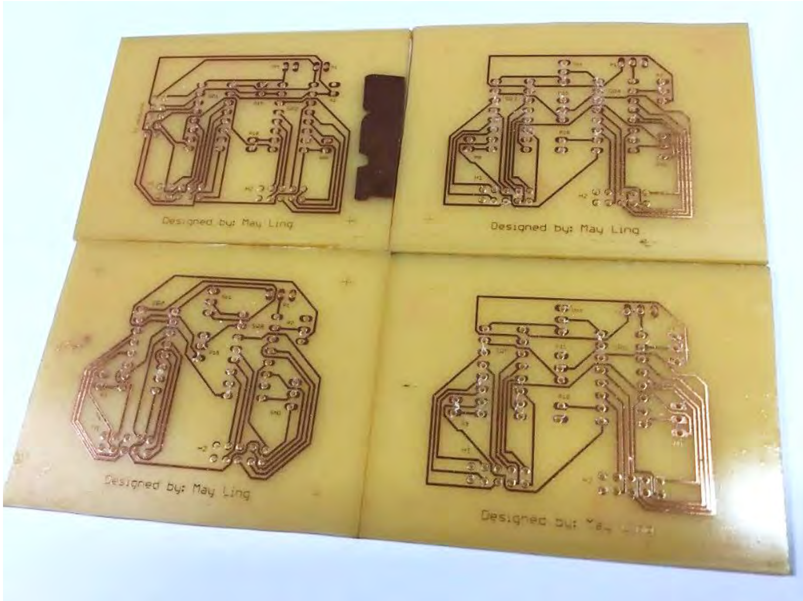

Figure 3.28: Etched and Drilled PCB Circuit of Shift Registers

3.6 Project Implementation

This section of project covers further information regarding the flow of the project and system are demonstrated in flow charts, a milestone is developed and then, a Gantt chart is created to illustrate the plan for this project.

3.6.1 Flow Chart

In overall, this project would take up about two semesters to complete, which include previous semester and current semester. The Final Year Project 1 (FYP 1) was started on the first week of September 2016 until December 2016. Meanwhile, the Final Year Project 2 (FYP 2) started on the second week of February 2017 until the end of this semester which is on the first week of June 2017. The procedure to accomplish this FYP 1 is as shown in Figure 3.29.

First and foremost, the general knowledge regarding a sports court was acquired and then, the literature reviews of the existing sports officiating system were studied and collected from various sources. After the objectives for this project were confirmed, the study of literature reviews on the development of sensors module based on selected parameters were done by reviewing past research journals and papers. To gain more insights concerning the idea to design sensors and circuit, the information and feasibilities study were assimilated from previous researches and doings. Subsequently, the silicone rubber keypad was chosen as the sensor to be designed for use in the project after the comparison of sensors are done, while the force-sensitive resistor was selected for use to accomplish pre-testing of the circuit. The consideration of method to design sensors will then be confirmed. Next, the design of circuit was constructed by using the software, Proteus ISIS Professional. By using Proteus ISIS Professional, the schematic capture to create schematic diagram was constructed and then circuit was simulated. When the pre-testing results obtained were verified, the analysis of the results was then done. Lastly, a full report of FYP 1 was written for this project.

Moreover, the flow of process is to be completed in the Final Year Project 2 (FYP 2) during this semester is shown in Figure 3.30. At first, the appropriate components for the implementation of the sensors are carefully chosen before purchasing. Software algorithm is integrated into the sensor module. Based on the reviews of research, the method for sensor designing is confirmed by using the alternative method, which is to buy the readily-made conductive silicone rubber keypad, taken from a calculator. A testing prototype is built following the schematic circuit to test the functionality of the components before proceeding with Printed Circuit Board (PCB) layout design circuit. The schematic diagram and PCB layout are done by using software, Autodesk EAGLE. As the testing prototype circuit is successfully tested, the confirmed PCB layout design is printed onto a PCB board. Next, the process of developing, etching, drilling, components placing and soldering are completed and the hardware prototype is being tested for its functionality. Once the functionality of the hardware prototype is validated, the results obtained is collected and analyzed. Lastly, the final report of the whole FYP 2 is improvised and then written for this project.

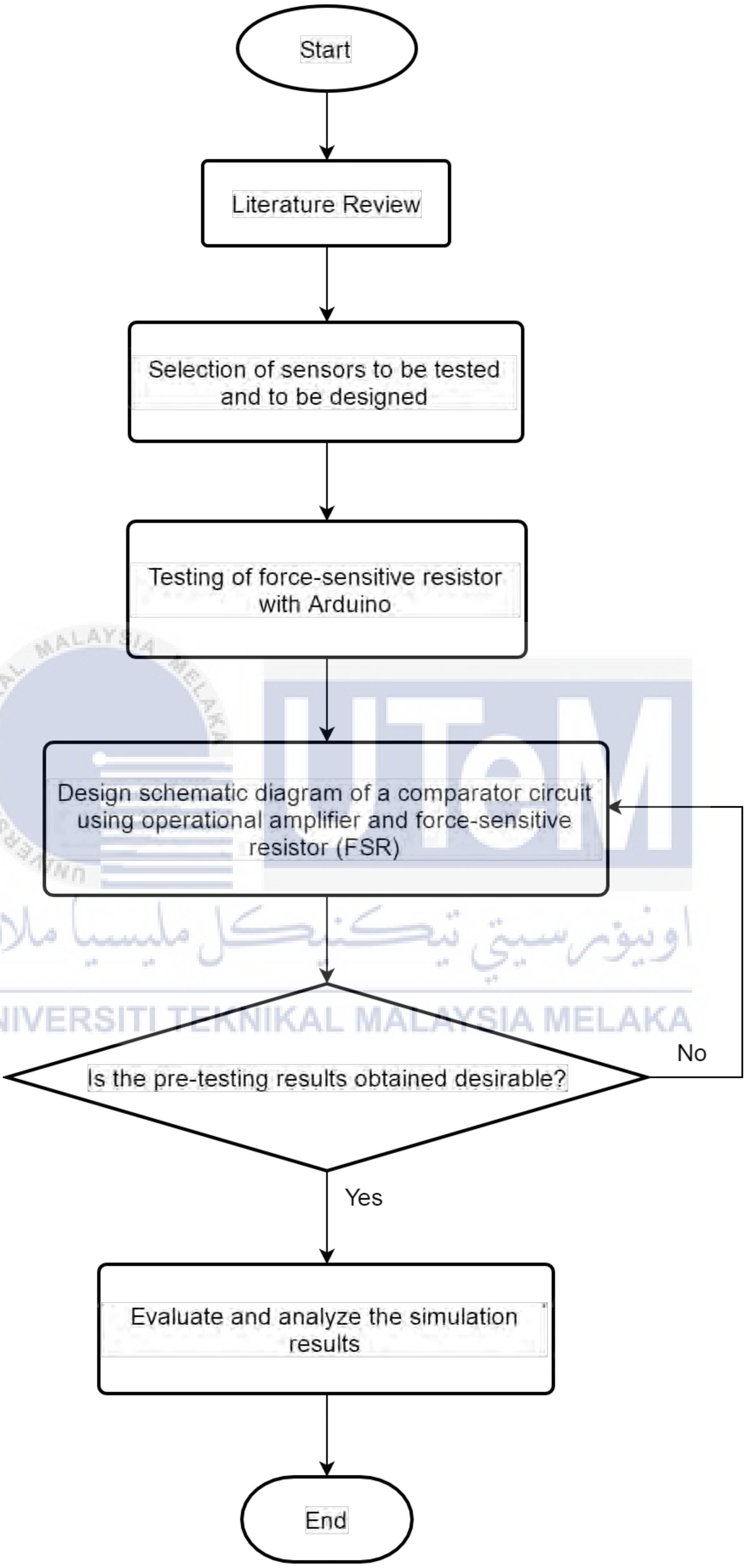

Figure 3.29: Flow Chart of Project Methodology for FYP 1

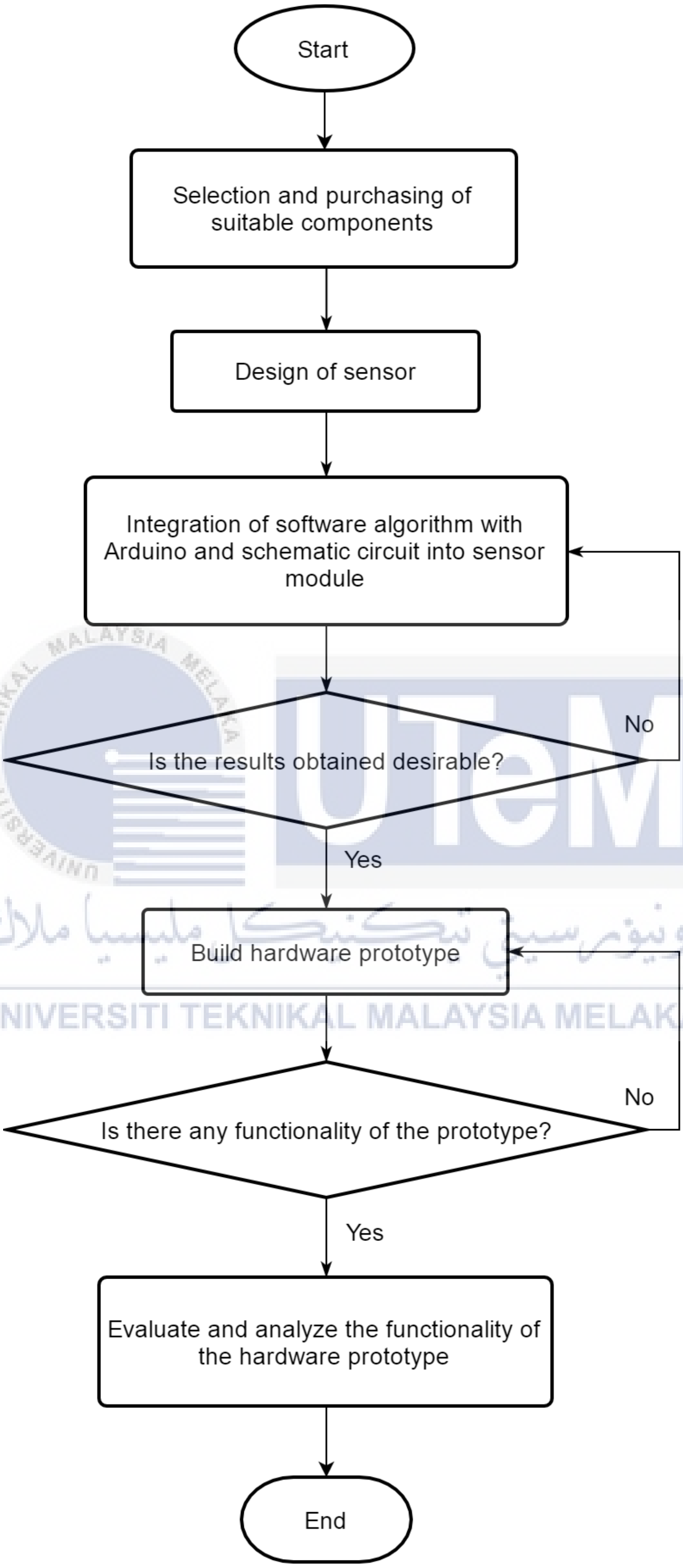

Figure 3.30: Flow Chart of Project Methodology for FYP 2

3.6.2 Milestone

The milestone assigned for the Final Year Project 1 done previously, was as shown below:

a) Milestone 1: Study and research on literature review
b) Milestone 2: Selection of sensors to be tested and to be designed
c) Milestone 3: Testing of force-sensitive resistor with Arduino
d) Milestone 4: Design of circuit using operational amplifier and force-sensitive resistor
e) Milestone 5: Pre-testing simulation of the circuit
f) Milestone 6: Report writing

The milestone assigned for this Final Year Project 2 is as shown below:

g) Milestone 7: Selection and purchasing of suitable components
h) Milestone 8: Design of sensor
i) Milestone 9: Integration of software algorithm with Arduino and schematic circuit into sensor module
j) Milestone 10: Pre-testing prototype circuit using shift registers and tactile switches
k) Milestone 11: Design of PCB layout and the making of PCB
l) Milestone 12: Functionality test of hardware prototype
m) Milestone 13: Report writing

3.6.3 Gantt Chart

Table 3.4: Gantt Chart of Final Year Project 1

Project Planning																	
No.	**Project Activity**	**Week**															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	Literature Review	■	■	■	■	■	■	■	■	■							
2.	Project Report Writing			■	■	■	■	■	■	■	■	■	■	■			
3.	Draft of Progress Report Submission													■	■		
4.	Progress Report Correction														■	■	
5.	Final Year Project Seminar															■	
6.	Final Progress Report Submission																■

Table 3.5: Gantt Chart of Final Year Project 2

Project Planning																	
No.	**Project Activity**	**Week**															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	Purchasing of Components	■	■	■	■	■	■	■	■	■	■						
2.	Design of Sensor		■	■	■												
3.	Testing of Prototype Circuit				■	■	■	■									
4.	Design and Making of PCB						■	■	■	■							
5.	Functionality Test of Hardware Prototype									■	■	■	■	■			
6.	Project Report Writing			■	■	■	■	■	■	■	■	■	■	■			
7.	Draft of Progress Report Submission													■	■		
8.	Progress Report Correction														■	■	
9.	Final Year Project Seminar															■	
10.	Final Progress Report Submission																■

CHAPTER 4

RESULTS AND DISCUSSION

This chapter covers about the results obtained from the testing of prototype circuit and experimental setup of hardware prototype, which had discussed earlier in Chapter 3. The results are analyzed and then, discussion is made.

4.1 Conductivity Test of Conductive Silicone Rubber Keypad

The conductive carbon pill underneath the conductive silicone rubber keypad has high resistance value, ranging from 15kΩ to 35kΩ each. As the conductive silicone rubber keypad rests on the PCB of switches circuit, and the switches circuit is opened, thus the value of voltage obtained is around 7mV. While, when the switches circuit is closed, the value of voltage approaches zero.

4.2 Testing of Prototype Circuit

The testing of prototype circuit is done by using mainly eight shift registers and 64 4-pin tactile switches, which is meant for testing purposes, before proceeding with hardware prototype. By doing so, errors and mistake could be reduced or even avoided in the process of producing the final hardware product later. Every component was tested with a multimeter for its functionality before using them. Besides, continuity test is done after each connection is made, by using a multimeter. The shift registers are used to control the multiple inputs of the switches, while the tactile switches are used to replicate the usage of a conductive silicone rubber keypad. The circuit is also connected to a microcontroller, Arduino. The coding used for the test is located at the Appendices section of this project paper.

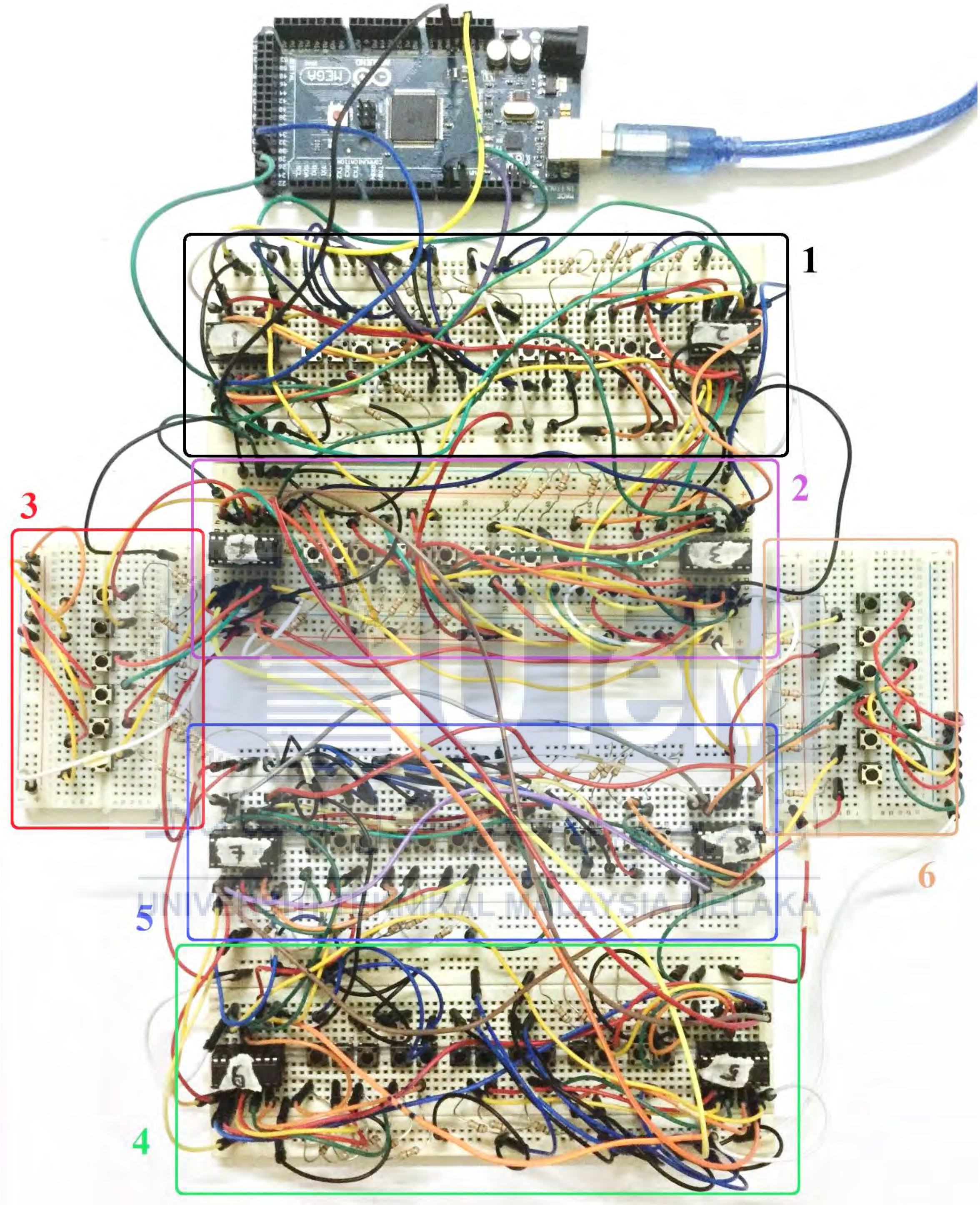

Figure 4.1: Testing of Prototype Circuit

Each of the eight shift registers are connected in daisy-chained method. It meant that the shift registers are connected in linear series. The Vcc (pin no. 16), GND (pin no. 8), CLK (pin no. 2), CLK INH (pin no. 15), SER (pin no. 10), and SH/$\overline{LD}$ (pin no. 1) of every shift registers are interconnected with each other. Meanwhile, the $\overline{Q}_H$ of every shift registers is connected to the Q_H (pin no. 9 of another shift register, from the first to the eighth shift registers. Also, the Vcc pin of the eight shift registers connected to 5V supply, which is supplied by the microcontroller, Arduino Mega 2560, and the GND is connected to the ground pin of the microcontroller.

The rest of the pins of the SN74HC165N shift registers such as the parallel inputs, namely A, B, C, and D (pin no. 11~14), then E, F, G, and H (pin no. 3~6), are connected to the keypad switches circuit, respectively. In another word, all eight of the shift registers, with eight parallel inputs, where each of the parallel inputs of all the shift registers are connected to the keypad switches circuit, which consisted of 64 keypad switches. The pin name, number, and function of the shift register can be seen from Table 3.1 shown earlier.

The 4-pin tactile switches are single pole, single throw (SPST) type of switches. Thus, each switch has an output and an input, suitable for on-off switching. One terminal of the switch is connected to parallel input of the shift register, while another pin is connected to a 10kΩ pull-down resistor.

By referring to Figure 2.1 as shown in chapter 2, the Figure 4.1 above are made based on the tennis court boundary line in Figure 2.1. The circuit on breadboard labelled as number 1 and 4 are representing the doubles side lines, whereas number 2 and 4 are representing the singles side lines on either side of a tennis court. In the meantime, the circuit on breadboard labelled as number 3 and 6 are representing the baselines on either side of the tennis court.

The figure below which are Figure 4.2, 4.3, 4.4, and 4.5 shows the output of the testing prototype whenever a tactile switch is pressed, in sequential form, in binary code format. The number “1” indicated the tactile switch was pressed or hold, while the number “0” states that the tactile switch was untouched or already been released from depressed.

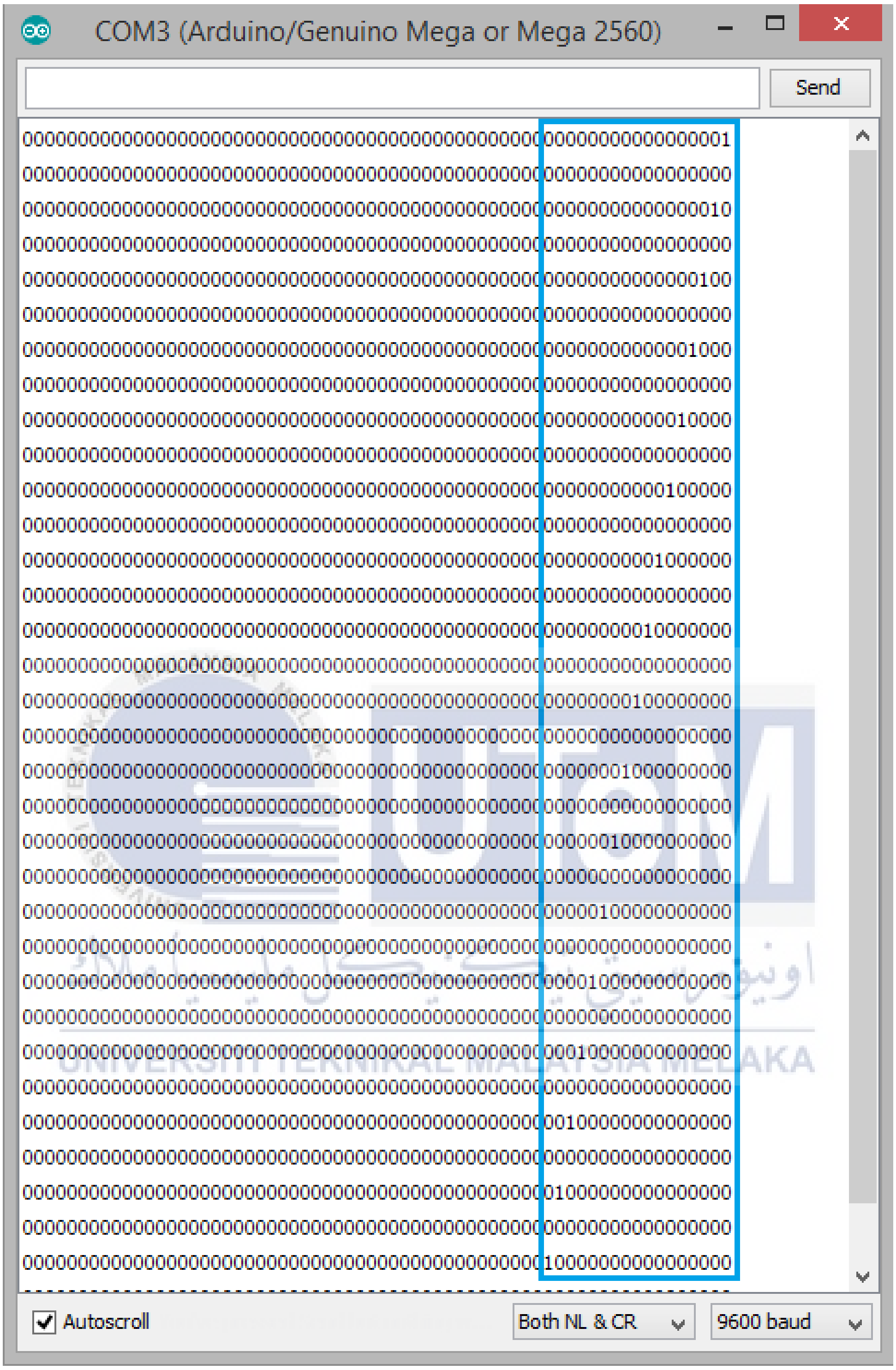

Figure 4.2: When Tactile Switches (SW1~SW16) is Pressed in Sequence

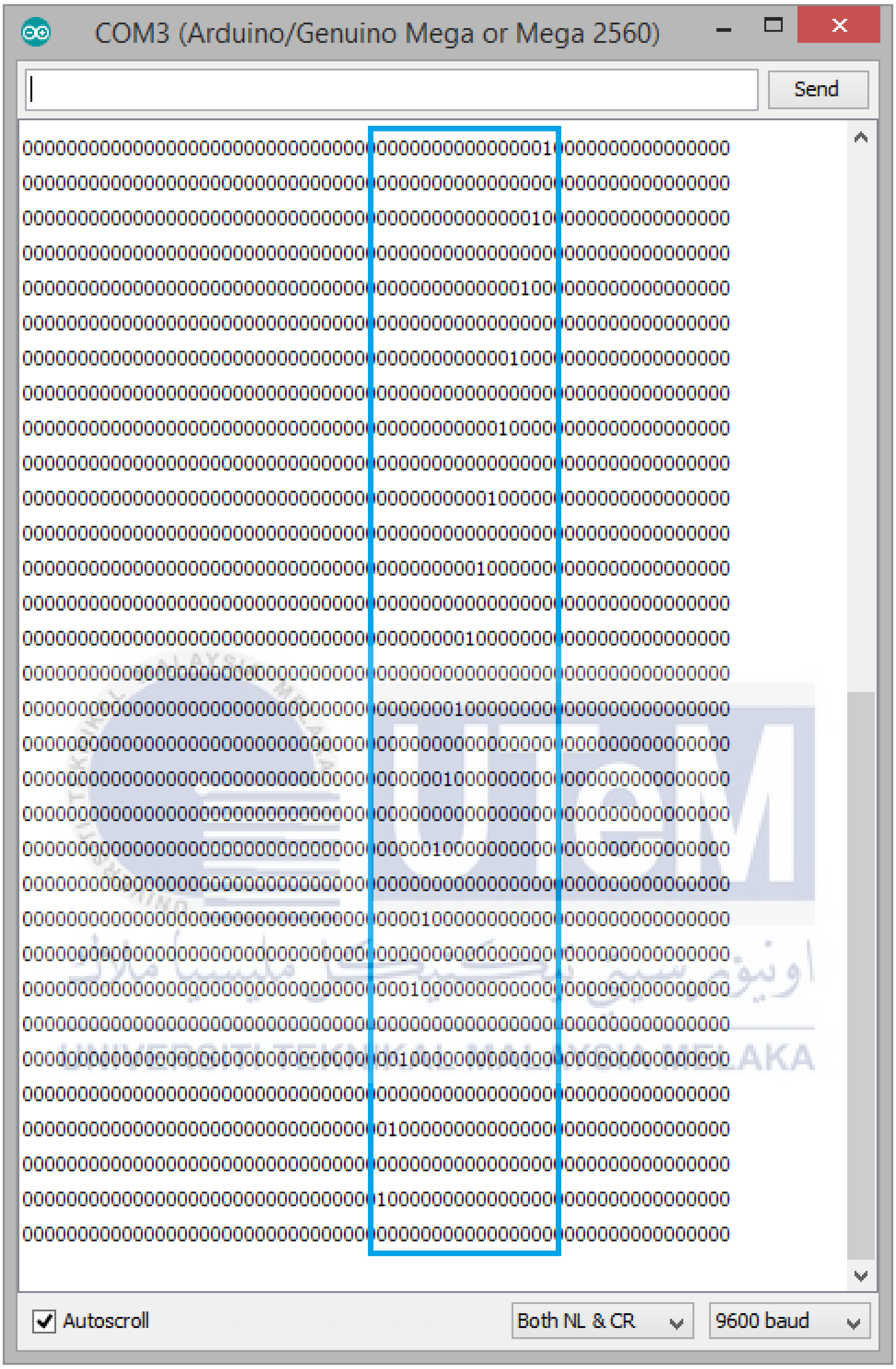

Figure 4.3: When Tactile Switches (SW17~SW32) is Pressed in Sequence

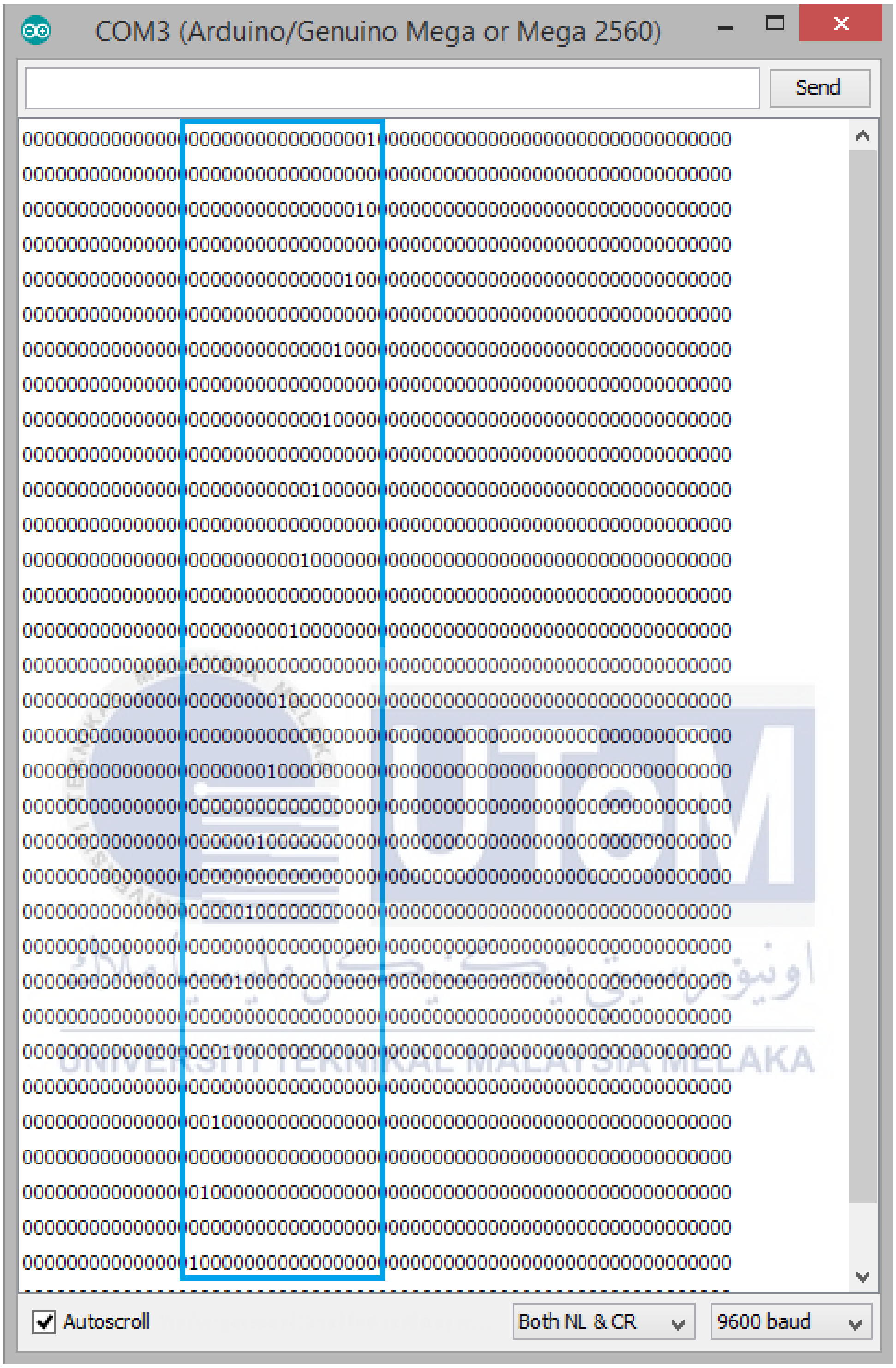

Figure 4.4: When Tactile Switches (SW33~SW48) is Pressed in Sequence

Figure 4.5: When Tactile Switches (SW49~SW64) is Pressed in Sequence

4.3 Experimental Setup of Hardware Prototype

The hardware prototype is produced after successful testing of the prototype circuit is done. The hardware prototype is a small-scaled tennis court, with a ratio scale of 1 cm to 6 feet. It is made up of medium-density fiber board (MDF) as the top and bottom base while wooden board is used as walls of the prototype. This enables the prototype to be sturdy and stable.

The figures from Figure 4.8 to Figure 4.12 show the hardware prototype comprising of the keypad switches circuit, shift registers circuit, and liquid crystal display (LCD) circuit, being powered by a voltage of 5V from the Arduino Mega 2560. The Arduino Mega 2560 is connected to the universal serial bus (USB) port of laptop. The components used in the keypad switches circuit consisted of 64 keypad switches designed on a PCB layout board, while in the shift registers circuit are eight daisy-chained shift registers.

The connection of the circuit is exactly same with the testing of prototype circuit, except the 64 4-pin tactile switches are replaced with conductive silicone rubber keypads and there were no resistors used due to the conductive silicone rubber keypad used contain carbon ink which have resistance value ranging from 15kΩ to 35kΩ each. It was obtained from a store and then cut in accordance of the sizing of the small-scaled tennis court.

At the inner side of the hardware prototype, it can be seen there are four PCB of shift registers circuit, where each of them containing two shift registers. It has a total of eight shift registers (SR1~SR8), with each of them connected to a 10-pin shrouded male header (H1~H9). Except for the first shift register (SR1) as it is connected to two headers (H1 & H2), where the first header (H1) is made to connect with the microcontroller, Arduino Mega 2560. Then, the rest of the headers will have connection with the headers from the keypad switches circuit.

Likewise, with the prototype testing circuit, the white lines as can be seen from Figure 4.6, shows the conductive silicone rubber keypad arranged in lines as the boundary line of a tennis sport courts floor. The PCB of keypad switches circuit are rested below the top base of the MDF board. It consisting of sixty-four keypad switches (SW1~SW64), with every eight of the keypad switches is connected to one of the 10-pin shrouded male header (H1~H8). The keypad switches have two terminals, one of which is connected to the header pin and the other one is connected to the ground pin (GND).

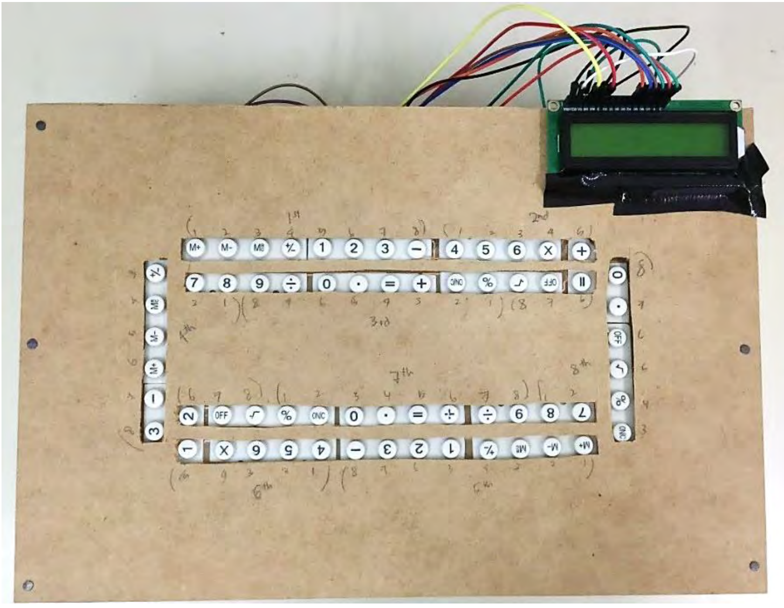

Figure 4.6: Top View of Hardware Prototype

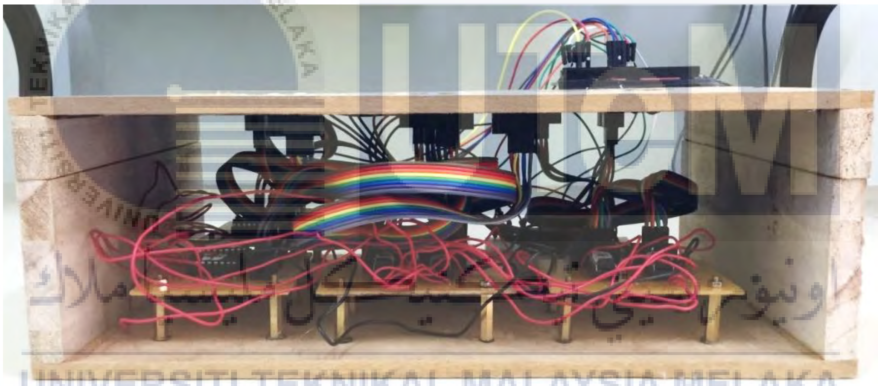

Figure 4.7: Side View of Hardware Prototype (back)

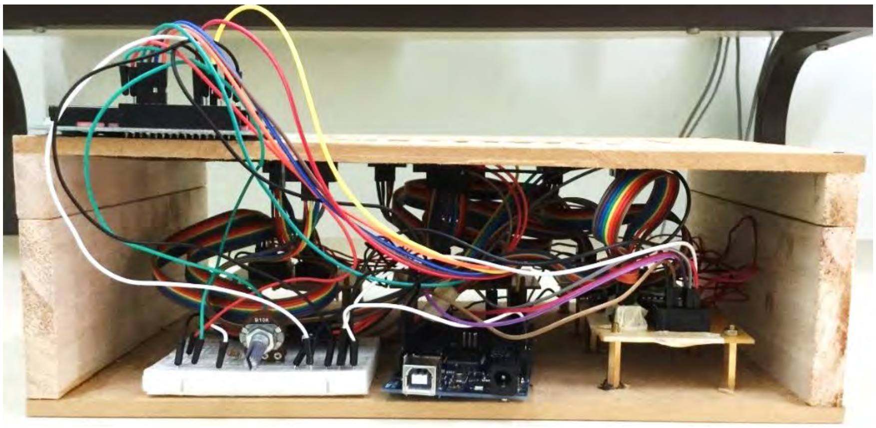

Figure 4.8: Side View of Hardware Prototype (front)

Figure 4.9: Side View of Hardware Prototype (left)

Figure 4.10: Side View of Hardware Prototype (right)

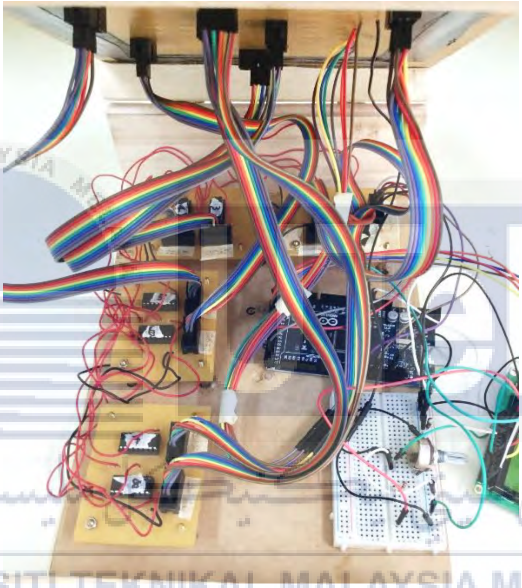

Figure 4.11: Elevated View of Hardware Prototype (side view)

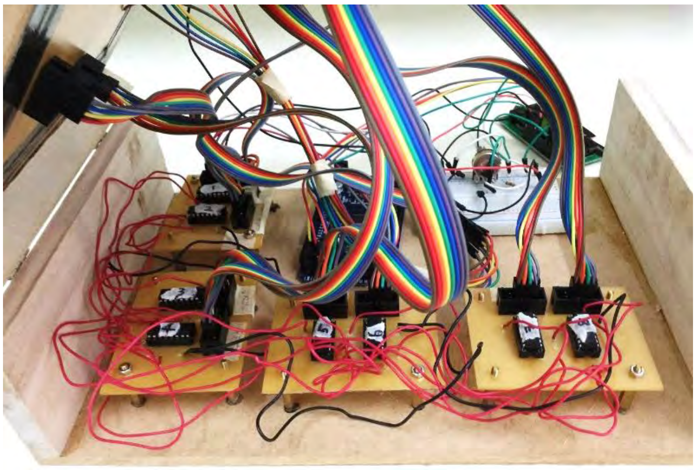

Figure 4.12: Elevated View of Hardware Prototype (inner view)

The LCD display circuit consists of a potentiometer and a 220Ω resistor. The potentiometer serves to adjust the backlight of the LCD display. Also, the rest of the LCD display pins are connected to the microcontroller, Arduino Mega 2560. The output of the hardware prototype will be displayed in terms of position as ‘IN!’ or ‘OUT!’.

Figure 4.13, 4.14, 4.15, and 4.16 show the results of the hardware prototype after the coding is uploaded from the Arduino IDE into the Arduino Mega 2560. The keypads on the hardware prototype were pressed randomly to test the functionality of the hardware prototype. A video demonstration of the hardware prototype testing and simulation is recorded. The results obtained from the hardware prototype are similar with the testing of prototype circuit, except that the hardware prototype has higher sensitivity of detection upon pressing conductive silicone rubber keypad.

4.4 Cost Evaluation of Hardware Prototype

Table 4.1: Price of Components Used

No.	List of Components	Units	Price (RM)
1.	Arduino Mega 2560	1	80.00
2.	Shift Registers SN74HC165N	8	16.00
3.	PCB UV Board	3	100.00
4.	4-pin Tactile Switches	64	-
5.	10kΩ Resistors	64	-
6.	16×2 Liquid Crystal Display (LCD)	1	25.00
7.	Male to Male Jumper Wires	40	8.00
8.	Male to Female Jumper Wires	40	8.00
9.	PCB Acid Developer	2	20.00
10.	PCB Ferric Chloride Acid	2	20.00
11.	Medium-density Fibreboard (MDF)	1	6.00
12.	Wooden Board	1	6.00
13.	Calculators	5	25.00
14.	10-pin Shrouded Male Headers	17	-
	TOTAL:		**314.00**

The table above shows the cost of producing the hardware prototype. Some of the components were taken from component store located in Electrical and Electronics Laboratory 2 in Block F, FKE. The hardware prototype system is considered low-cost for this small-scaled tennis court.

Figure 4.13: When Conductive Silicone Rubber Keypad is Pressed (1st)

Figure 4.14: When Conductive Silicone Rubber Keypad is Pressed (2nd)

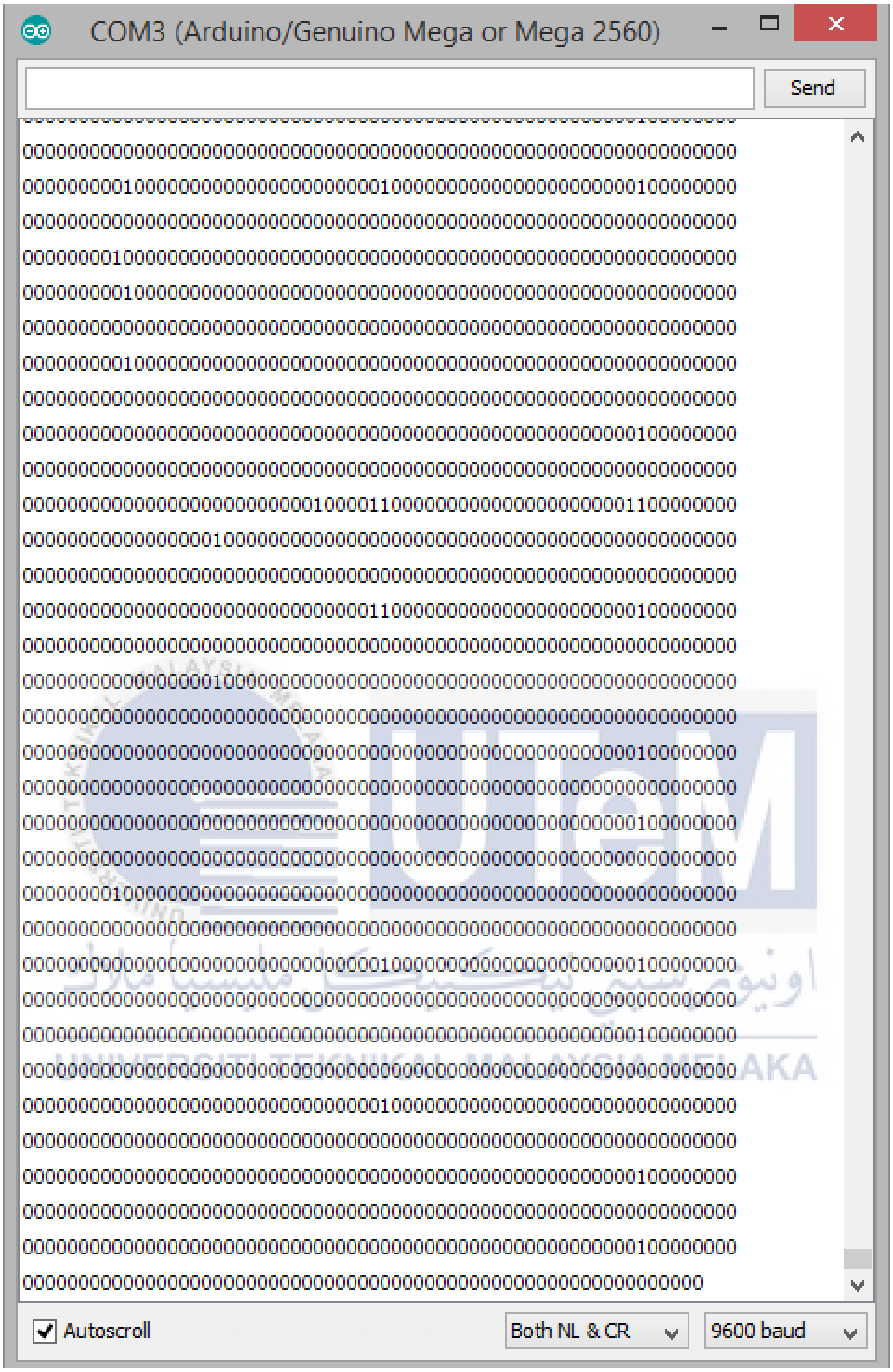

Figure 4.15: When Conductive Silicone Rubber Keypad is Pressed (3rd)

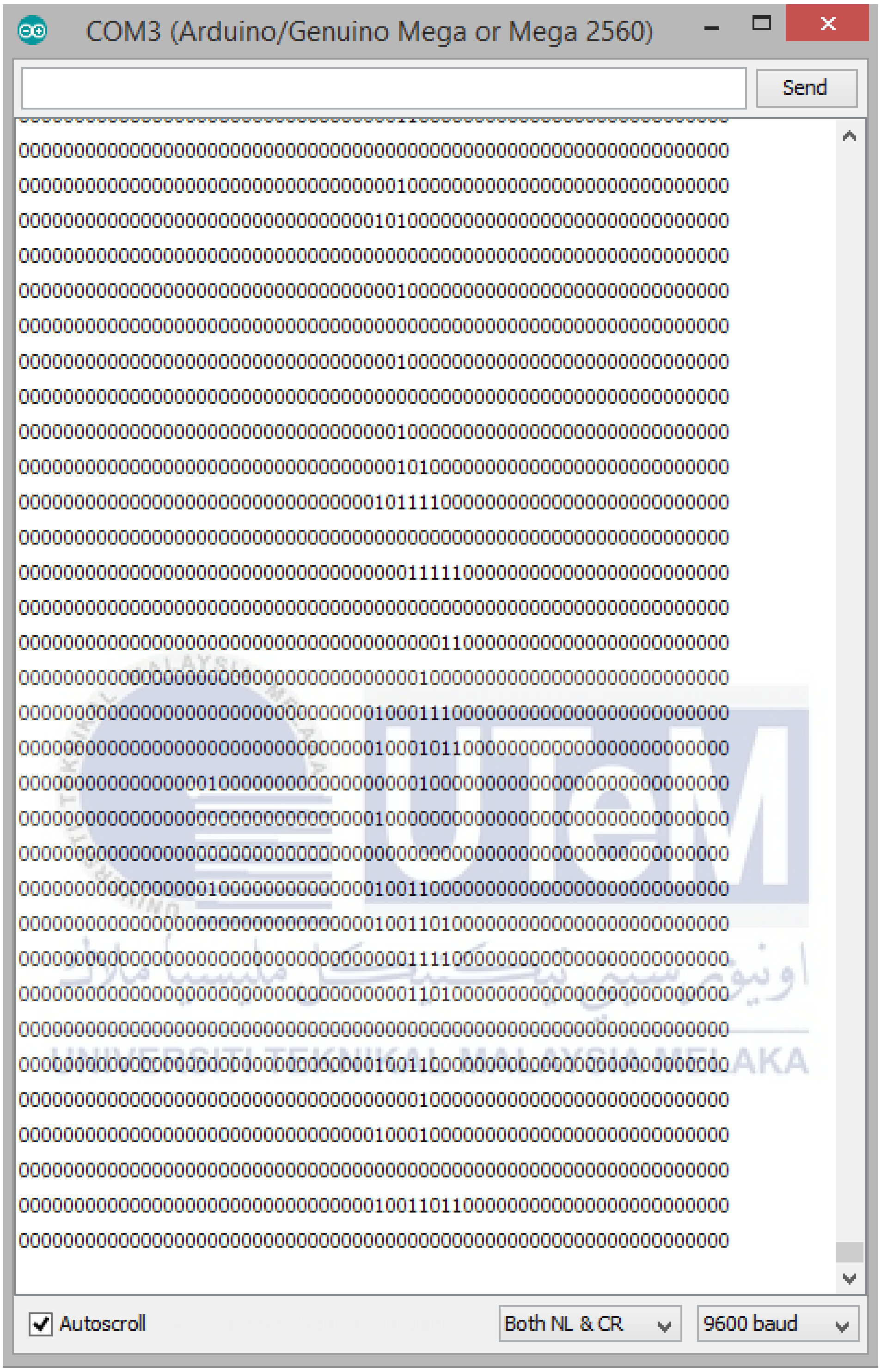

Figure 4.16: When Conductive Silicone Rubber Keypad is Pressed (4th)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter describes the conclusion gained throughout this project and the future works recommended that can be accomplished.

5.1 Conclusion

In summary, the testing of prototype circuit and the hardware prototype successfully tested.

Both the result of prototype testing circuit and hardware prototype were obtained. The output is in the form of position of the detected impact on the conductive silicone rubber keypad, which lies on the boundary line of the tennis sport court floor. The output is displayed on a LCD, showing 'IN!' or 'OUT!' as the result.

In the meantime, the objectives of identifying the parameters required for designation of sensor module has been achieved in FYP 1 during previous semester. The parameters such as forces and pressures were identified and the type of sensor to be used was determined.

In a nutshell, a low-cost sports court system application is implemented by using the designed sensor module, namely the conductive silicone rubber keypad. It has the properties of being pressure-sensitive and has electrical conductivity which allows electrical voltage to be able to pass through the silicone rubber whenever it is being pressed. Conductive silicone rubber keypads are undeniably robust and very simple to use, as it can be integrated easily with the use of a microcontroller, such as Arduino Mega 2560. It is also a fairly low-cost sensor. Lastly, a smart and cost-effective sport court system is developed.

5.2 Recommendation for Future Research

The implemented sport court system is not perfect and still has rooms for improvement. The flexibility of the system could be enhanced, to be able to differentiate between an impacted ball and a player's foot. This can be done by making measurements in terms of voltage or current to the circuit to analyze the force of the impact. The reason is because different type of impacts has different forces applied on to the surface of the sport court. The measurement in terms of detection of force applied by an impacted ball and a player's foot must be distinguished, to differentiate the detection of the ball and a human's foot. It is essential to know the maximum force that can be obtained from a moving tennis ball or a human footstep before any analysis could be made.

Thus, to improvise the low-cost sports court system application, modification in terms of hardware can be made on to the conductive silicone rubber keypad and the whole prototype circuit. Meanwhile, modification in terms of software can be done towards the coding of the Arduino IDE which will be uploaded into the microcontroller, Arduino Mega 2560.

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APPENDICES

Appendix A:

Coding for Testing Prototype Circuit using 8 Shift Registers and 64 4-Pin Tactile Switches

EightShiftRegisters | Arduino 1.6.12

File Edit Sketch Tools Help

EightShiftRegisters

```
#include <ShiftIn.h>

// Init ShiftIn instance with eight chips
ShiftIn<8> shift;

void setup() {
  Serial.begin(9600);
  // declare pins: pLoadPin, clockEnablePin, dataPin, clockPin
  shift.begin(28, 9, 11, 22);
}

void displayValues() {
  // print out all 64 buttons
  for (int i = 0; i < shift.getDataWidth(); i++)
    Serial.print( shift.state(i) ); // get state of button i
  Serial.println();
}

void loop() {
  if (shift.update()) // read in all values. returns true if any button has changed
    displayValues();
  delay(1);
}
```

Appendix B:

Coding for Final Hardware Prototype using 8 Shift Registers, 64 4-Pin Tactile Switches, and 16×2 LCD Display (page 1 of 2)

EightShiftRegistersLCD | Arduino 1.6.12

File Edit Sketch Tools Help

EightShiftRegistersLCD

```
#include <ShiftIn.h>
#include <LiquidCrystal.h>

// Init ShiftIn instance with eight chips
ShiftIn<8> shift;
// initialize the library with the numbers of the interface pins
LiquidCrystal lcd(52, 51, 45, 44, 43, 42);

void setup() {
  Serial.begin(9600);
  // declare pins: pLoadPin, clockEnablePin, dataPin, clockPin
  shift.begin(28, 9, 11, 22);
  // set up the LCD's number of columns and rows:
  lcd.begin(16, 2);
  lcd.print("Position:");
  lcd.setCursor(0, 0);
}

void displayValues() {
  // print out all 64 buttons
  for (int i = 0; i < shift.getDataWidth(); i++)
    Serial.print( shift.state(i) ); // get state of button i
  Serial.println();
}
```

Appendix C:

Coding for Final Hardware Prototype using 8 Shift Registers, 64 4-Pin Tactile Switches, and 16×2 LCD Display (page 2 of 2)

EightShiftRegistersLCD | Arduino 1.6.12

File Edit Sketch Tools Help

EightShiftRegistersLCD

```
  Serial.println();
}

void displayLCD() {
  if (displayValues > 0) {
    // Print a message to the LCD.
    lcd.print("IN!");
  }
  else {
    lcd.print("OUT!");
  }
}

void loop() {
  {
    if (shift.update()) // read in all values. returns true if any button has changed
      displayValues();
      displayLCD();
    delay(5);
  }
  // set the cursor to column 0, line 1
  // (note: line 1 is the second row, since counting begins with 0):
  lcd.setCursor(0, 1);
}
```

Appendix D:

TurnItIn Originality Report

Final Year Project (FYP2) by Soh May Ling

by Turnitin library1

FILE	FINAL_YEAR_PROJECT_FYP2_BY_SOH_MAY_LING.TXT (95.52K)		
TIME SUBMITTED	29-MAY-2017 12:06PM	WORD COUNT	15052
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