DEVELOPMENT OF A SYRINGE PUMP AND DRUM COLLECTOR FOR AN ELECTROSPINNING PROTOTYPE

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B092110391

BACHELOR OF MECHANICAL ENGINEERING TECHNOLOGY (Refrigeration and Air Conditioning System) WITH HONOURS

2025

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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A thesis submitted
in fulfilment of the requirements for the degree of
Bachelor of Mechanical Engineering Technology (Refrigeration and Air Conditioning) with Honours

Faculty of Mechanical Technology and Engineering

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2025

DECLARATION

I declare that this Choose an item. entitled “Development of a Syringe Pump and Drum Collector for an Electrospinning Prototype” is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : Mohamad Tarmizi bin Yusop ....

Date : 12/01/2025 ....

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology (Refrigeration and Air Conditioning) with Honours.

Signature :

Supervisor Name : Ts. Dr. Amir Abdullah Muhammad Damanhuri

Date : 12/01/2025

DEDICATION

I would like to dedicate my Bachelor Degree to my beloved family, for their endless encouragement, belief in my abilities and the one that give me an inspiration for not giving up in life and also who worked hard to give me some advice and financial support to finish my studies. To my supervisor, Ts. Dr. Amir Abdullah Muhammad Damanhuri that always taught some knowledge to complete this project. This project represents an acknowledgement to the collective effort that made it possible. Lastly, I want to thank all my friends for their encouragement and help to complete this project.

ABSTRACT

This project focuses on the development of a syringe pump and drum collector for an electrospinning prototype made for small-scale research applications. Electrospinning is a suitable technique used to fabricate nanofibers with significant applications in biomedical engineering and energy storage. However, the high cost of commercial electrospinning equipment limits its accessibility in academic and research contexts. This project emphasizes the design and fabrication of four main components: the syringe pump, drum collector, speed regulator, and control panel. The syringe pump uses a lead screw as a frame structure and system powered by a NEMA 17 stepper motor controlled through a DRV8825 driver, ensuring precise polymer solution flow. The control panel, based on an Arduino Uno R3 microcontroller, features an LCD and keypad interface for parameter input, such as flow rate and volume. The drum collector, equipped with a height-adjustable scissor lift mechanism, is driven by a DC motor for controlled rotational speeds. Additionally, this study includes a comparative analysis of the mechanical design and specifications of the developed prototype with an existing commercial electrospinning specifically the model CES20-S. The comparison evaluates cost-effectiveness, modularity, and functionality to highlight the feasibility of the prototype as a low-cost alternative for research applications. This prototype integrates affordable components to create a modular, efficient system for advanced nanotechnology research within a limited budget.

ABSTRAK

Projek ini memberi tumpuan kepada pembangunan pam picagari dan pengumpul dram untuk prototaip electrospinning yang dibuat untuk aplikasi penyelidikan berskala kecil. Electrospinning ialah teknik yang sesuai digunakan untuk membuat gentian nano dengan aplikasi penting dalam kejuruteraan bioperubatan dan penyimpanan tenaga. Walau bagaimanapun, kos tinggi peralatan elektrospinning komersial mengehadkan kebolehcapaiannya dalam konteks akademik dan penyelidikan. Projek ini menekankan reka bentuk dan fabrikasi empat komponen utama: pam picagari, pengumpul dram, pengatur kelajuan dan panel kawalan. Pam picagari menggunakan skru plumbum sebagai struktur bingkai dan sistem yang dikuasakan oleh motor stepper NEMA 17 yang dikawal melalui pemacu DRV8825, memastikan aliran larutan polimer yang tepat. Panel kawalan, berdasarkan mikropengawal Arduino Uno R3, mempunyai antara muka LCD dan pad kekunci untuk input parameter, seperti kadar aliran dan kelantangan. Pengumpul dram, dilengkapi dengan mekanisme angkat gunting boleh laras ketinggian, didorong oleh motor DC untuk kelajuan putaran terkawal. Selain itu, kajian ini termasuk analisis perbandingan reka bentuk mekanikal dan spesifikasi prototaip yang dibangunkan dengan electrospinning komersial sedia ada khususnya model CES20-S. Perbandingan menilai keberkesanan kos, modulariti dan kefungsian untuk menyerlahkan kebolehlaksanaan prototaip sebagai alternatif kos rendah untuk aplikasi penyelidikan. Prototaip ini menyepadukan komponen mampu milik untuk mencipta sistem modular yang cekap untuk penyelidikan nanoteknologi termaju dalam bajet yang terhad.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for taking me as a student at this university.

I extend my heartfelt appreciation to my supervisor, Ts. Dr. Amir Abdullah Muhammad Damanhuri who has helped me with precious guidance, words of wisdom and patient throughout this project.

Also, from the bottom of my heart a gratitude to my colleagues who are diligently working and collaborating with me on this project, especially those from BMKH section 1/1 and section 1/2 who are actually boosting our morale together.

Last but not least, I would like to thank all the student at the fellow colleagues and classmates, the faculty members, as well as other individuals who are not listed here for being cooperative and helpful.

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LIST OF SYMBOL AND ABBREVIATIONS

HVVPS	-	High voltage variable power supply
HVPS	-	High voltage power supply
DC	-	Direct current
PWM	-	Pulse width modulation
LED	-	Light emitting diode
SCM	-	Subsea control module
CO2	-	Carbon Dioxide
3D	-	Three-dimensional
PEMFCs	-	Proton Exchange Membrane Fuel Cells
SBS	-	Solution blow spinning
PS	-	Polystyrene
PSF	-	Polysulfone
PEO	-	Polyethylene oxide
PVA	-	Polyvinvl alcohol
NEMA	-	National electrical manufacturer association
LCD	-	Light crystal display

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CHAPTER 1

INTRODUCTION

1.1 Background

Over the last several decades, there have been major developments in the science of nanotechnology, with electrospinning becoming as a key method for the manufacture of nanofibers. These nanofibers, which have a high surface area-to-volume ratio and adjustable characteristics, are used in a variety of fields, including energy storage, textiles, biomedical engineering, and environmental remediation (Ramakrishna et al., 2006).

Using a strong electric field, the process of electrospinning turns a polymer melt or solution into tiny fibres. A polymer solution is put into a syringe and attached to a high voltage power source to begin the procedure. The polymer solution forms a charged flow that shoots out of the needle's tip when the voltage rises due to the electric field. As the polymer flow approaches a grounded target substrate, it becomes longer and thinner, causing the solvent to evaporate and solid polymer fibres to remain behind (Keirouz et al., 2023).

By depositing these fibres on the substrate, a non-woven mat or aligned structure is formed. Electrospinning may result in the production of very tiny fibres with diameters ranging from nanometres to micrometres. Applications including medication administration, tissue engineering, filtration, and composite materials can all benefit from this technology. Process variables like polymer content, solvent type, voltage, flow rate, and needle-to substrate distance may all be changed to affect the fibre’s characteristics, including diameter and shape.

The high expense of commercial electrospinning equipment, despite its usefulness, is a major obstacle, particularly in educational settings where funds are frequently tight. The cost effectiveness of producing nanofibers is a challenge in real-life applications due to factors such as yield, cost efficiency, reproducibility, and inconsistent quality, especially at the commercial scale (Nirwan et al., 2022).

Researchers have tried a number of times to lower the price of electrospinning apparatus. Researchers have looked into a number of strategies, including reusing old laboratory equipment, simplifying the design, and utilising off-the-shelf components. In spite of these attempts, a large number of inexpensive prototypes fall short of achieving the accuracy and dependability required for reliable nanofiber manufacturing.

The project aims to develop syringe pump control system for low-cost electrospinning machine application that is affordable, easy to use, and safe for user environments. The machine should provide a robust platform for teaching and learning, allowing user to engage with advanced technology and explore its applications.

1.2 Problem Statement

Nanofibers are more desirable for a variety of applications due to their many advantages in the commercial sector. Their large surface area-to-volume ratio is very helpful for filtration systems because it makes particulate matter collection more effective, which improves the efficiency of water and air purification procedures. This characteristic improves ion transport and enhances efficiency, making them highly useful in energy storage systems like batteries and supercapacitors. Additionally, the biomedical sector benefits from the high porosity and tiny hole size of nanofiber membranes, which are employed in tissue engineering to create scaffolds that recreate the extracellular matrix and encourage cell growth and tissue regeneration.

Producing high-quality nanofibers for industrial use requires careful control of several variables. The choice of material or polymer is critical as it defines the nanofiber's properties. Additionally, the solution's concentration and viscosity significantly affect the fibre's shape and formation during the electrospinning process. Optimal values of these parameters ensure the production of uniform, perfect nanofibers. Good nanofiber production also requires precise adjustment of process parameters including flow rate, tip-to-collector distance, and applied voltage to obtain the required fibre diameter and alignment.

To produce nanofibers the development of a simple and affordable prototype electrospinning machine is essential. An important component is the syringe pump control panel, which regulates the flow rate of the polymer solution during electrospinning and drum collector to collect the nanofiber. By develop and fabricating prototype a control panel and drum collector that is both reliable and cost-effective it can produce a good nanofiber for application.

1.3 Research Objective

This project intended to develop of a syringe pump and drum collector for an electrospinning prototype. Therefore, this research objective as follows:

i. To develop and fabricate prototype of syringe pump control system and drum collector for low-cost electrospinning machine application.

ii. To compare the mechanical design and specifications of the developed syringe pump control system and drum collector prototype with commercially available electrospinning machines, emphasizing cost-effectiveness, design features, and potential functionality.

1.4 Scope of Research

The project aims to developed of a syringe pump control system and drum collector for an electrospinning prototype with a specific focus on the control panel, syringe pump and drum collector. The control panel will be designed to provide precise and user-friendly management of the electrospinning process. The control panel will used an Arduino Uno R3 as main part and connect to the LCD display and DRV 8825 driver will connect to NEMA 17 stepper motor.

Delivering the polymer solution at a regulated and constant rate is the function of the syringe pump, an important part of the electrospinning machine. The objective of this research is to maintain high precision in flow rate control while studying cost-effective options for the syringe pump design and the syringe pump is made to hold a single syringe with a volume of 10 ml.

The drum collector offers operational flexibility with a height range of 20 to 40 cm. It is possible to precisely position the syringe pump and drum collector for optimal electrospinning by adjusting the distance between them between 0 and 20 cm. Although suitable materials can be used for manufacturing the syringe pump and drum collector, mild steel will be used in this project to ensure cost-effectiveness and durability.

The system will design to meet the requirements small scale research like laboratory university or beginner student while maintaining affordability. The project excludes large scale manufacturing and focuses on the development and testing of a prototype system.

CHAPTER 2

LITERATURE REVIEW

2.1 Historical of Electrospinning Machine

The first technique for creating nanofibrous materials from polymer solutions was patented in 1934 by Anton Formhals. Jayesh Doshi and Darrell Reneke's research in the early 1990s marked the beginning of the contemporary age of electrospinning (Keirouz et al., 2023).

The electrospinning machine's history began in the early 1900s, when John Francis Cooley submitted electrospinning-related patent applications in 1900, 1902, and 1903. Using high electrical current to fabricate textile yarns from cellulose acetate, Antonin Formhals made a significant breakthrough in 1934. One well-liked technique for creating continuous nanomaterials with different chemical, biological, and physical characteristics is electrospinning. Using various types of nozzles, such as clip, tube-less, co-axial, and heating nozzle, as well as creating mutual repulsive forces to overcome surface tension in the charged polymer liquid, are all part of setting up an electrospinning machine. By applying a high voltage between the collector and needle, a charged polymer is created. The schematic illustration of electrospinning principle and set up is shown in Figure 2.1. The different type of nozzles, electrospinning machine consist of three components, high voltage power supply (HVPS), capillary tube with needle and collecting screen is shown in Figure 2.2 (Islam et al., 2019).

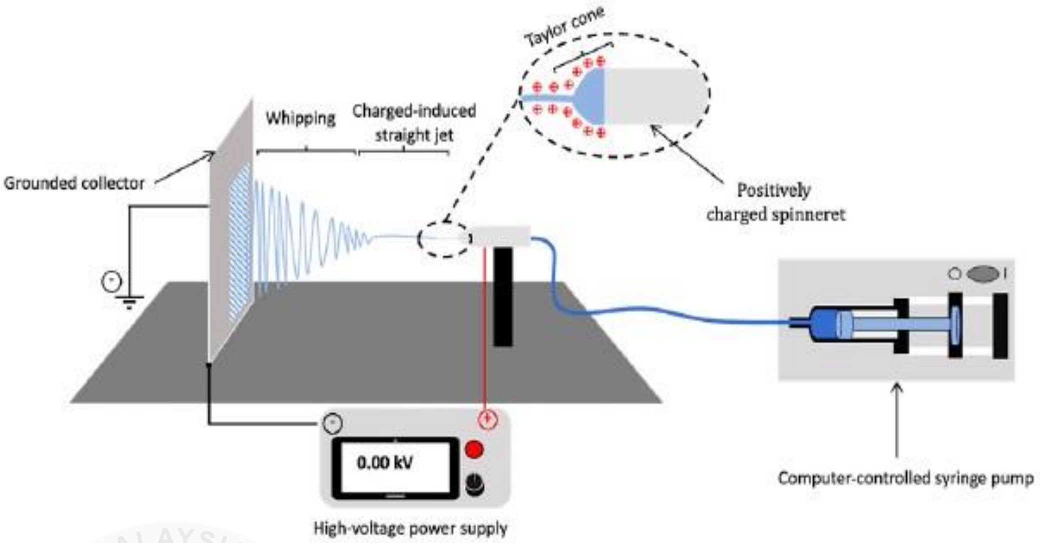


Figure 2.1 Schematic illustration of electrospinning principle and set up (Abdulhussain et al., 2023)

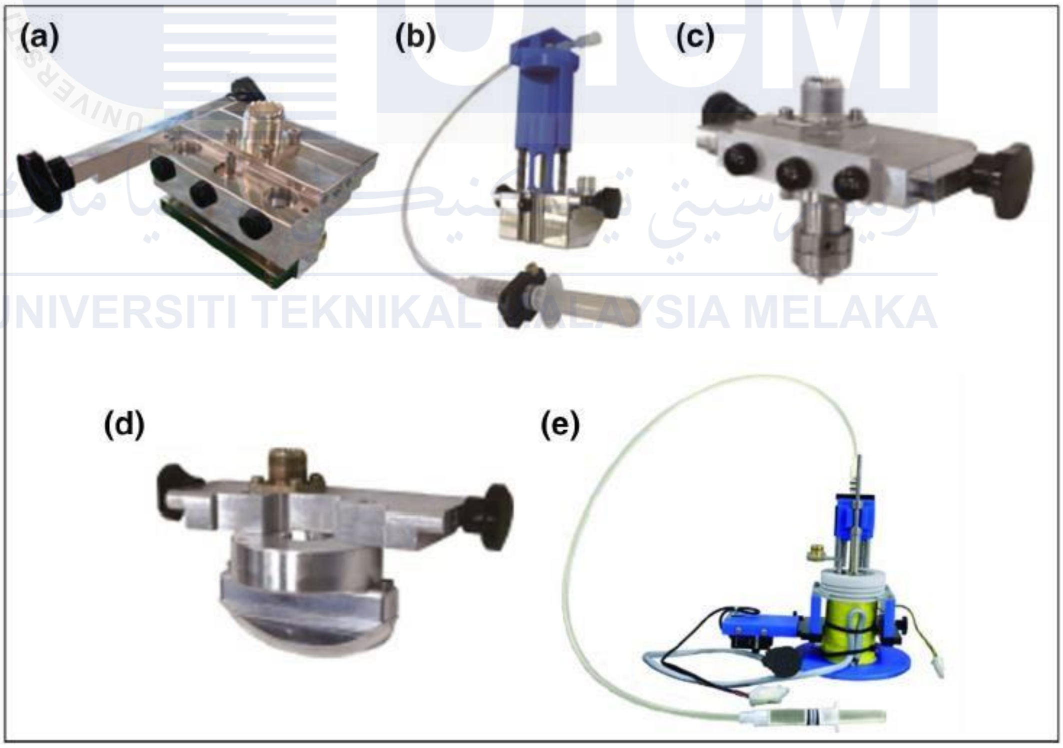


Figure 2.2 Different types of nozzle (a) clip nozzle, (b) tube-less nozzle, (c) coaxial nozzle, (d) multi jet nozzle, (e) heating nozzle (Islam et al., 2019)

Electrospinning is a popular method used to fabricate nanofibers by utilizing a high voltage electric field to charge and eject a polymer solution through a syringe. These nanofibers have a large surface area-to-volume ratio and can be tailored for specific applications such as tissue engineering scaffolds, filtration membranes, and drug delivery systems. The development of low-cost electrospinning machines has become crucial to democratize access to this technology, particularly in research and small-scale manufacturing settings (Dewi Wijayanti et al., 2022).

2.2 Overview of Electrospinning Machine

Electrostatic forces are used in the process of electrospinning to create tiny fibres, usually in the submicron range. The process spins polymer solutions or melts them into nanofibers using a high voltage electric field. Electrospinning has come a long way since the 1930s, and in the last several years, it has made major progress. Understanding the procedure, adjusting parameters, and investigating the uses of nanofibers have been the main research goals. The electrospinning procedure involves adding charges into the polymer solution, creating a projection resembling a cone at the capillary's tip, and expelling a jet of liquid, which hardens into fibres after the solvent evaporates. The method is easy to use and flexible, which makes it a useful way to create nanofibers with large surfaces and tiny pores (Keirouz et al., 2023).

The amount of polymer used, the solvent, and process variables including applied high voltage, drum collector distance, and spinning environment all affect how many nanofibers are produced. It's critical to comprehend and regulate these parameters for effective nanofiber manufacturing since studies have demonstrated how fluctuations in these parameters can affect fibre shape, diameter, and pore size (Reneker & Yarin, 2008).

Since nanofibers have special mechanical and thermal characteristics, their large surface area and porosity make them ideal for a range of uses, including tissue scaffolds, drug delivery systems, and catalytic materials. Electrospinning is still difficult to scale up commercially, although research is still being done to improve productivity and regulate fibre diameter for more uses (Muthukrishnan, 2022).

2.2.1 Electrospinning Principle

The principles of hydrodynamics and the application of electrostatic forces to stretch and solidify a polymer solution, electrospinning is a method for creating polymer nanofibers. A high-voltage capillary needle is used in the procedure to introduce a polymer, which causes the polymer to stretch and create nano-scale fibre mats onto a grounded collector. Numerous variables, including voltage, polymer properties, flow velocity, and collector distance, impact the electrospinning procedure. A syringe pump, a collector, and a high-voltage power source are usually included in an electrospinning system. Producing smooth, bead-free nanofibers depends critically on a few device, solution, and ambient factors, such as humidity, solvent concentration, needle-to-collector distance, electric field, and solvent concentration. The applied voltage is a key factor in fibre formation, inducing the stretching and deformation of the polymer solution droplet at the needle tip, leading to the formation of the Taylor cone and subsequent jet formation (Abdulhussain et al., 2023).

The principle of electrospinning involves the application of high voltage to polymers in solution or melt, resulting in the spinning of micron- or even nanometre-sized fibres. These nanofibers possess advantageous characteristics such as high porosity and specific surface area, making them suitable for various applications (Jin et al., 2023).

2.2.2 Electrospinning Technique

The flexible method of electrospinning is used to create nanofibers from melts or solutions of polymers. There are several electrospinning processes, each designed to produce certain fibres shapes and qualities. Under various titles and classifications, such as top-down and bottom-up procedures, physical, chemical, and biological approaches, or spinning and non-spinning methods, nanofibers can be created using a variety of manufacturing processes (Anusiya & Jaiganesh, 2022).

There are various techniques have been used in electrospinning, including needleless ultrasound-enhanced electrospinning, cold-plate electrospinning, and dual-rotation corona electrospinning (Keirouz et al., 2023).

2.3 Concept of Electrospinning Design

The concept of developing a low cost electrospinning machine involves creating an affordable device that can produce ultrafine fibres from polymer solutions or melts, enabling researchers and small-scale manufacturers to explore nanotechnology applications without high equipment costs. The project was designed for specific applications and is divided into three components, which are the drum collector, syringe pump and high voltage variable power supply (HVVPS). The syringe pump and drum collector sections are linked to the control panel, which controls the operation of the system. The three main components of a common electrospinning system are a collector, a syringe pump with a steel needle, and a high voltage power supply (HVPS) (Abu Owida et al., 2022).

The syringe pump connected to control panel because to adjust the speed flow rate syringe. The components used in the automated device for producing sub-micrometric polymer fibres based on the Solution Blow Spinning method include Arduino Nano microcontrollers, A9488 stepper driver, NEMA 17 stepper motor, DC motor, TB6612FNG DC motor driver, Bluetooth module, switch, and career switch (Domínguez et al., 2021).

2.3.1 Control Panel

The function of the control panel in an electrospinning machine is to provide operators with a centralized interface to monitor and adjust parameters such as voltage, flow rate, and spinning duration, ensuring precise control over the electrospinning process for consistent nanofiber production.

2.3.2 Syringe Pump

The function of a syringe pump in an electrospinning machine is to precisely control the flow rate of polymer solution or melt, ensuring a consistent and uniform supply of material to the spinneret to produce nanofibers. By pressing the injection pump, whose speed has been set to match the flow rate, the syringe pump operates. By adjusting the stepper motor is delay time with pulse width modulation (PWM) pins from the Arduino Uno, the speed, flow rate, and volume can be determined (Supriyanto et al., 2021).

Key components of the stepping motor control system include the ATMEL89C51 microcontroller, motor driver chips, buttons, power and clock circuits, LED modules, SCM control module, control circuit, magnifying and driving circuit, and LED display of common anode in serial port mode. Additionally, a step pulse generator module is part of the system. Block diagram of stepper motor control system is shown in Figure 2.3 (Qi et al., 2011).

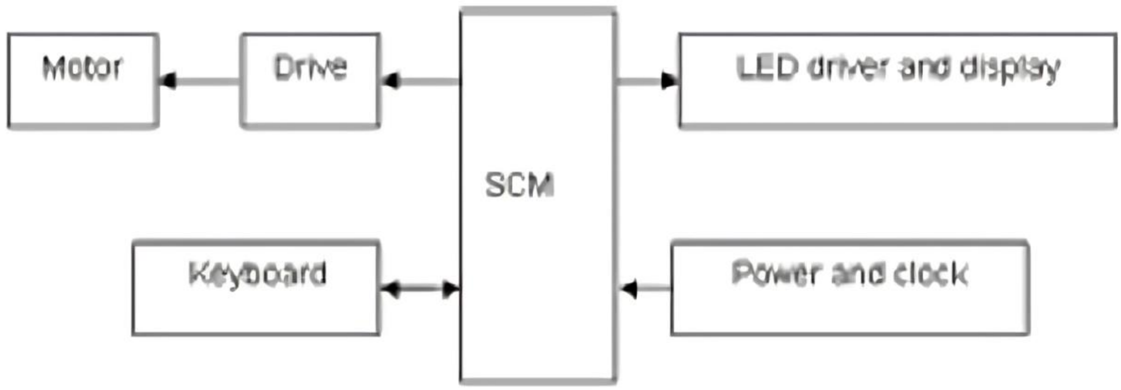


Figure 2.3 Block diagram of stepper motor control system (Qi et al., 2011)

The automatic syringe injection pump achieves an injection speed of approximately 0.17 cc per second by using a three-step motor that requires 2000 pulses for every cc of fluid injected into the patient. Each motor pulse lasts 3 ms, resulting in the ideal injection speed (Jafarzadeh & Farokhi, 2016).

2.3.3 Drum Collector

The function of a drum collector in an electrospinning machine is to collect and accumulate the electrospun nanofibers onto a rotating drum surface, forming a uniform and continuous nanofiber mat for various applications such as tissue engineering scaffolds or filtration membranes. Due of its high conductivity, aluminium is used to make the collectors primary body, which is where the fibres are gathered. Polyethylene, a non-conductive material, makes up the remaining collection parts. An aluminium tube set atop a circular piece of polyethylene served as the cylinder collector. Moreover, only the bars in wire drum and parallel bar collectors as well as the four sides of the polygon collector are composed of aluminium. Common lathe and milling tools and equipment, including as reamers, taps, and column drills, are utilised in the building of collectors. Carbon dioxide (CO2) laser cutting equipment and plexiglass are used to create the bases. Refer Figures 2.4 different the manufactured collectors (Sheikhi et al., 2024).

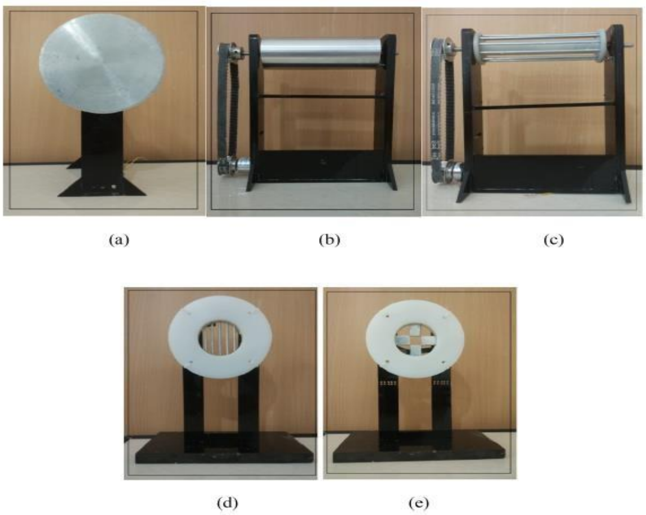


Figure 2.4 Different collector (a) plate or disc, (b) cylinder, (c) wire drum, (d) parallel bars, (e) polygon (Sheikhi et al., 2024)

2.3.4 High Voltage Variable Power Supply (HVVPS)

The function of the high voltage variable power supply in an electrospinning machine is to provide the necessary electrical voltage to create an electric field that draws and stretches polymer fibres from the spinneret, enabling the production of nanofibers with controlled diameter and morphology. The in-house built electrospinning machine comprises various components, including a High Voltage Variable Power Supply (HVVPS) and a syringe pump, among others, to facilitate the fabrication process. Refer Figure 2.5 the components HVVPS used in electrospinning (Dewi Wijayanti et al., 2022).

Figure 2.5 Shows the high voltage variable power supply (HVVPS)

(Dewi Wijayanti et al., 2022)

2.3.5 Type of Polymer and Solvent Used

The materials selected for the low-cost construction of the automated device to produce sub-micrometric polymer fibres based on the Solution Blow Spinning (SBS) method included polymers such as polystyrene (PS), polysulfone (PSF), and polyethylene oxide (PEO) (Domínguez et al., 2021).

Polyvinyl alcohol (PVA) was used as the polymer in the fabrication of nanofibers (Dewi Wijayanti et al., 2022). The type of polymer used in an electrospinning machine to produce fibres can vary, but for this experiment is polyvinyl alcohol (PVA) (Jin et al., 2023). The electrospinning machine is fabricated using polyvinyl alcohol (PVA) as the liquid or solution for the experiment, with a concentration of 10 wt% (Supriyanto et al., 2021).

The chosen qualities and uses can influence the choice of polymer fibres for electrospinning. For the electrospinning of nanofibers, a variety of polymers have been used, including Poly (methyl methacrylate-random), Polyethylene terephthalate, Polyaniline/PEO blends, Polyvinyl chloride, Polyethylene oxide, Polyvinyl alcohol, Cellulose acetate, Poly (2-hydroxy ethyl methacrylate), Polystyrene, Poly (ether amide), Silk-like polymer with fibronectin functionality, Polyurethane, Polycaprolactone, Styrene-Butadiene-Styrene triblock copolymer, and Poly-L-Lactide (Subbiah et al., 2005).

The polymers used in electrospinning include Polycarbonate, Poly acrylic acid, Collagen-I, and Collagen-II. For specific application, there are different mixture between polymer and solvent. Refer table 2.1 electrospinnable polymers (Islam et al., 2019).

2.4 Application of Electrospinning Machine

Potential uses in a variety of industries, including energy, medicine, food industry and environmental protection. Nanofibers have various applications in biomedical fields such as tissue engineering, wound dressing, stent coating, drug delivery, and antibacterial films (Nirwan et al., 2022).

2.4.1 Application in Nanofiber Based on Healthcare

Electrospun nanofibers can be utilized in healthcare applications for various purposes such as tissue engineering, drug delivery, skin revitalization, vascular stents, bone void fillers, hernia repairs, and general tissue repairs. They can also be used in diagnostics for disease and genetic screening, as well as in medical instruments for filtering membrane impermeable biomolecules, bacteria, and viral particles. Their high surface area-to-volume ratio and fine structure make them ideal for creating biomimetic scaffolds that promote cell growth and tissue regeneration (Ramakrishna et al., 2006).

Nanofibers have been utilized in drug delivery systems to achieve efficient and controlled release of drugs specific to tissues or cells for defined periods of time. Additionally, nanofiber-based drug delivery systems offer controlled release of therapeutic agents, improving treatment efficacy and patient outcomes. In wound care, nanofiber dressings provide enhanced breathability, moisture management, and antibacterial properties compared to traditional materials. Furthermore, nanofiber membranes are used in filtration applications to remove contaminants and pathogens from air and water, contributing to improved public health and environmental sustainability (Muthukrishnan, 2022).

2.4.2 Application in Nanofiber Based on Energy Generation

There are several uses for electrospun nanofibers in the energy generating process. By using them, energy storage and conversion efficiency may be increased by creating electrodes and membranes for batteries and fuel cells. Furthermore, the development of renewable energy technologies can benefit from the use of nanofibers as parts of solar cells and thermoelectric devices. Nanofiber membranes have the potential to be used in Proton Exchange Membrane Fuel Cells (PEMFCs) for electricity generation. These membranes can enhance proton conductivity and water retention, making them suitable for use in PEMFCs (Ramakrishna et al., 2006).

2.4.3 Application in Nanofiber Based on Food Industry

Electrospun fibers with immobilized enzymes have potential applications in food processing, particularly in enhancing food quality in terms of nutritional value, flavours, and freshness. To increase the nutritional value of food, for example, anti-nutritional components can be broken down by enzymes. Furthermore, by disassembling complicated compounds into simpler, more tasty parts, they can aid in the development of more potent and appealing flavours. Furthermore, by halting the development of bacteria that cause food to decay and reducing the oxidative processes that cause food to deteriorate, the usage of these fibres can help preserve the freshness of food. Innovative food processing methods like this one have the potential to develop food items that are more nutritious, delicious, and long-lasting, which will benefit food producers and consumers alike (Jankowska et al.,2023).

2.5 Comparison Past Studies on Development of Electrospinning Machine

The past studies were about the component, development and technology of electrospinning machine. As some of component and technology used was different for each project, the result will be slightly different for development electrospinning machine. Refer Table 2.1 past studied on development of electrospinning machine.

Table 2.1 Comparison past studies on development of electrospinning machine

No	Title	Author	Method
1	An ultra-low-cost and adjustable in-house electrospinning machine to produce PVA nanofiber (2022)	Ika Dewi Wijayanti, Ari Kurniawan Saputra, Faris Ibrahim, Amaliya Rasyida, Putu Suwarta, Indra Sidharta (HardwareX)	The electrospinning machine described in the document utilizes components such as DC motors, a stepper motor, and a cover made of acrylic. The machine is developed to fabricate nanofibers using the electrospinning process. The technology used includes Arduino support for smooth operation and the electrospinning fabrication method for achieving controllable morphology of nanofibers
2	Designing an Integrated Low-cost Electrospinning Device for Nanofibrous Scaffold Fabrication (2022)	Hamza Abu Owida, Bashar Al-haj Moh'd, Mohammad Al Takrouri (HardwareX)	The components of the electrospinning machine include a high voltage power supply (HVPS), a syringe pump, and a collector. The development of the electrospinning machine involves using off-the shelf and low-cost components, with structural elements being 3D printed. The technology used in the electrospinning machine includes a high voltage power supply with a simple main single switch, step-up transformer, rectifier circuit, high voltage capacitor, and embedded voltage reading circuit with LCD for accurate voltage measurement.

Table 2.1 Comparison past studies on development of electrospinning machine (Continued)

no	Project Title	Journal Author	Comment
3	Automated low-cost device to produce submicrometric polymer fibres based on blow spun method (2021)	José E. Domínguez, E Olivos, Carlos Vázquez, J.M. Rivera, Rigoberto Hernández-Cortes, Javier González-Benito (HardwareX)	The components of the electrospinning machine include a syringe pump, a collector, and a 3D printed nozzle. The development of an electrospinning-based rapid prototyping technique has been presented for the fabrication of patterned scaffolds from fine fibres with high repeatability and reproducibility. The technology used in electrospinning includes the use of a syringe pump, a collector, and a 3D printed nozzle.
4	Design of stepping motor control system based on AT89C51 microcontroller (2011)	QI Fa -Qun, JING Xue-Dong, ZHAO Shi-qing (Procedia Engineering)	The development used in an electrospinning machine includes a microcontroller, motor driver chips, buttons, LED display module, step pulse generator module, optical coupler, 74HC244 chips, power amplifiers, and AT89C51 microcontroller.
5	Design and construction of an automatic syringe injection pump (2016)	Mohsen Jafarzadeh, Fardad Farokhi (Pacific Science Review A: Natural Science and Engineering)	Based on the provided document, the components used in an electrospinning machine include a syringe, fluid bag, clamp or hook, tube, small gears, and a roller. The technology used in an electrospinning machine includes the use of three-step motors for manufacturing the injection device
6	A Control System on the Syringe Pump Based on Arduino For Electrospinning Application (2021)	Amir Supriyanto, Rani Anggriani, Sri Wahyu Suciyati, Arif Surtono, Junaidi and Sutopo Hadi (Journal of Physical Science)	The components used in an electrospinning machine include a syringe pump, stepper motor, Arduino Uno microcontroller board, four-digit seven-segment display, and keypad matrix as an input interface. The technology used in the electrospinning machine includes pulse width modulation (PWM) of stepper motors based on the Arduino Uno microcontroller board.

Table 2.1 Comparison past studies on development of electrospinning machine (Continued)

no	Project Title	Journal Author	Comment
7	Multi-material electrospinning: from methods to biomedical applications (2023)	Xing, J., Zhang, M., Liu, X., Wang, C., Xu, N., & Xing, D. (Materials Today Bio)	Recent advancements in multi-material electrospinning, which refers to the engineering of two or more types of materials, have made it possible to fabricate a variety of intricate fibrous structures with superior performance, considerably advancing the field of biomedicine.
8	A Review on the Electrospinning of Polymer Nanofibers and Its Biomedical Applications (2024)	Venmathi Maran, B. A., Jeyachandran, S., & Kimura, M. (Journal of Composite Sciences)	The goal of this study is to provide an extensive overview of the many uses of polymer nanofibers in the biotechnological and medical fields today. Tissue engineering, controlled drug delivery, wound-healing dressings, molecular separation, biosensors, dental nanocomposites, medical implants, and the preservation of bioactive substances are some notable uses.
9	Applications of co-axial electrospinning in the biomedical field (2024)	Khan, J., Khan, A., Khan, M. Q., & Khan, H (Next Material)	Based on the provided document, the components used in an electrospinning machine include a syringe, fluid bag, clamp or hook, tube, small gears, and a roller. The technology used in an electrospinning machine includes the use of three-step motors for manufacturing the injection device

2.6 Summary

This chapter discussed the key component used in existing machine used in the development of low-cost electrospinning machine. It is a lot of implementations in the selection material due to growing technology and expensive like electrospinning machine by referring to the method and technologies used.

A complete review of the literature on the development of affordable electrospinning machines is given in Chapter 2 of the study. The historical background is covered first, with an account of electrospinning's initial appearance by Abbé Nollet in 1747 and its major developments by John Cooley, William Morton, and Anton Formhals in the early 1900s. The chapter emphasises the development of electrospinning through several technical breakthroughs and its significance in the development of nanofibrous materials. It talks about the many kinds of spinnerets and the essential parts of an electrospinning apparatus, such as the collecting screen, capillary tube with needle, and high voltage power supply.

The analysis highlights the need for affordable ways to increase accessibility to electrospinning technology, particularly in settings for small-scale industry and research. The design and operation of control panels, stepper motors, and syringe pumps are also covered, highlighting how crucial accuracy and consistency are to the electrospinning process. To secure the manufacture of high-quality and dependable nanofibers, the chapter ends by outlining the difficulties encountered in the development of affordable electrospinning machines and the ongoing attempts to solve these hurdles.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This study aims to development a prototype syringe pump control system and drum collector for low-cost electrospinning machine application. This study beginning with a through literature review. This initial step involves researching existing technologies and relevant information to inform the design requirements. The project design has been planned and improved. The House of Quality (HOQ) helps translate client or project requirements into clear, measurable technical goals. Using SolidWorks, a computer-aided design (CAD) program, the product is modelled to create a visual representation of the system and ensure it meets both functional and technical requirements. Therefore, the project development process is initiated, where detailed plan and specifications for the machine are outlined. This project has four crucial components, where syringe pump, drum collector with speed regulator and control panel are developed. The syringe pump is designed to control flow of the polymer, drum collector is designed to collect the nanofiber, and the control panel is responsible for monitoring the machine various functions. After components are ready, the fabrication process involves assembling necessary parts according to design specifications. The next step involves comparing prototypes, where the mechanical specifications of the current market machines will be evaluated against those of the developed prototype. The project ends after all stages are completed and the outputs are finalized. A research flow chart is shown in Figure 3.1.

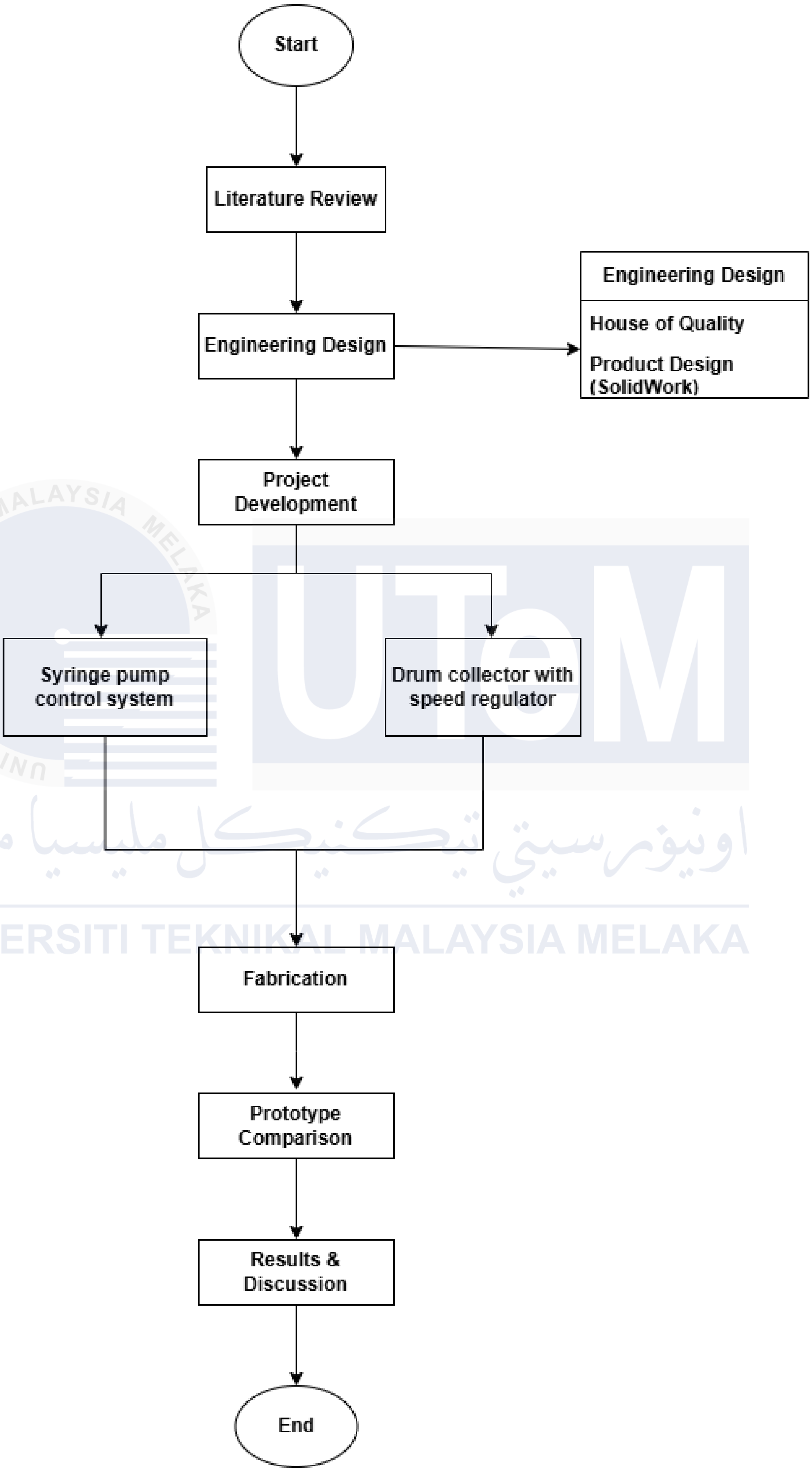
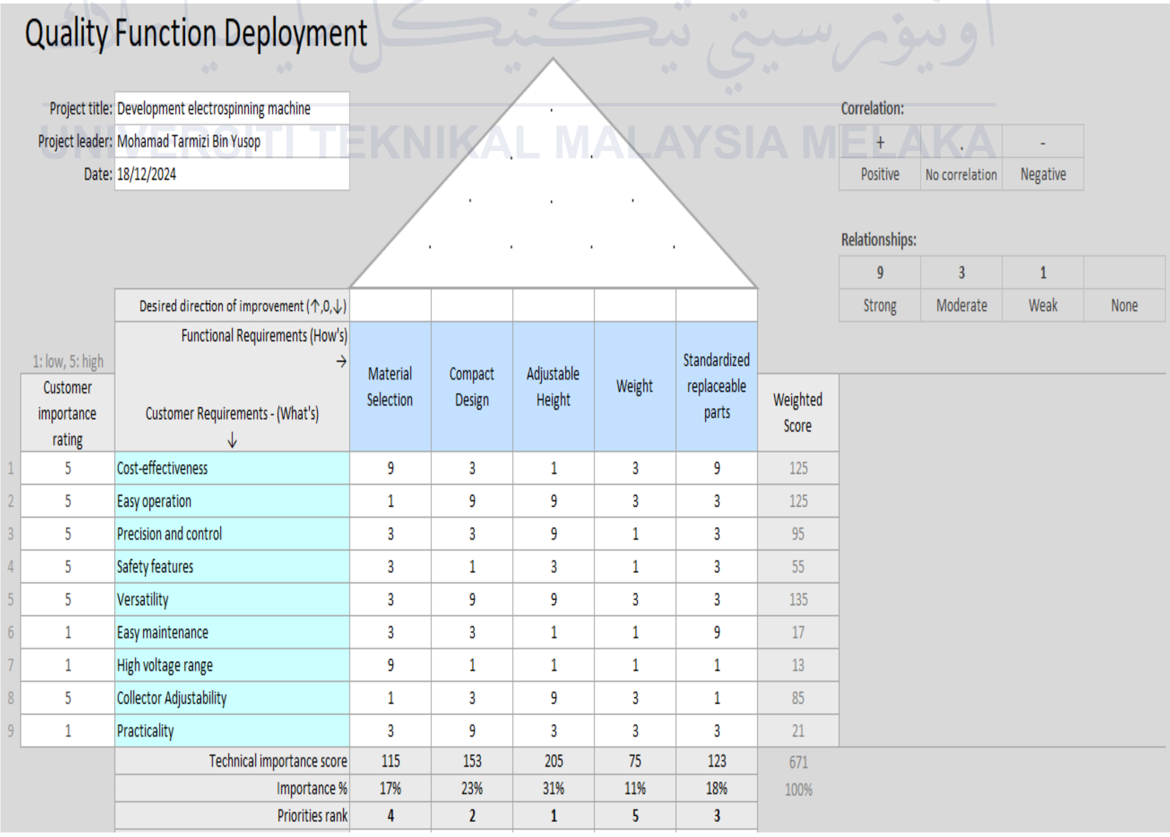


Figure 3.1 Research Flow Chart

3.2 House of Quality (HoQ)

Customer requirements are methodically translated into technical specifications or design features during the product design and development process using the structured House of Quality (HOQ) technique. It is a crucial component of the Quality Function Deployment (QFD) approach and facilitates the constant prioritization and consideration of customer demands in the process of developing new products. To develop the final design, the House of Quality (HOQ) technique is presented to quantify the link between specific requirements and engineering specifications (Ismail et al., 2016).

Figure 3.2 below show the House of Quality (HoQ) matrix which highlights the relationship between customer requirements (CRs) and functional requirements (FRs) for the development prototype of the electrospinning machine. This analysis allows for prioritizing design decisions that align with customer expectations.



	Customer importance rating	Customer Requirements - (What's)	Material Selection	Compact Design	Adjustable Height	Weight	Standardized replaceable parts	Weighted Score
1	5	Cost-effectiveness	9	3	1	3	9	125
2	5	Easy operation	1	9	9	3	3	125
3	5	Precision and control	3	3	9	1	3	95
4	5	Safety features	3	1	3	1	3	55
5	5	Versatility	3	9	9	3	3	135
6	1	Easy maintenance	3	3	1	1	9	17
7	1	High voltage range	9	1	1	1	1	13
8	5	Collector Adjustability	1	3	9	3	1	85
9	1	Practicality	3	9	3	3	3	21
		Technical importance score	115	153	205	75	123	671
		Importance %	17%	23%	31%	11%	18%	100%
		Priorities rank	4	2	1	5	3	

Figure 3.2: House of Quality Matrix (Ben Horne., 2022)

Based on Figure 3.2 show the House of Quality (HoQ) matrix identifies specific priorities for the development of the electrospinning machine, focusing on functional requirements that address customer needs effectively. The top priority is adjustable height, which scores the highest at 31%. This reflects its critical role in providing versatility for various applications and ensuring precise control during the electrospinning process. Next is compact design, with 23% importance, emphasizing the need for a practical and user-friendly machine that is easy to operate and integrate into different environments.

Material selection ranks third, contributing 17% to the total score, highlighting its importance in ensuring cost-effectiveness and durability of the machine. Standardized replaceable parts, at 18%, are crucial for easy maintenance and reducing long-term costs, making the machine more accessible and sustainable. Lastly, weight, with an 11% score, focuses on portability and practicality, ensuring that the machine is not only efficient but also convenient to handle.

The analysis identifies adjustable height, compact design, and material selection as the most critical focus areas for design improvements. These functional requirements are vital to satisfying the high-priority customer requirements such as versatility, cost-effectiveness, and ease of operation.

3.3 Prototype Development

This project intends to provide a syringe pump control system and drum collector for low-cost electrospinning machine applications. The procedure starts with acquiring necessary information on the electrospinning machine and its components. This stage involves reviewing current literature, comprehending electrospinning principles, and determining the needs for the syringe pump, drum collector, and speed regulator. It also involves looking into control systems, material characteristics, and electronic components.

This consists of both the mechanical and electrical designs for the machine. The syringe pump and drum collector must be constructed to enable accurate material flow and consistent fibre output. CAD software like SolidWorks is often used to design detailed 3D models of individual components and the complete system. In addition, the control circuit for regulating motor speed and syringe flow rate has been constructed. This process assures that all components are compatible and that the machine is operational before physical building begins.

During this phase, the intended components are physically constructed. The electronic circuit is built, with connections for the microcontroller, motor drivers, sensors, and speed regulator. Welding is also used to fabricate mechanical elements like the syringe pump and drum collector. During this step, the student carefully assembles and tests each component to ensure that it fulfils the design expectations. For example, the drum collector should revolve at a precise rate, and the syringe pump should consistently deliver material.

The next stage is to create the software or code necessary to operate the machine. This comprises coding the syringe pump to regulate material flow, regulating the speed of the drum collector, and synchronizing all components. Programming is usually done in languages like C++. The code comprises processes for controlling hardware, receiving student input (using a control panel), and handling errors. This stage is crucial for turning the idea into a working system that runs automatically.

After developing the code, it is uploaded to the microcontroller and tested to ensure that it works as planned. Students determine if the program connects correctly with the hardware. For example, the drum should start and stop at the proper speed, and the syringe pump should follow the specified flow rate. This step involves monitoring real-time performance and finding any differences between predicted and actual results.

If the coding does not operate as expected, the problems are recognized and corrected. The first mistake is a syntactic problem. These arise when there is an error in the programming syntax, such as missing semicolons or improper instructions. These errors prohibit the software from running and must be resolved before further testing. Logical mistakes make up the second type of error. These are caused by improper coding logic, which causes the system to generate unexpected results, such as the syringe pump dispensing incorrectly or the drum collector revolving at an inconsistent pace. Hardware communication problems make up the third type of mistake. These occur when the software fails to interface properly with hardware components owing to difficulties such as an improper baud rate, wiring issues, or unrecognized commands. For example, the stepper motor may not respond because of a mismatch between software and hardware settings.

After identifying the error, the process returns to the coding stage to fix problems. This procedure can include changing the code, recalibrating sensors, or rechecking hardware connections. Once the problems have been fixed, the system is retested to guarantee appropriate operation. This iterative procedure continues until all faults have been fixed and the machine is performing as planned.

The project progresses to the final stage once the coding is error-free, and the machine operates effectively. At this point, the hardware and software are fully integrated, making the electrospinning machine ready for use. The system's performance is evaluated against the initial specifications to ensure precise material flow, consistent drum speed, and seamless operation. The successful completion of this stage signifies the achievement of the product development prototype. The general process to development of a syringe pump and drum collector electrospinning prototype is shown in Figure 3.3.

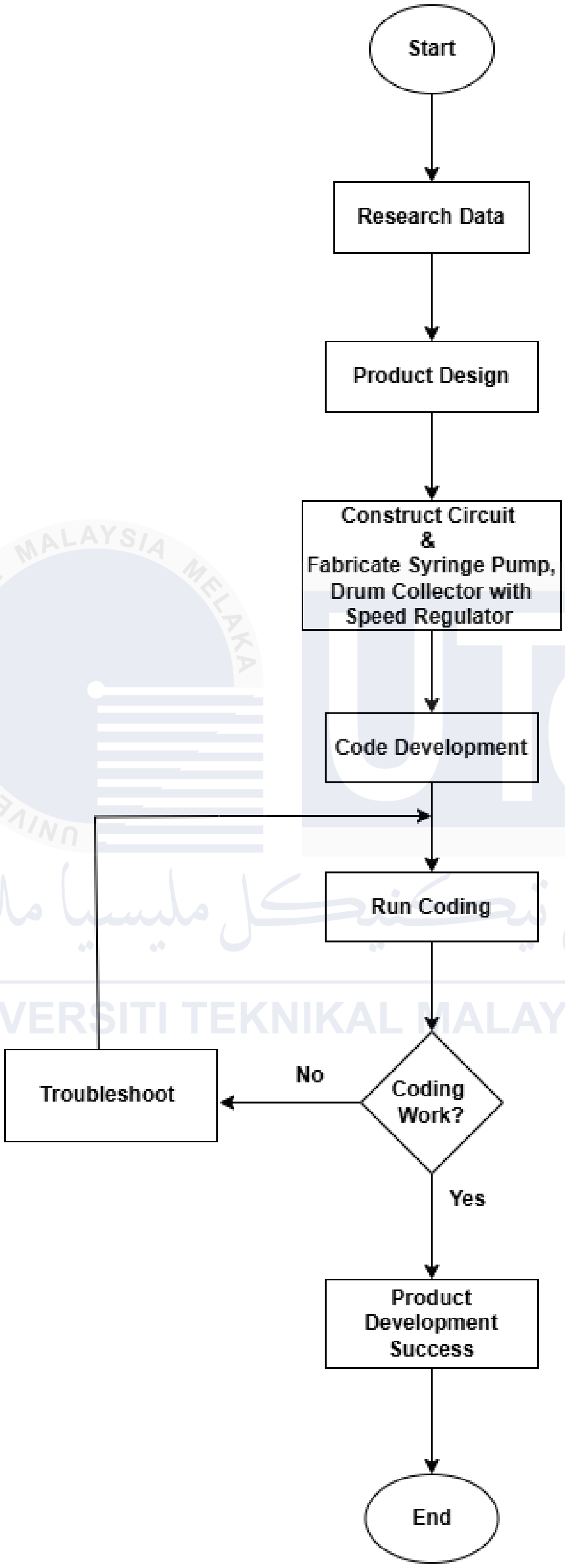


Figure 3.3 The general process to development of a syringe pump and drum collector electrospinning prototype

3.4 Syringe Pump Development

The syringe pump is crucial for precise control of polymer solution flow, ensuring consistent nanofiber production and accommodating various solutions in the electrospinning process.

3.4.1 Manufacturing Process

According to Figure 3.4 show the fabrication process of syringe pump begins with cutting and preparing the frame with dimensions size 44 cm (L) x 26 cm (W) x 23 cm (H). Mild steel hollow sections are measured and marked according to the design specifications, then cut using a grinder to achieve precise dimensions. To be able to make sure that the frame components fit and line correctly during assembly, the edges of the cut steel are smoothed to remove burrs and sharp edges.

After that, the frame is drilled with holes to provide space to fit parts like the linear motion system and the lead screw brackets. To create a strong and solid frame, the steel components are welded together. To ensure perfect assembly and functioning in the following steps, proper alignment is maintained throughout the welding process.

Once the frame is assembled, mechanical components are installed. The linear motion shafts are mounted in parallel, supported by bearings to minimize friction. The lead screw is securely connected to the stepper motor using a coupler, while custom brackets are attached to hold the syringe and plunger pusher mechanism on the moving carriage.

Finally, the assembled components are tested for alignment and smooth operation. Lubrication is applied where necessary to ensure seamless movement of the carriage along the linear shafts. Once all adjustments are complete, the assembly is finalized and ready for integration into the electrospinning machine.

Figure 3.4: Fabrication process (A) Cut raw material, (B) welding frame structure, (C) Modified holder and pusher syringe, (D) Connected motor with coupling and shaft, (E) Completed frame syringe pump

3.4.2 Mechanical Design and Modelling of Syringe Pump

For a syringe pump to be accurate, useful, and durable, mechanical design and modelling are essential. For operations like electrospinning, the syringe pump is essential since its main function is to precisely regulate the dispensing of liquids or fluids. This section focuses on the syringe pump's design model, which is seen in Figure 3.5 and table 3.1 show the component prototype of syringe pump.

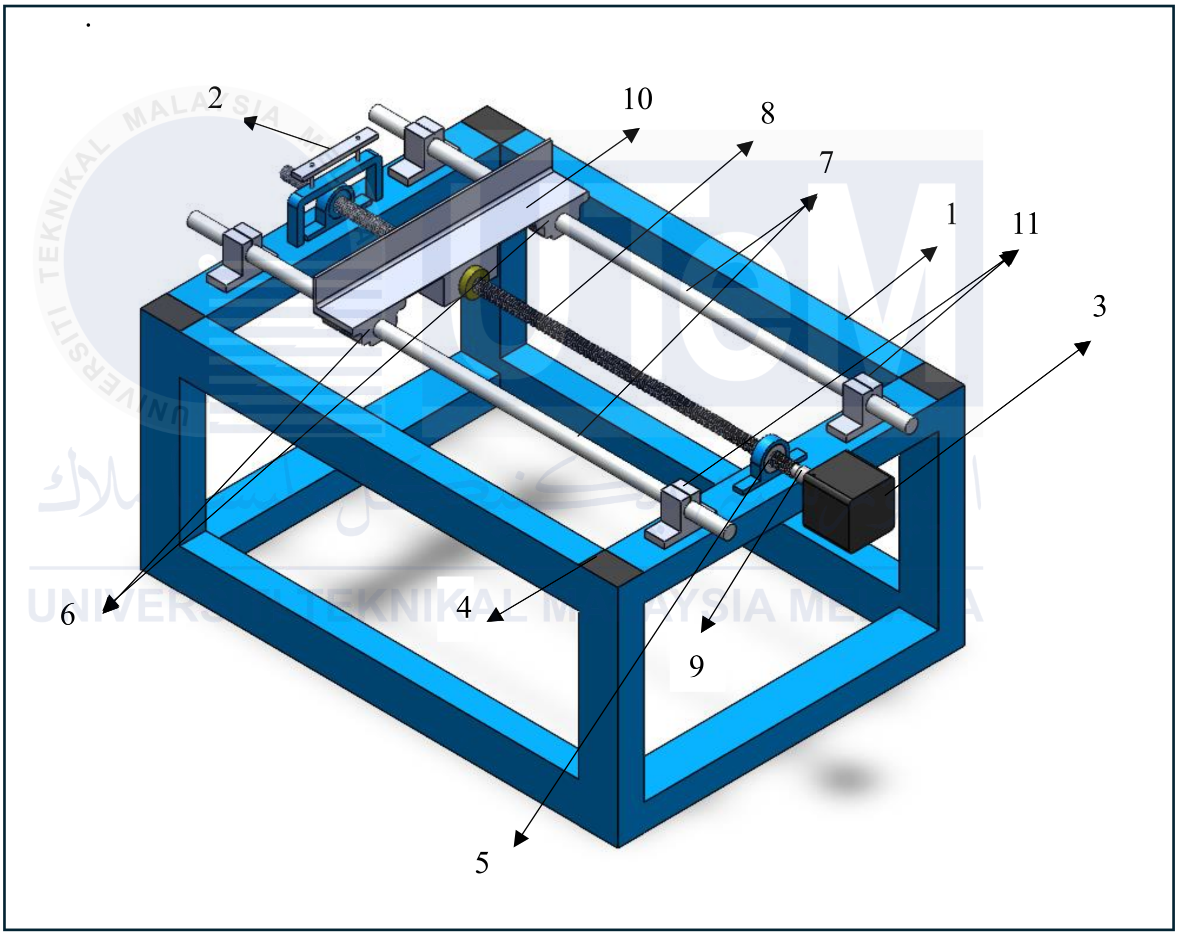


Figure 3.5: Modelling design prototype of syringe pump

Table 3.1 Component prototype of syringe pump

NO.	DESCRIPTION
1	Frame
2	Holder Syringe
3	NEMA 17 Stepper Motor
4	Square PVC
5	KP08 Bearing
6	Linear Bearing (SC8UU)
7	Slider Bar Shaft
8	Lead Screw
9	Aluminium Coupling
10	Plunger Pusher
11	SK8 Bearing

3.5 Control Panel Development

Managing and regulating the flow of nanofibers during the electrospinning process requires the electrospinning machine's control panel. It functions as the main interface, enabling operators to modify important settings such as the drum collector speed, high voltage supply, syringe pump flow rate, and others. Its primary goal is to make sure that the process proceeds without problems and produces quality nanofibers with the required and consistent qualities.

The control panel's primary responsibility is to operate the syringe pump, which controls the polymer solution's flow rate via the syringe. The most important variable in influencing the thickness, diameter, and quality of the generated nanofibers is the flow rate. Under the electric field, a constant jet of polymer solution is emitted if the flow rate is kept precisely constant. A flow rate that is too low might interfere with the electrospinning process, while a flow rate that is too high can cause the fibres to become uneven or take on bead-like shapes.

The control panel ensures a precise, safe, and effective functioning of the syringe pump, making it an essential part of the building process of an electrospinning machine. To produce nanofibers with the appropriate uniformity and quality, this control and accuracy are essential. In this section focus on electrical schematic diagram, flowchart control panel, block diagram and isometric drawing.

This diagram for a syringe pump makes sure that voltage levels, current ratings, and circuit ensures are precisely developed, improving the system's reliability and safety. It shows students how various components are integrated and work together. The electrical schematic illustration shows in detail the electrical connections and components present within the control panel. It involves all the necessary components such as power supply circuits, relays, microcontrollers, sensors, and actuators.

The flowchart control panel illustrates the explanation and sequence of actions that regulate the syringe pump. This graphic representation divides the process into many parts, such as initialization, parameter setup, sensor feedback monitoring, and pump actuation. The flowchart simplifies complicated operations, allowing engineers to better grasp the control logic and solve any problems. It ensures that the syringe pump runs consistently by following the flow rate, pressure, and volume settings that have been established.

A high-level knowledge of the control panel design is given by the block diagram. It separates the system into functional parts, such as output units (stepper motor), control units (microcontrollers), and input units (sensors and user interfaces). For students to comprehend how data moves through the system and how various subsystems interact, this image offers a conceptual foundation. The connections between the control panel, the syringe drive mechanism, and the feedback loops necessary for precision are displayed in the syringe pump block diagram.

Isometric drawing is an important part of engineering design, especially for visualizing components and systems in three dimensions. An isometric drawing of an electrospinning machine's control panel provides a precise visual representation of its layout, including the location of buttons, switches, and displays. This style of drawing is especially useful for assembly, troubleshooting, and checking that all components fit properly within the design specifications.

3.5.1 Electrical Schematic Prototype of Control Panel

The control panel (filament extruder) schematic diagram illustrates in detail the system's electrical components and their connections, which are critical for its performance and safety. The power supply unit provides controlled voltage and current to power the whole system. This section is frequently shown with input terminals connected to a mains power supply, which is regulated through safety devices such as fuses and circuit breakers to avoid overloads or short circuits. The electricity is then routed to various subsystems to ensure proper operation.

The Arduino Uno R3 is a great option for an electrospinning machine control panel considering to its versatility, low cost, and compatibility with a wide range of components. It comes with 14 digital input/output connectors and 6 analogue input pins, making it useful for controlling several devices with precision. The keypad connects to Arduino Uno R3 as input. It used to input parameters like volume and flow rate, and sensors like the micro switch sensor ensure that the syringe's starting position is indicated before moving it. Also, the LCD connected to Arduino as output. So, the LCD display provides a clear interface for users to monitor settings, operational status, and notifications of errors, thus enhancing usability and productivity. The open-source nature of Arduino and the extensive support community further simplify the development, customization, and troubleshooting of the control panel, making it a cost-effective and reliable solution for a control panel electrospinning machine.

The DRV8825 motor driver is an ideal choice for operating the electrospinning machine's NEMA 17 stepper motor because to its high performance, efficiency, and compatibility. This driver enables microstepping up to 1/32, allowing for smooth and precise control of the stepper motor, which is necessary for accurate and consistent fibre production. The DRV8825 can handle a maximum current of 2.2A per coil with proper cooling, making it ideal for the NEMA 17 motor's power requirements.

Its integrated overcurrent protection and thermal shutdown enhance system safety and dependability, particularly in applications like electrospinning that need precision and stability. Additionally, the driver is compact and simple to include into the control panel, which reduces space requirements and streamlines circuit design. You may change the motor's performance according to the particular needs of the machine by using a basic potentiometer for adjustable current limitation. Because of these features, the DRV8825 is a reliable and efficient substitute for managing the stepper motor in an electrospinning machine.

The NEMA 17 and other stepper motors work in phases, where each step denotes a distinct angular revolution. The "step angle," which determines how much the motor shaft turns with each step, is the angle at which the motor moves.

The step angle for most of common NEMA 17 stepper motors is normally 1.8 degrees per step. This indicates that the shaft rotates by 1.8 degrees for each step the motor makes. Consequently, after 200 steps (360 ÷ 1.8 = 200), the motor completes a full revolution (360 degrees).

The motor may, however, take smaller steps if it is operated by microstepping (drivers such as the DRV8825). Each of the stepper motor's first steps, which normally measure 1.8 degrees, is split into two smaller steps in this instance utilizing 1/2 microstepping. This indicates that for each microstep, the motor travels half of the first step. Consequently, the motor advances 0.9 degrees each microstep (1.8 degrees ÷ 2) when using 1/2 microstepping. Finer control over the motor's movement is made possible by this division, which is especially helpful in applications that call for more accurate changes, such regulating the feed rate in an electrospinning machine. The system may move more smoothly and accurately by lowering the step size, which enhances the electrospinning process's overall effectiveness and quality.

Safety features including heat cut-offs, emergency stop switches, and circuit isolation techniques are included in the schematic. These features ensure that the extruder can operate safely in a range of scenarios, shielding the operator and the machine from potential issues.

In summary, the schematic layout provides a clear and structured picture of how power flows, signals are processed, and mechanical operations are carried out in the filament extruder. The electrical schematic for control panel is shown in Figure 3.6.

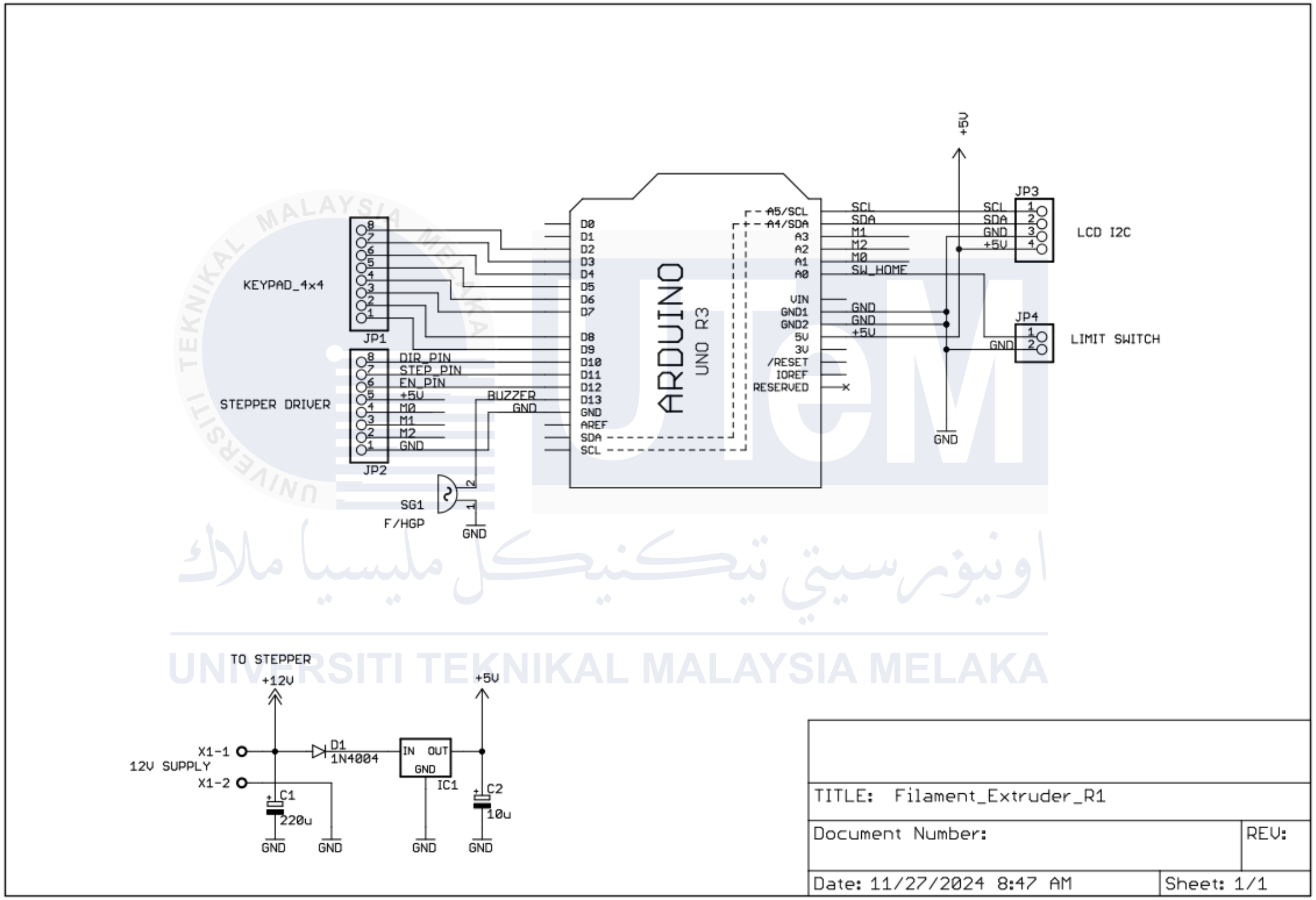


Figure 3.6: Electrical schematic prototype of syringe pump control panel

3.5.2 Block Diagram Prototype of Control Panel

The displays of block diagram system of syringe pump control panel are shown in Figure 3.7. The block diagram illustrates the sequential functioning of the component control panel of an electrospinning machine, where all parts cooperate to regulate the syringe pump system. The 12V, 5A power supply starts the process by giving the Arduino Uno R3, the central control unit, and other associated parts like the LCD display and the DRV8825 driver the electricity they need.

A 4x4 keypad is used by the user to interface with the system. The keypad enables the user to enter certain parameters, including flow rate and volume, or back move for the stepper motor of the syringe pump. The Arduino Uno receives these inputs, interprets the information, and decides how to drive the stepper motor appropriately.

The input data and other system characteristics are shown on a 20x4 I2C LCD screen to ensure user-friendly operation. The user can keep an eye on the system's condition and make any required modifications thanks to the real-time feedback this display offers, which includes volume, flowrate, and fault signals.

After receiving user input, the Arduino sends control signals to the DRV8825 motor driver. The DRV8825 driver controls the NEMA 17 stepper motor's power and current and features a heatsink to dissipate heat while operating. The syringe plunger may move precisely and slowly because of to the stepper motor that powers the syringe pump. This controlled movement is necessary for the polymer solution used in the electrospinning process to flow at a constant rate.

The mechanical assembly of the syringe pump is powered by a NEMA 17 stepper motor, which drives the syringe plunger in a straight line. In order to produce homogeneous electrospun fibres, the polymer solution must be extruded at a steady and regulated pace, which requires this exact movement.

To prevent overtravel or damage to the syringe pump, a micro switch sensor is used as a limit switch. When the syringe plunger reaches its mechanical limit, the micro switch sends a signal back to the Arduino Uno. Upon receiving this signal, the Arduino stops or adjusts the motor operation, ensuring safety and preventing mechanical failures.

The Arduino Uno acts as the central controller that integrates all the components, processes user inputs, displays information on the LCD, controls the motor via the driver, and ensures safety through the micro switch. The overall system works in a loop, where the user inputs parameters, the Arduino processes these inputs, and the syringe pump is actuated accordingly while providing real-time feedback.

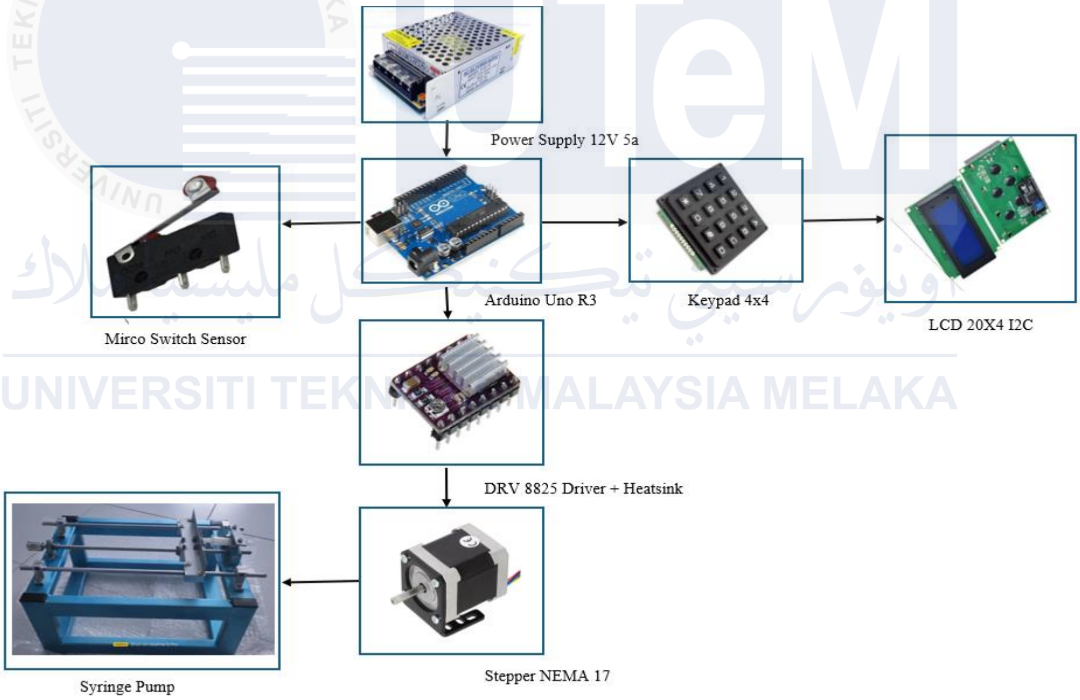


Figure 3.7: Block diagram prototype of control panel

3.5.3 Mechanical Design and Modelling of Control Panel

The control panel is an important part that controls PVA flow out from the syringe. In this control panel, student will design several parameters to control like flowrate and volume. This section focuses on the control panel design model, which is seen in Figure 3.8 and table 3.2 show the component of control panel.

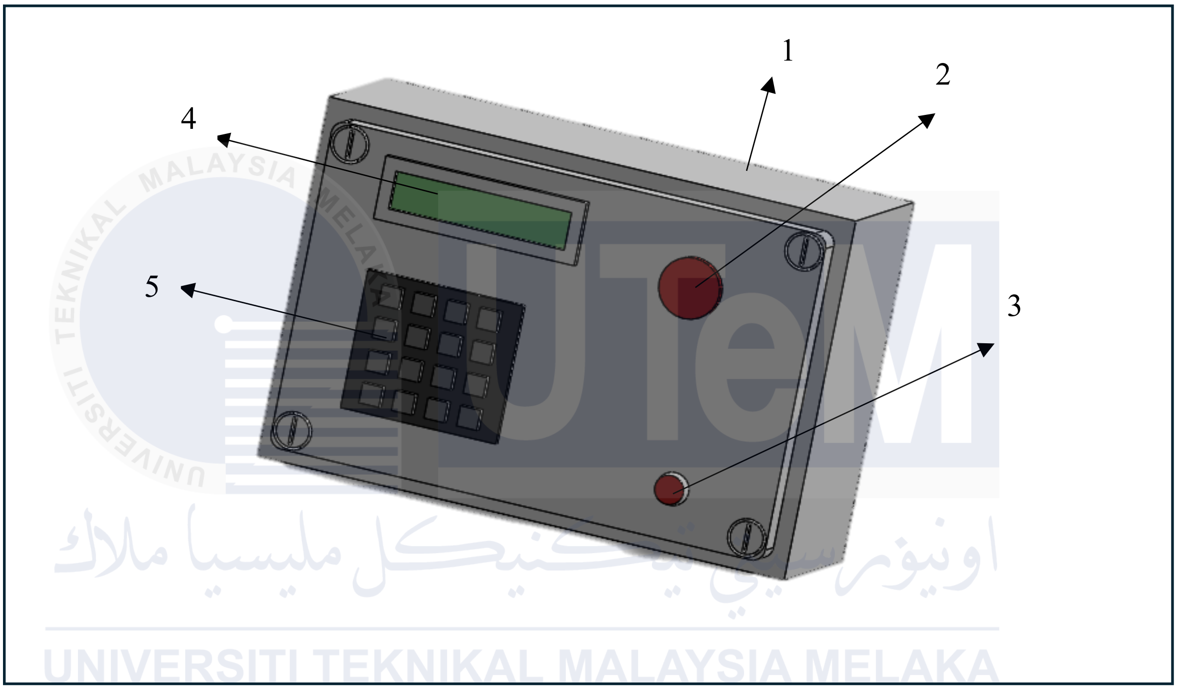


Figure 3.8: Modelling design prototype of control panel

Table 3.2 Component prototype of control panel

NO.	DESCRIPTION
1	Control Box
2	Emergency Button
3	On/Off Button
4	LCD
5	Keypad

3.6 Drum Collector Development

The drum collector is a important component in electrospinning, serving as the surface for collecting nanofibers. Its controlled rotation influences the direction, thickness, and uniformity of the fibres during the process, ensuring precise and consistent fibre deposition.

Nanofiber placement is mostly determined by the drum collector's spinning speed. The nanofibers tend to deposit randomly at lower rates, creating a disordered, non-woven structure. Nevertheless, the drum collector produces centrifugal force at higher rotating speeds, which aligns and stretches the nanofibers over the drum surface in a consistent, parallel pattern

Mild steel hollow is used to make the drum collector because it has strong conductivity for grounding. When a high-voltage electric field is applied, a conductive surface guarantees that the nanofibers will gather. Additionally, it keeps charges from building up, which could interrupt the electrospinning process. To facilitate the simple removal of the deposited fibres after spinning, the drum is frequently coated or smoothed.

The development of the drum collector involves precise mechanical design to achieve stability and accuracy during rotation. It is typically driven by a DC motor, controlled through a speed regulator to allow adjustment of its rotational speed in revolutions per minute (RPM). The design also includes proper alignment of the motor shaft with the drum axis to avoid vibrations that could affect fibre deposition.

3.6.1 Manufacturing Process

The fabrication process of a drum collector is shown in the Figure 3.9 involves several stages, including cutting, assembly, integrating the main structure with the scissor lift and testing. The fabrication process of drum collector begins with cutting and preparing the frame. Mild steel hollow sections are measured and marked according to the design specifications, then cut using a grinder to achieve precise dimensions. To be able to make sure that the frame components fit and line correctly during assembly, the edges of the cut steel are smoothed to remove burrs and sharp edges.

Next, the cut metal parts are arranged and assembled into a frame using welding techniques. The images show precise alignment and welding of the components to create a sturdy structure. After the frame is welded, it is combined with the scissor lift platform to allow adjustable height for the drum collector. Brackets and bolts are used to secure the connections and provide stability to the machine. Additionally, rubber is added at the base to reduce vibrations during operation, ensuring stability and smooth functionality.

Next step, the assembled components are prepared for integration with electronic parts. A motor is mounted onto the structure, and wiring is connected to a control panel, as seen in the close-up of the labelled terminals. After finalizing the electronics, the frame is coated with spray paint to prevent rust and enhance its appearance, as shown in the outdoor painting process.

Finally, the completed machine is tested for functionality and vibration performance after being combined with the scissor lift. The setup, including the control box, scissor lift platform, and drum collector, is carefully observed during operation to ensure proper alignment of all components.

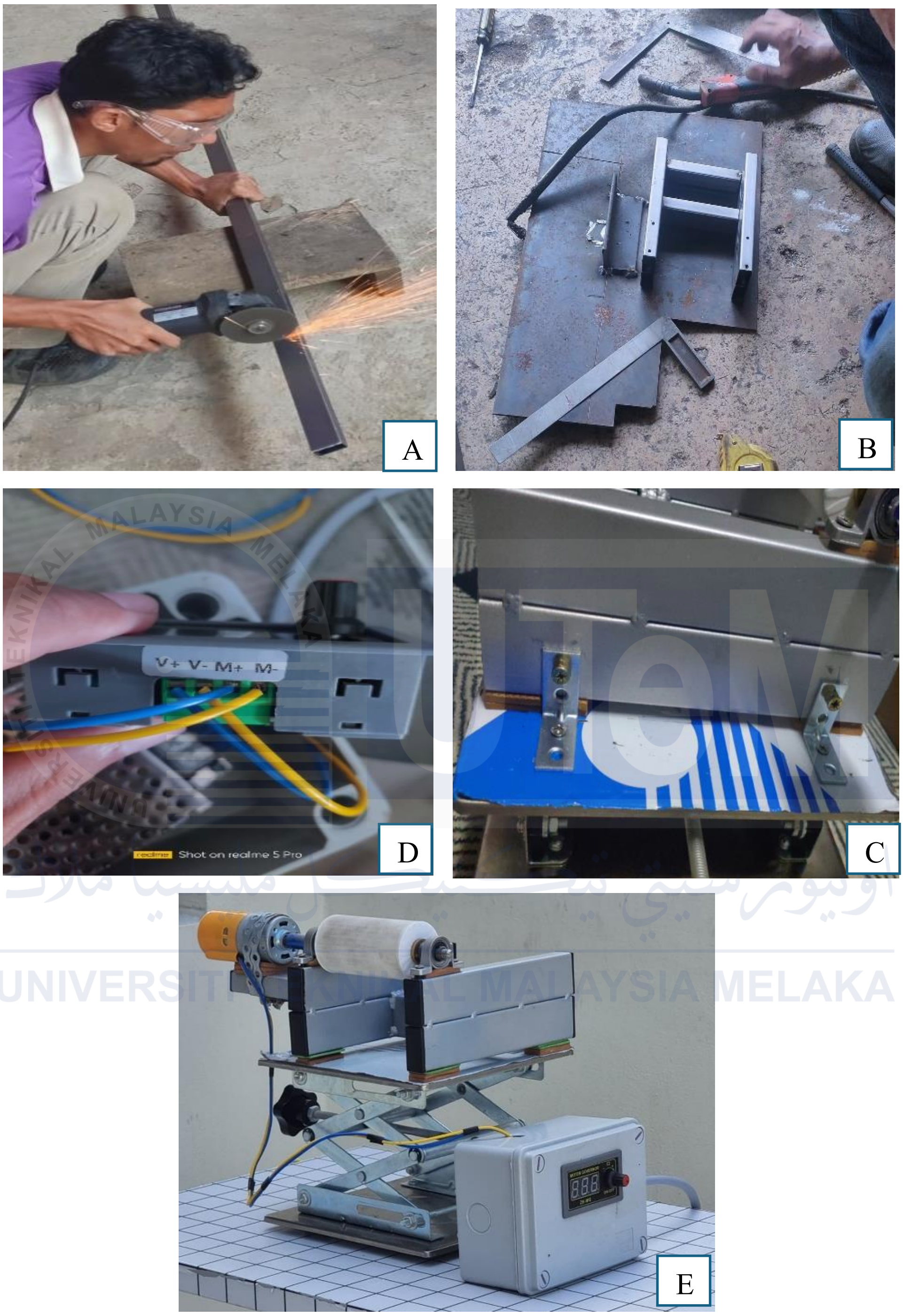


Figure 3.9: Fabrication process (A) Cut raw material, (B) welding frame structure, (C) Combined drum structure with scissor lift, (D) Connected wiring motor, (E) Completed frame drum collector

3.6.2 Mechanical Design and Modelling of Drum Collector

The mechanical design and modelling for a drum collector involves the systematic development of a robust and functional component that ensures smooth operation, durability, and precise control, particularly for processes like electrospinning. The design must integrate mechanical, structural, and rotational considerations to achieve efficiency and reliability. This section will show the design for drum collector. Figure 3.10 is modelling design drum collector and table 3.3 show the component of drum collector.

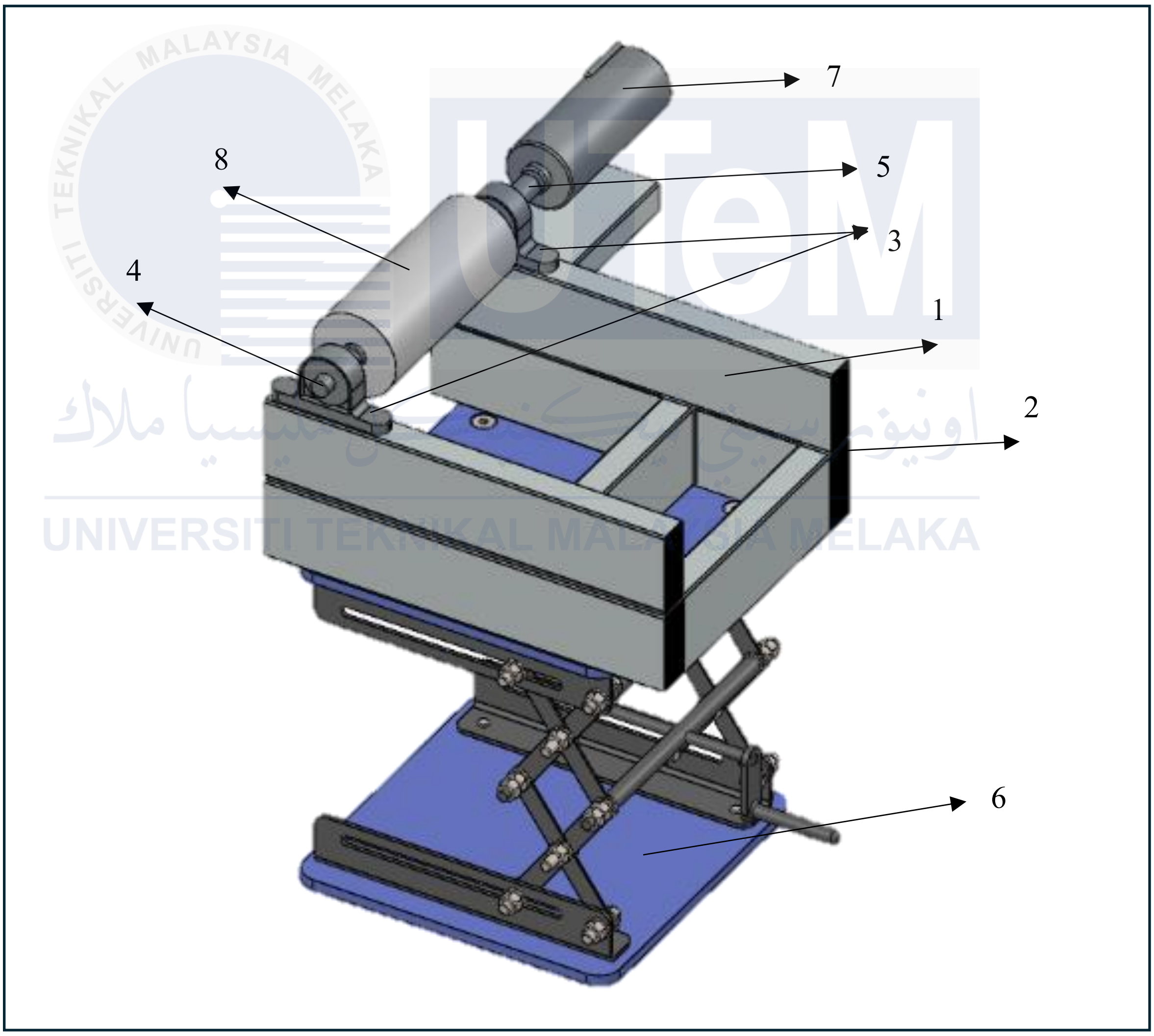


Figure 3.10: Modelling design prototype of drum collector

Table 3.3 Component prototype of drum collector

NO.	Component
1	Frame
2	Square PVC
3	KP08 Bearing
4	Lead Screw
5	Aluminium Coupling
6	Scissor Lift
7	Brush Motor
8	Drum

3.6.3 Speed Regulator Development

A speed regulator is a necessary component of an electrospinning machine that regulates the drum collector's rotational speed, which is expressed in revolutions per minute (RPM). To create a consistent and consistent nanofiber mat, electrospun nanofibers are applied onto a revolving cylindrical component called a drum collector. The speed regulator ensures uniform fibre thickness, alignment, and a uniformity over the collecting surface by precisely controlling the drum's spinning speed.

The speed regulator's basic function is to adjust the power or voltage that is given to the motor that drives the drum to regulate the drum collector's spinning speed. The speed regulator modulates the voltage or current to change the motor's speed usually, a DC motor or stepper motor is utilized. To effectively manage speed without causing a large waste of power, a Pulse Width Modulation (PWM) speed controller is frequently used for DC motors. It is possible to fine-tune the electrospinning process to affect the density, alignment, and orientation of the nanofibers by varying the drum speed.

The fibre collecting process in electrospinning is affected directly by the drum's rotational speed. For applications requiring highly ordered nanofiber structures, a higher RPM causes ordered fibres because the centrifugal force stretches and orients the fibres along the rotation axis. On the other hand, fibres with a lower RPM are randomly oriented and can be used to create isotropic nonwoven mats. By avoiding extreme speed variations that might damage fibre quality, the speed regulator also aids in keeping the motor operating stably.

This part will be focused on the isometric drawing and block diagram. The control panel design may be understood at a high level because for the block diagram. Input units (sensors and user interfaces), control units (microcontrollers), and output units (stepper motors) are among the functional components that it separates into. Students may understand how data moves through the system and how various subsystems interact with one another according to this graphic's conceptual framework. The syringe pump's block diagram illustrates the connections between the control panel, the syringe drive mechanism, and the accuracy-depending feedback loops.

Isometric drawing is an important part of engineering design, especially for visualizing components and systems in three dimensions. An isometric drawing of an electrospinning machine's control panel provides a precise visual representation of its layout, including the location of buttons, switches, and displays. This style of drawing is especially useful for assembly, troubleshooting, and checking that all components fit properly within the design specifications.

3.6.4 Block Diagram Prototype of Speed Regulator

The displays of block diagram system of syringe pump control panel are shown in Figure 3.11. The block diagram illustrates the operation of the component speed regulator for the drum collector in an electrospinning machine. The power supply (12V, 5A) at the start of the system supplies the electrical energy required to run the components. The incoming AC voltage is changed by the power supply into the steady DC voltage (12V) needed to run the system. To guarantee that every component operates dependably and effectively, this steady power is essential.

The next important part of the system is the speed regulator. It is employed to regulate the voltage or current that is delivered to the DC motor to control its rotational speed. The motor's RPM (revolutions per minute) is adjusted by the speed regulator, giving the drum collector's rotating speed exact control. This is accomplished by adjusting the output power using a control knob or digital input on the regulator. Since the speed affects the alignment and thickness of the nanofibers sprayed on the drum collector, it must be properly adjusted.

The speed regulator delivers the controlled power to the DC motor (12V~24V). The drum collector is powered by this motor, which transforms electrical energy into mechanical rotation. The voltage that the speed regulator applies is exactly proportionate to the motor's speed. The drum collector can rotate at the required RPM by adjusting the motor speed.

Lastly, the drum collector rotates in sync with the speed of the DC motor after being mechanically connected to it. The substrate on which the electrospun nanofibers are placed is the drum collector. The placement and uniformity of the nanofibers may be managed by adjusting the drum's spinning speed. Because of centrifugal force, a higher speed improves fibre alignment, while a lower speed produces fibres that are oriented casually.

Overall, this control panel system allows precise adjustment of the drum collector’s speed, ensuring consistent and high-quality nanofiber production in the electrospinning process. The combination of the power supply, speed regulator, DC motor, and drum collector provides an efficient and flexible setup for controlling the collection process in the electrospinning machine.

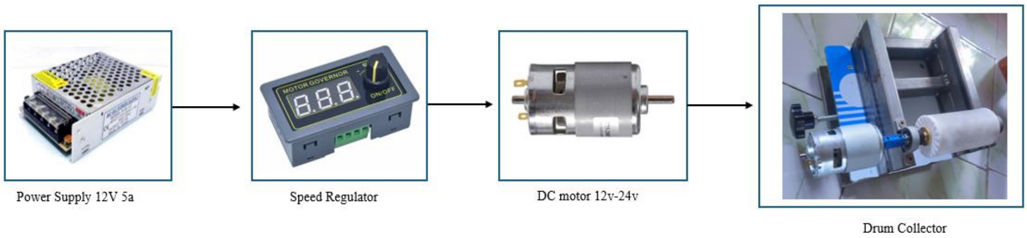


Figure 3.11: Block diagram prototype of speed regulator

3.6.5 Mechanical Design and Modelling of Speed Regulator

The speed regulator is one of the important parts to control the rotating drum collector. This section focuses on the speed regulator design model, which is seen in Figure 3.12 and table 3.4 shows the component of speed regulator.

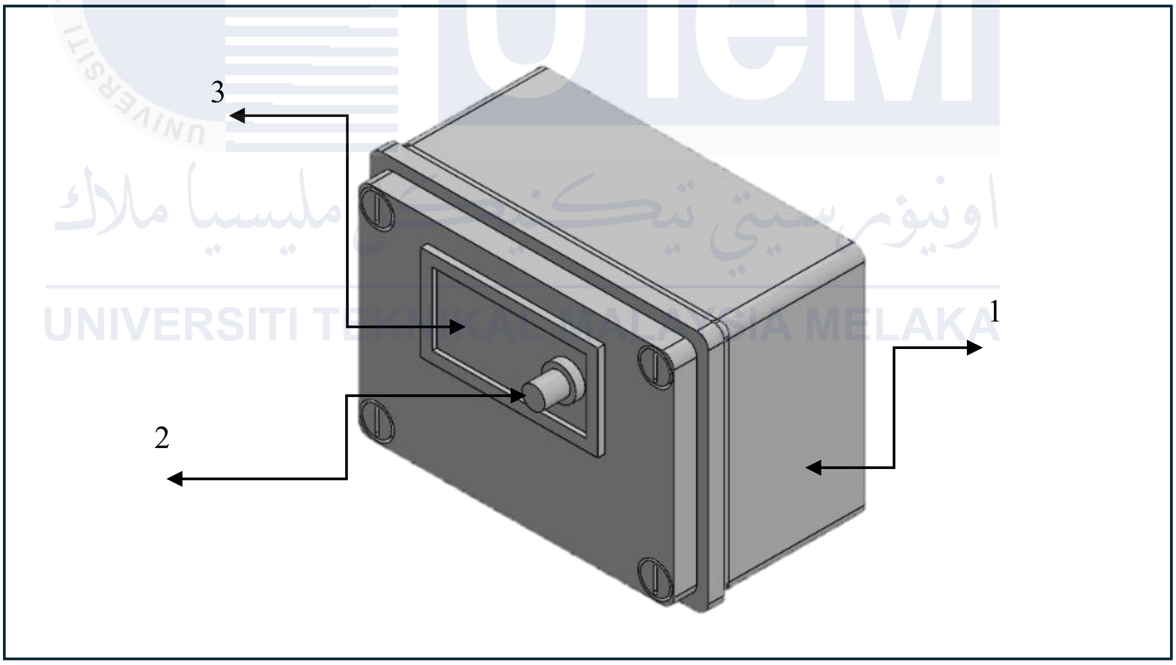


Figure 3.12: Modelling design prototype of speed regulator

Table 3.4 Component prototype of speed regulator

NO.	DESCRIPTION
1	Control Box
2	Button Speed Regulator
3	LCD

3.7 Product Comparison

The House of Quality (HoQ) approach can also serve as a benchmark analysis tool to compare the developed syringe pump control panel and drum collector prototype with established market standards, such as the P-CES20-09-24-01 model (CES20-S). The model CES20-S represents a semi-automated, compact electrospinning unit widely recognized in the market for its high precision and enclosed design, making it an ideal benchmark for evaluating the functionality and competitiveness of the developed prototype.

Using the model CES20-S as a benchmark, the developed prototype focuses on several functional requirements such as adjustable height, compact design, material selection, standardized replaceable parts, and weight. While the model CES20-S excels in delivering a polished, integrated solution, the prototype emphasizes modularity, affordability, and customization.

The adjustable height feature in the prototype addresses a limitation in the CES20-S, which has fixed collector and syringe positions, making the prototype more versatile for diverse electrospinning configurations.

The compact design of the model CES20-S serves as an industry standard for enclosed and user-friendly systems, whereas the prototype adopts an open-frame structure prioritizing accessibility for maintenance and experimentation. Although less polished in appearance, the prototype aligns with the practical needs of budget-conscious users or those requiring experimental flexibility.

The CES20-S's higher-end material choices set a benchmark for durability, but the prototype strikes a balance between cost-effectiveness and performance by using lightweight and affordable materials. This makes the prototype a more accessible option for users prioritizing affordability over long-term durability.

In terms of standardized replaceable parts, the prototype aims to surpass the benchmark by incorporating easily replaceable, non-proprietary components, reducing maintenance costs and downtime. The model CES20-S, while advanced, relies on proprietary parts, which may increase operational expenses and repair complexity.

Lastly, the weight of the developed prototype offers an advantage over the model CES20-S benchmark, as its lightweight design ensures greater portability and ease of use. This feature is particularly beneficial for users who require a mobile or flexible system for multiple locations.

Overall, the model CES20-S provides a valuable benchmark, setting industry standards for precision and integration. However, the developed prototype differentiates itself by targeting users seeking cost efficiency, modularity, and accessibility, while retaining functionality that meets customer requirements.

Figure 3.13: Electrospinning machine model CES20-S (Progene Link.,2025)

3.8 Prototype Design Specifications

The syringe pump is designed with several critical specifications to ensure precision and reliability in the electrospinning process. The flow rate control, adjustable from 0.5 mL/hr to 1.5 mL/hr, enables precise regulation of the polymer solution flow, which is essential for achieving uniform electric fields and consistent nanofiber formation. Further, the volume control, that provides a range of 1 mL to 10 mL, provides adjustability for variable solution levels and allow longer operation periods between refills. The syringe compatibility with a single 10 mL syringe ensures ease of use and connection with common syringes, simplifying maintenance and replacement. All these requirements are integrated to make sure that the syringe pump achieves a balance between precision, practicality, and affordability, which prepares it for use in research and small scale. Refer to Table 3.5 for a detailed breakdown of the syringe pump specifications.

Similarly, the drum collector is designed to enhance functionality and practicality. It features a rotational speed range adjustable from 0 to 100 RPM and the adjustable height range of 20 cm to 40 cm ensures the optimal positioning of the drum relative to the syringe tip, allowing for fine-tuning of the electric field strength, which directly impacts fibre quality. Refer to Table 3.6 for more detailed specifications of the drum collector.

Table 3.5 Specification prototype of syringe pump

Component	Specification	Detail
Syringe Pump Control Panel	Dimension	Compact size: 44 cm (L) x 26 cm (W) x 23 cm (H)
	Frame Material	Mild steel Hollow
	Flow Rate Control	0.5 mL/hr to 1.5 mL/hr
	Volume Control	1 mL to 10 mL
	Voltage Range	10 kV to 30 kV
	Syringe Capacity	Single syringe, 10 mL
	Control System	Arduino Uno R3 - Based system with LCD display, keypad interface
	Motor Type	NEMA 17 stepper
	Safety Features	Emergency button
	weight	1.5 kg

Table 3.6 Specification prototype of drum collector

Component	Specification	Detail
Drum Collector with Speed Regulator	Dimension	Compact size: ⌀ 16 cm, 20 cm (L) x 20 (W)
	Frame Material	Mild steel hollow for lightweight, durability
	Collector Type	Rotating drum collector with adjustable height
	Drum Collector Material	PVC
	Rotational Speed	0 to 100 RPM
	Adjustable Height Range	20 cm to 40 cm
	Motor Type	Brush Motor 24 DC
	Weight	3.5 kg

3.9 Summary

In conclusion, Chapter 3 combines systematic planning, technical design, and practical manufacturing to develop a functional, low-cost electrospinning machine prototype. This comprehensive approach ensures the machine meets user needs while maintaining high performance, making it a valuable tool for nanofiber production in research and small-scale applications.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter provides an overview of the developed prototype and the results of the syringe pump and drum collector. It also includes a comparison with the commercially available compact electrospinning unit, specifically the P-CES20-09-24-01 model (CES20-S) (Semi-Automated). The analysis focuses on the structural, design, and functional aspects of the prototype, emphasizing several features such as adjustability, cost-effectiveness, and usability, while highlighting the differences between the two designs.

4.2 Prototype Overview

The developed prototype consists of four basic components, including a syringe pump, a drum collector, control panels and speed regulators as seen in Figure 4.1. The frame is constructed using lightweight yet sturdy materials, designed for modularity and ease of maintenance. The drum collector integrates an adjustable-height mechanism for flexibility in different experimental setups. The control panel and speed regulator houses an LCD screen and input buttons for user-friendly operation.

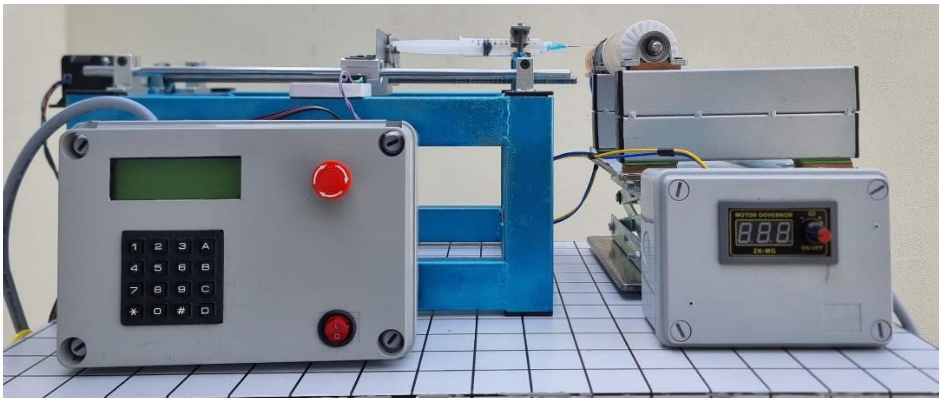


Figure 4.1: Electrospinning machine prototype

4.3 Final Development Prototype of Syringe Pump

The completed prototype of the electrospinning machine, as shown in the figure, demonstrates the successful integration of all critical components designed for low-cost fabrication. The machine includes a syringe pump mechanism, a drum collector mounted on a scissor lift for height adjustment, and a control panel equipped with speed regulation and operational controls, it shows in Figure 4.2. The components have been assembled to provide functionality, but the prototype has not yet been fully tested in an operational environment.

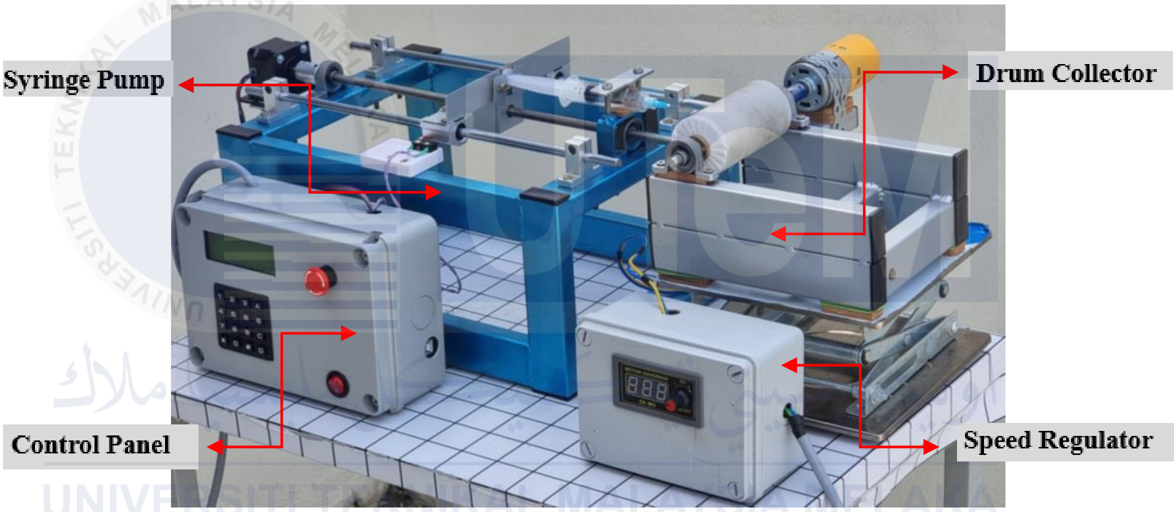


Figure 4.2: Electrospinning machine prototype

The syringe pump mechanism is designed with a lead screw system to provide precise linear motion for controlled dispensing of the polymer solution. A stepper motor drives the mechanism, enabling fine adjustments in the flow rate, which is crucial for consistent nanofiber production. The mechanical assembly includes a robust syringe holder and plunger pusher, ensuring stability during operation. The system is specifically designed to accommodate 10 ml syringes while supporting various sizes of needles for flexibility in application as seen in Figure 4.3. Furthermore, the syringe pump's frame structure is made of mild steel, which gives the entire system a solid and secure base.

The syringe pump is specially managed by the control panel, which provides an intuitive interface for accurate control of the machine's operating settings. With thoughtfully positioned buttons, switches, and an LCD display for convenience of operation, it is contained in a sturdy, lightweight casing. The display shows the controlled parameters, including flow rate and volume, providing real-time feedback to the user. Input settings are managed through an LCD interface and a keypad, allowing users to conveniently key in desired values. Additionally, the panel features an emergency stop button, ensuring enhanced safety during operation.

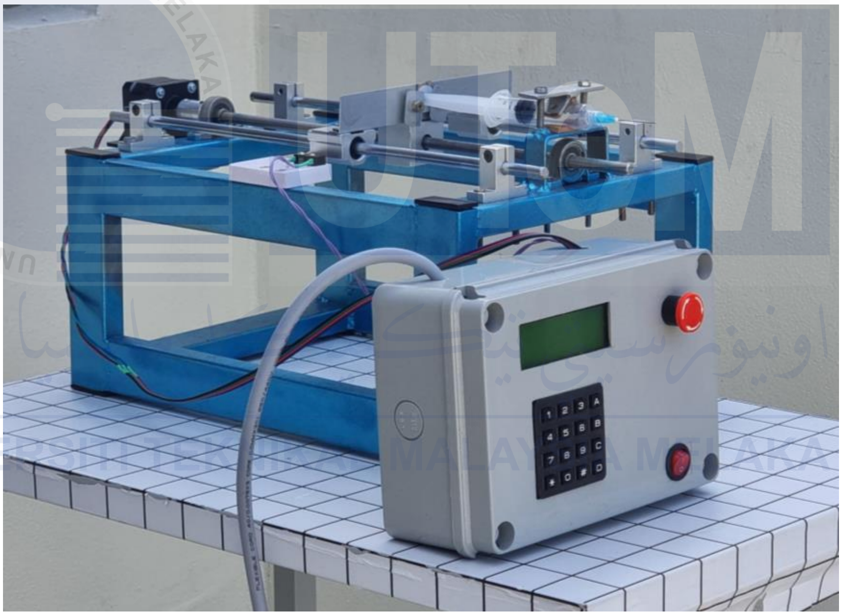


Figure 4.3: Syringe pump control panel prototype

4.4 Final Development Prototype of Drum Collector

The drum collector is mounted on a scissor lift platform, allowing adjustable height to optimize the working distance between the collector and the syringe tip as shows in Figure 4.4. The drum itself is made of lightweight, non-corrosive material and is driven by a DC motor capable of variable rotational speeds. This mechanical setup ensures uniform fibre collection while maintaining system stability. The scissor lift and frame structure, constructed from mild steel, provides smooth height adjustment through a lead screw mechanism, ensuring precise alignment during the electrospinning process.

The speed regulator for the drum collector utilizes a motor governor that allows precise control of the drum's rotational speed. This feature ensures uniform deposition of nanofibers by maintaining consistent RPM. Mechanically, the speed regulator is compact and robust, housed in a protective casing to safeguard against environmental factors.

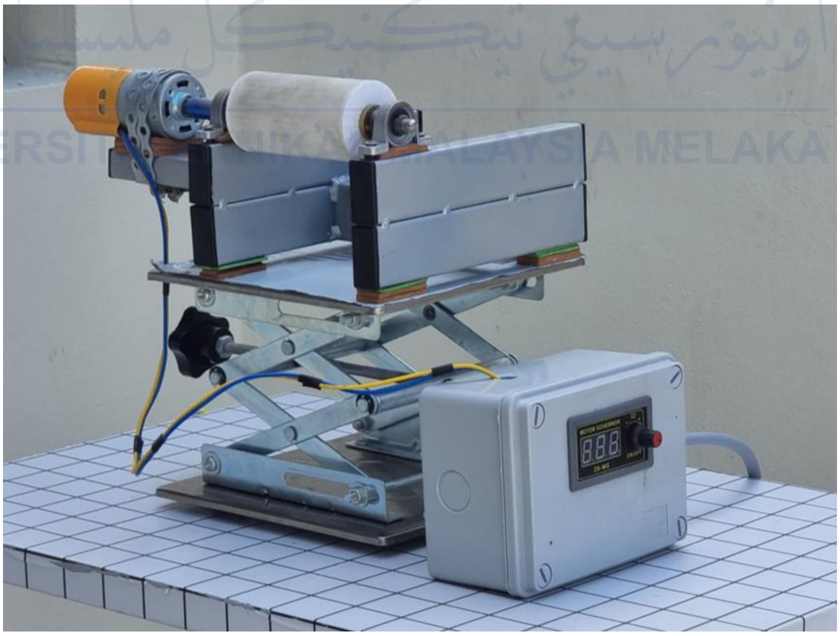


Figure 4.4: Drum collector with speed regulator prototype

4.5 Product Comparison

This section provides a comparison between the syringe pump prototype and those of existing electrospinning machines available in the market specifically the P-CES20-09-24-01 model (CES20-S) (Semi-Automated). It highlights the key differences to showcase the unique features and advantages of the proposed design.

4.5.1 Developed Prototype of Syringe Pump

The Figure 4.5 show the syringe pump control panel on the developed prototype has been carefully designed with an emphasis on simplicity, affordability, and ease of use. Its operation is based on manual input, ensuring that users can easily navigate and control the system without requiring extensive technical knowledge. The control panel includes a keypad for input and an LCD display for real-time monitoring, allowing users to set precise flow rates and observe system performance during operation. This straightforward interface ensures that the device remains user-friendly and accessible, even for those in educational or resource-constrained settings.

Figure 4.5: Syringe pump control panel prototype

The design supports the attachment of a single syringe, making it ideal for basic applications where advanced capabilities are not required. By incorporating widely available and standardized electronic components, the system achieves a high level of cost-effectiveness while also being easy to maintain. If repairs are needed, components can be sourced and replaced with minimal effort, further reducing operational costs. While the system does not feature advanced functionalities such as touchscreen interfaces or automated calibration, this trade-off allows the prototype to maintain its focus on practicality, affordability, and suitability for entry-level and small-scale research environments.

4.5.2 P-CES20-09-24-01 (CES20-S) (Semi Automated)

According to the Figure 4.6 show the control panel on this compact unit offers a more refined interface, the syringe pump features a double-syringe spinneret with a scanning range of up to 25cm. It is ideal for a single needle or coaxial setup for electrospinning or electrospraying. The HMI touchscreen allows fast, easy setup of electrospinning parameters and operational control, it increases the overall cost and dependency on proprietary technology. Maintenance can be more challenging due to the reliance on specific parts or software.

Figure 4.6: Syringe pump (Semi Automated) (Progene Link.,2025)

Conclusion, while the P-CES20-09-24-01 (CES20-S) (Semi-Automated) may have a technological edge with automation, the developed prototype stands out for its simplicity, cost-effectiveness, and ease of maintenance. These attributes make it more suitable for budget-conscious users, such as academic researchers or small laboratories.

4.5.3 Developed Prototype of Drum Collector

According to the Figure 4.7 show the drum collector in the developed prototype is equipped with an adjustable-height mechanism, providing significant flexibility to support a wide range of experimental setups. This feature allows users to easily modify the drum's position to optimize the alignment for specific requirements or configurations. Furthermore, the distance between the needle and the drum can be precisely adjusted, offering fine control over the electrospinning process. This adjustability is crucial for achieving consistent fibre deposition and tailoring the setup to different material compositions or experimental parameters.

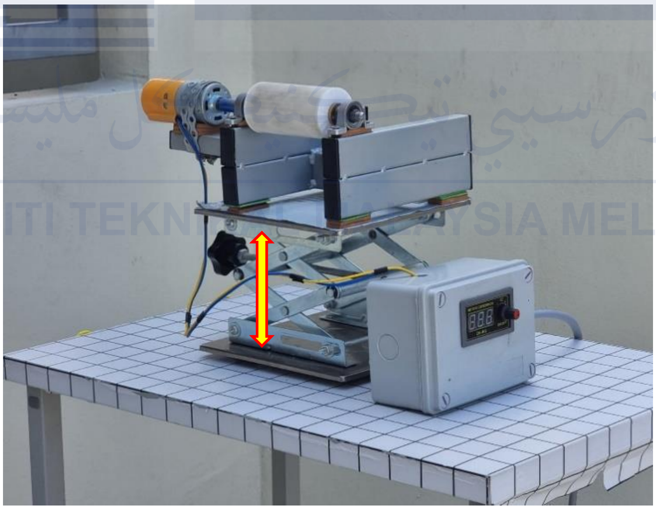


Figure 4.7: Drum collector with speed regulator prototype

The drum's rotation speed is controlled by a straightforward yet effective speed regulator. This system ensures smooth and uniform rotation, which is essential for producing evenly distributed fibres on the drum surface. Despite its simplicity, the regulator delivers reliable performance and makes the system easy to operate, even for users with minimal technical expertise. The materials used in the drum collector are lightweight and corrosion-resistant, enhancing both durability and portability. This robust design ensures that the prototype can withstand prolonged usage while remaining easy to transport and handle, making it well-suited for academic and small-scale research environments.

4.5.4 P-CES20-09-24-01 (CES20-S) (Semi Automated)

According to the Figure 4.8 show the drum collector in this unit likely interchangeable rotary collector (drum, wire, mandrel or vertical plate), arranged in a horizontal setup. Its modular component design allows for easy maintenance and service. Collector distance is adjusted by unscrew and moving the collector manually as shown in arrow at figure above.

Conclusion, the adjustable height in the developed prototype offers a unique advantage, allowing the drum collector to be adapted to different applications. While the P-CES20-09-24-01 (CES20-S) (Semi-Automated) might outperform in terms of precision and integration, the developed prototype's flexibility and ease of use make it a more practical choice for users seeking portability and affordability.

Figure 4.8: Drum collector (Semi Automated) (Progene Link.,2025)

4.5.5 Cost-Effectiveness

The created prototype uses standardized, widely accessible parts and reasonably priced materials, with an emphasis on usability and cost-effectiveness. In addition to lowering production costs, this method makes maintenance easier because parts may be readily replaced or repaired without the need for specific equipment or knowledge. For instance, the drum collecting mechanisms and syringe pump control panel are made of lightweight, corrosion-resistant materials to guarantee affordability and durability.

The P-CES20-09-24-01 (CES20-S) (Semi-Automated), on the other hand, is a premium commercial model that uses proprietary components and cutting-edge materials. These characteristics improve its performance, accuracy, and dependability, which qualifies it for high-precision or demanding applications. However, its accessibility for low-budget research or educational objectives is limited because to the large rise in production and maintenance costs caused by the usage of specialist components. For consumers looking for an affordable yet efficient electrospinning solution, the created prototype offers a good substitute by emphasizing affordability without sacrificing functionality.

4.5.6 Maintenance and Repair

Standardized and easily accessible components are used in the developed prototype's design, greatly simplifying maintenance and cutting expenses and downtime. Without the need for specialist equipment or technical know-how, consumers can quickly find new components from nearby vendors or internet marketplaces in the event of a failure. Because repairs can be completed efficiently and affordably thanks to this design approach, consumers with limited funds or access to expert resources will find the prototype very appealing.

The P-CES20-09-24-01 (CES20-S) (Semi-Automated), on the other hand, uses a proprietary design that depends on cutting-edge materials and specially produced parts. Its overall performance and accuracy are improved, but maintenance becomes more difficult as a result. Specialized equipment, knowledge, or access to particular replacement parts that are only available from the manufacturer may be needed for repairs. In addition to making maintenance more difficult, this raises the expense of repairs and may cause delays, especially if components are hard to find. For consumers who value price and ease of maintenance, the produced prototype thus provides a more workable and accessible alternative.

4.5.7 Practicality

The developed prototype features a lightweight and compact design, making it highly practical for use in smaller laboratories, academic institutions, or research facilities with limited space. Its portability ensures that it can be easily moved or reconfigured to accommodate different experimental setups without requiring significant effort or additional equipment. This design makes it particularly suitable for environments where flexibility and ease of use are prioritized, such as teaching labs or entry-level research projects.

On the other hand, the P-CES20-09-24-01 (CES20-S) (Semi-Automated), although also compact, tends to have a bulkier design due to the inclusion of advanced integrated features and additional components. These features enhance its functionality and precision but come at the cost of increased size and weight, making it less portable and harder to reposition or transport. This design may be more suitable for larger, well-equipped laboratories where space and mobility are less of a concern, but it could pose challenges for users working in confined or resource-limited settings. Consequently, the developed prototype offers a more versatile and accessible option for smaller-scale operations.

4.6 Specifications Product Comparison

To help with decision-making, this comparison provides an in-depth review of the important features and technical details of several items. Every product has been evaluated according to its advantages and disadvantages, giving an accurate understanding of how effectively it operates. Table 4.1 show specification for two products.

Table 4.1: Specifications comparison

No.	Specifications	Prototype Electrospinning	P-CES20-09-24-01 (CES20-S) (Semi-Automated)
1.	Input Power	100-240V AC	100-240V AC
2.	Dimensions (LxWxH) / Weight	44 cm x 26 cm x 23 cm	91cm x 66cm x 66cm / 80 kg
3.	High Voltage Power Supply	10kV to 30kV	Max output voltage, +35kV±0.1 kV
4.	Collector (Standard)	Rotary drum (using aluminium foil)	Stainless steel Rotary drum and attachable vertical plate collector
5.	Drum Collector Rotation Speed	0-100 rpm	0-3000 rpm (optional)
6.	Collector Distance Range	0-20 cm	6-29 cm
7.	Collector Distance Control	Manual control to adjust distance	Manual (CES20-S: Semi automated unit with manual control to adjust distance)
8.	Adjustable Height	20 cm - 40 cm	-
8.	Stainless Steel Collector	Drum:16 cm x 20 cm x 20 cm (ø x L x W)	Drum: 8cm x 28 cm (ǿ x L) Attachable Plate: 29cm x 31cm (H x W)
9.	Syringe Pump Flow Rate	0.5 to 1.5 ml/h	0.01 ml/h to 60 ml/h in 0.01 ml/h resolution
10.	Attachable Needles	1	1 or 2
11.	Usable Syringe Size	1-10 ml	1- 60 ml

4.7 Procedure Setup Electrospinning Machine Prototype

The following step-by-step guide outlines the procedure for setting up the electrospinning machine prototype. Although the machine is not operational yet, the steps describe the intended setup process from powering on the system to turning it off safely.

Step 1: Initial Inspection

- Ensure all components, including the syringe pump, control panel, drum collector, and power connections, are properly assembled and securely fastened.
- Verify that the syringe is filled with the polymer solution and appropriately mounted in the syringe holder.
- Check that the needle is securely attached to the syringe and properly aligned with the target area.

Step 2: Power On the System

- Connect the power supply to the machine and turn on the main power switch on the control panel.
- Observe the LCD display to ensure the control panel is powered and functioning.
- Confirm that the speed regulator for the drum collector is connected and operational.

Step 3: Set Operational Parameters

- Using the keypad on the control panel, input the desired flow rate and volume for the syringe pump. Ensure the values correspond to the intended electrospinning process.
- Adjust the speed regulator to set the rotation speed (RPM) of the drum collector. Note: Adjustments are based on the required fibre deposition rate.
- Confirm the entered parameters on the LCD display.

Step 4: Positioning the Drum Collector

- Adjust the height of the drum collector using the scissor lift to ensure the correct distance between the needle tip and the drum. This distance is critical for nanofiber formation during electrospinning.

Step 5: Simulate Operation

- Although the machine is not fully functional, simulate the operation by activating the syringe pump and drum collector via the control panel.
- Observe the mechanical movements (e.g., lead screw operation and drum rotation) to ensure alignment and stability of all components.

- Check for any unusual sounds or movements that might indicate misalignment or loose connections.

Step 6: Power Off the System

- After completing the setup or testing, turn off the main power switch on the control panel to safely shut down the machine.
- Disconnect the power supply to ensure complete isolation of the system.
- Clean the syringe and needle to prevent clogging and prepare the machine for future use.

4.8 Discussion

The comparison between the developed prototype and the P-CES20-09-24-01 (CES20-S) (Semi-Automated) highlights a clear trade-off between cost-effectiveness and precision, reflecting the distinct priorities of each design. The developed prototype is specifically tailored to provide an affordable, modular, and adaptable solution, making it particularly appealing to users operating under budget constraints or requiring customizable features. Its adjustable-height drum collector and straightforward syringe pump control panel offer considerable flexibility, enabling users to easily modify the system for a variety of experimental setups. These features make the prototype highly suitable for academic, educational, or small-scale research applications where simplicity and flexibility are valued over advanced functionality. However, its lack of advanced automation and integration means it may not fully meet the demands of high-precision industrial processes or advanced research environments requiring greater control and efficiency.

The P-CES20-09-24-01 (CES20-S) (Semi-Automated), on the other hand, stands out for its advanced technology and smooth component integration. With advanced features including automated calibration, customized controls, and improved precision mechanisms, this system is made for consumers who value great accuracy and less manual labour. It is a favoured option for industrial applications or research settings needing accurate and dependable findings because of its high-performance capabilities and simplified operation. However, the cost of these sophisticated features is much more, which limits its accessibility for those on a tight budget. The user's particular demands will ultimately determine which of the two systems is best for them. The P-CES20-09-24-01 (CES20-S) (Semi-Automated) offers better automation and precision, while the designed prototype excels in price and adaptability.

4.9 Summary

The developed prototype showcases significant potential as a cost-effective, modular, and practical alternative to commercially available systems such as the P-CES20-09-24-01 (CES20-S) (Semi-Automated). Its design prioritizes affordability and adaptability, making it particularly well-suited for academic institutions, educational settings, and research environments with limited budgets. The use of standardized, readily available components ensures that the prototype is not only economical to produce but also easy to maintain and repair, enhancing its long-term usability.

Although the prototype lacks some of the advanced features and precision found in high-end commercial units, such as automated calibration, touchscreen interfaces, or integrated feedback control systems, it compensates for these limitations through its simplicity and flexibility. Features like the adjustable-height drum collector and the manually operated syringe pump control panel allow users to tailor the setup for a variety of applications, providing flexibility that is often absent in more rigidly designed commercial systems.

By finding a balance between cost and functionality, the prototype effectively bridges the gap for users who require an electrospinning solution but cannot afford the high costs associated with advanced commercial models. While it may not yet be suitable for high-precision industrial applications, its robust performance and accessible design position it as a valuable tool for fostering innovation and experimentation in resource-constrained environments. Future enhancements, such as improving precision and incorporating additional automated features, could further increase its appeal and broaden its range of applications.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Overview

In Chapter 5, the development of the drum collector and syringe pump for the electrospinning machine is evaluated to determine if the objectives of the project were successfully realized. It evaluates the prototype's functionality, dependability, and practicality in reaching its desired objectives. The chapter emphasizes important achievements such as the system's capacity to deliver constant nanofiber manufacturing and exact control over polymer flow. Along with analyzing the limitations that faced during development, it makes recommendations for improvements. The prototype has been compared with other products on the market, highlighting its height adjustment, small size, low cost, and ease of maintenance. Even though the system successfully accomplishes the project's objectives, the evaluations demonstrate that there is potential for improvement to increase its efficiency for small-scale applications.

5.2 Conclusion

The project successfully achieved its objectives, including the development and evaluation of the syringe pump control system and drum collector for a low-cost electrospinning machine. The second objective, which involved comparing the mechanical specifications of the developed prototype with existing market alternatives, was also accomplished. The analysis highlighted the prototype's advantages, such as adjustable height, compact design, durable yet affordable material selection, standardized replaceable parts, and portability. These features demonstrated that the developed system meets or exceeds the functionality and practicality of market counterparts while maintaining a low-cost design, fulfilling the project's goals effectively.

5.3 Limitations and Recommendation

The developed prototype has not yet undergone testing under real-world operational conditions, which currently limits the ability to evaluate and compare importance performance metrics such as flow rate accuracy and fibre uniformity. These parameters are critical for assessing the overall effectiveness of the system in producing high-quality results during the electrospinning process. Without such testing, it remains uncertain how the prototype will perform in practical scenarios or how it measures up against established commercial models.

To address these limitations, the recommendation should prioritize testing the prototype under a variety of operational conditions to identify potential areas for improvement. Refining the electronic systems will be essential to enhance precision and reliability, particularly in controlling flow rates and ensuring consistent performance. Additionally, incorporating advanced features such as automated calibration and feedback control could significantly improve the system's usability and appeal for more demanding applications. These enhancements would not only increase the prototype's functionality but also make it a more competitive and flexibility solution for both research and industrial purposes.

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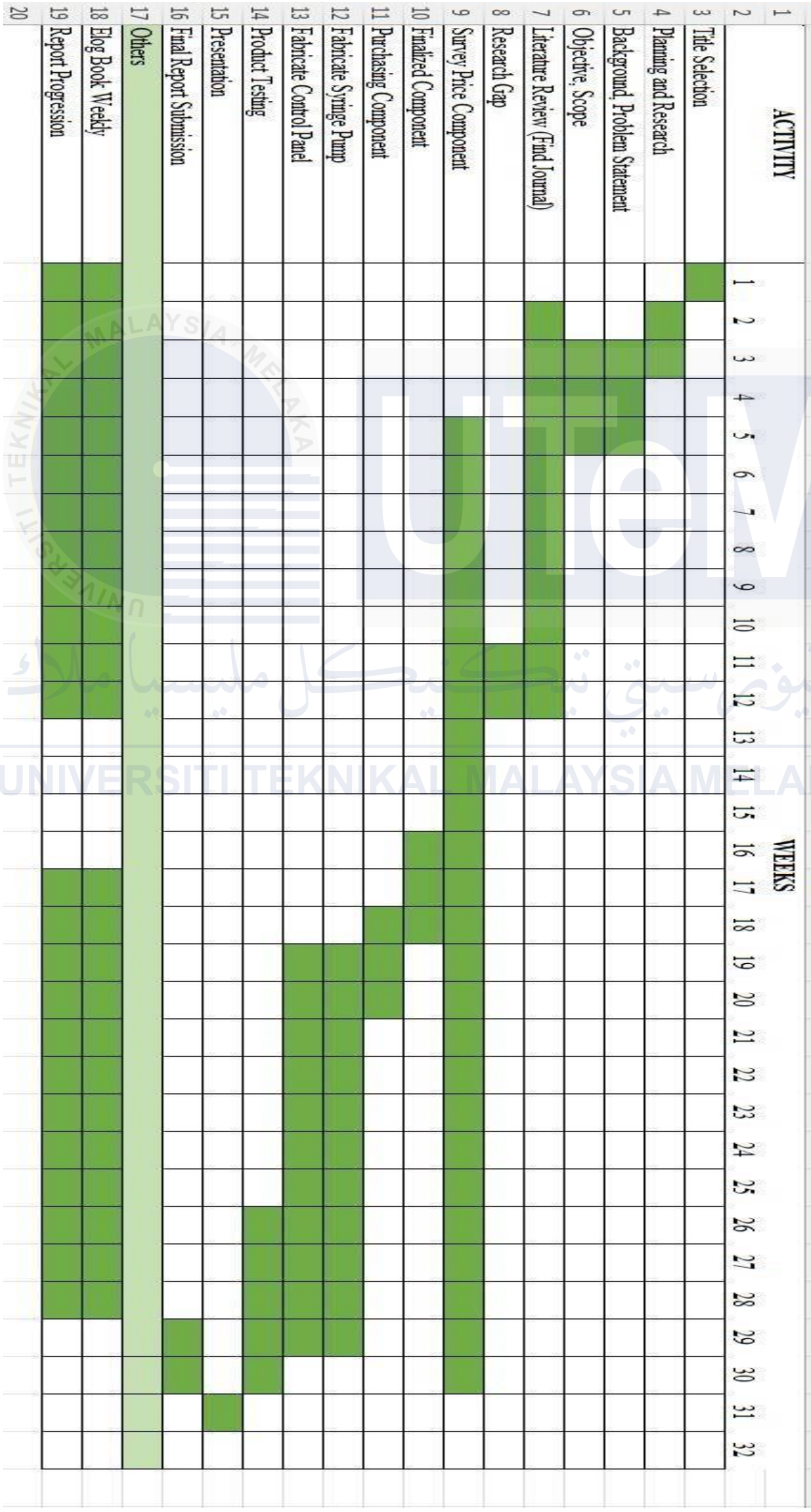
APPENDICES

APPENDIX A Gantt chart



APPENDICES

APPENDIX B Coding extrude filament

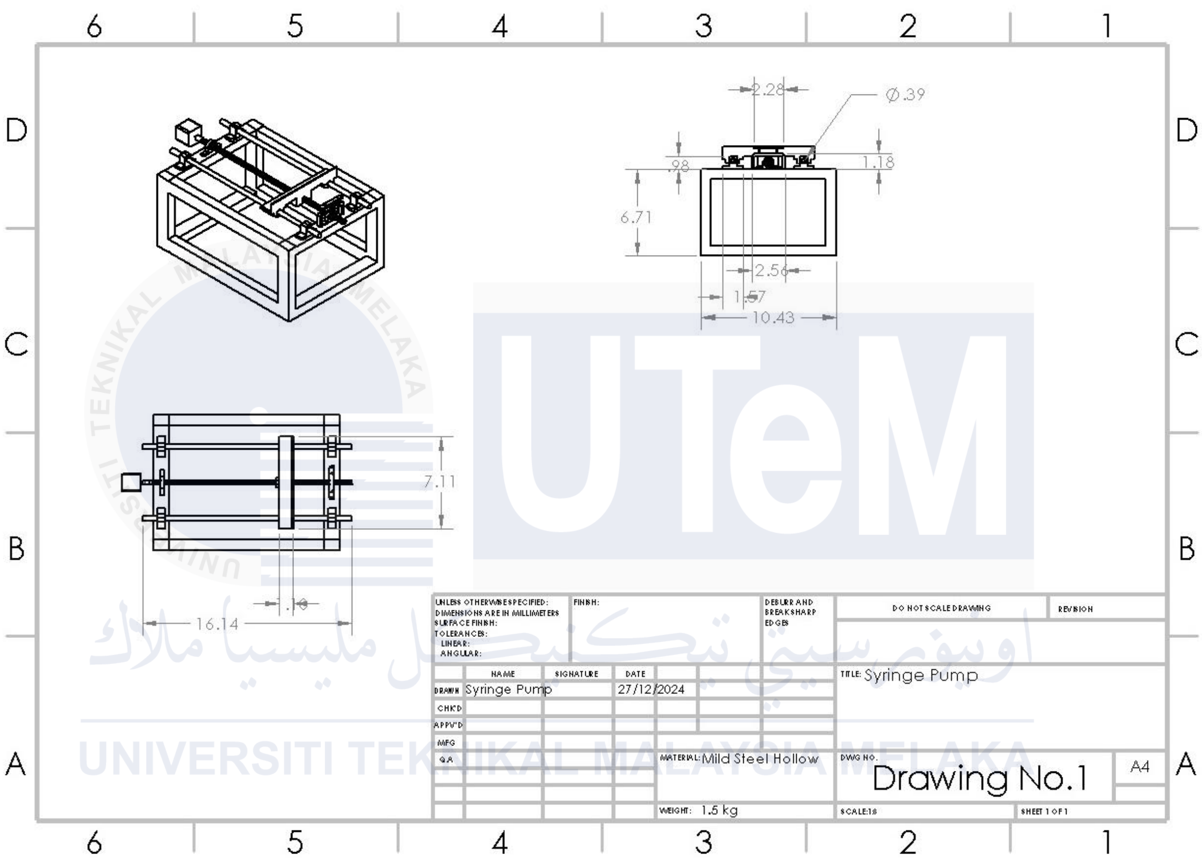
```
/*
 * Filament_Extruder_R11.ino
 * ------------------------
 * System controls a linear gantry to push a
 * syringe to dispense liquid. The speed and dispense
 * amount is controlled from keypad inputs.
 * Stepper runs on half-step mode requiring 400 pulses
 * per revolution. The linear gantry return to home
 * position is detected by a micro switch.
 *
 * DRV8825 stepper driver mode control
 * ------------------------------------
 *  M0     M1     M2     Microstep Resolution
 *  ----   ----   ----   --------------------
 *  Low    Low    Low    Full step
 *  High   Low    Low    Half step
 *  Low    High   Low    1/4 step
 *  High   High   Low    1/8 step
 *  Low    Low    High   1/16 step
 *  High   Low    High   1/32 step
 *
 */

#include <Wire.h>                //
#include <LiquidCrystal_I2C.h>   // CD library
#include <Keypad.h>              // Keypad library
#include <EEPROM.h>              //

// Stepper pin definitions -----------------------------
#define DIR_PIN       12    // Stepper direction output
#define STEP_PIN      11    // Stepper step output
#define EN_PIN        10    // Stepper enable output
#define M0            A3    // Step control pin
#define M1            A1    // Step control pin
#define M2            A2    // Step control pin

// Other pins -----------------------------------------
#define SW_HOME       A0    // Stepper Home position detector
#define BUZZER        13    // Buzzer output

// Stepper motor drive parameters -----------------------
int stepPulse;      // Step Pulse width in msec
unsigned int dispRate;          // msec
unsigned long time_now = 0;
unsigned int  stepCounter = 0;


// Keypad key definitions, 4 ROWS x 4 COLUMNS
const byte ROWS = 4;      // 4 rows
const byte COLS = 4;      // 4 columns
char keys[ROWS][COLS] = {
  {'1','2','3','A'},
  {'4','5','6','B'},
  {'7','8','9','C'},
  {'*','0','#','D'}
};
byte rowPins[ROWS] = {5, 4, 3, 2};   // Connect to the rows
byte colPins[COLS] = {9, 8, 7, 6};   // Connect to the columns

// Keypad variables -------------------------------------
int numVal;                    // Variable to store number entered
char key;                      // Value of key pressed

// Other variables --------------------------------------
float flowRate_f;              // Used to display flowrate in decimal
float dispVolume_f;            // Used to display volume in decimal
unsigned int dispSteps;        // umber of stepper steps to dispense
int flowRate    = 0;           // Speed Range 0.5 - 1.5 ml/hr
int dispVolume  = 0;           // Volume Range 1 - 10 ml

int eeAddress   = 0;           // E2PROM starting address
bool startState = false;       // Start state flag

LiquidCrystal_I2C lcd(0x27, 20, 4);  // LCD object
Keypad keypad = Keypad(makeKeymap(keys), rowPins, colPins, ROWS, COLS); // Keypad object

void setup() {
  lcd.init();
  lcd.backlight();
  Serial.begin(115200);

  pinMode(BUZZER, OUTPUT);
  pinMode(DIR_PIN, OUTPUT);
  pinMode(STEP_PIN, OUTPUT);
  pinMode(EN_PIN, OUTPUT);

  pinMode(SW_HOME, INPUT_PULLUP);
  pinMode(M0, OUTPUT);
  pinMode(M1, OUTPUT);
  pinMode(M2, OUTPUT);

  digitalWrite(EN_PIN, HIGH);   // Disable stepper
```

```
  // Load saved values from EEPROM --------------
  EEPROM.get(eeAddress, flowRate);
  EEPROM.get(eeAddress+2, dispVolume);

  // Initialise the system ---------------------------
  lcd.home();
  lcd.print("Filament Ext R11");
  lcd.setCursor(0,1);
  lcd.print("Wait ...");
  lcd.setCursor(0,2);
  lcd.print("Stepper Return");
  Serial.println("Stepper Return");

  // Return stepper to home --------------------------
  initStepper();
  delay(500);

  Serial.println("Stepper Home");
  lcdLineClear(1);
  lcd.print("Return done");
  delay(1000);

  // Display the menu -----------------------
  lcd.clear();
  lcd.print("---- Setup Menu ----");
  lcd.setCursor(0,1);
  lcd.print("A = Set Flowrate");
  lcd.setCursor(0,2);
  lcd.print("B = Set Volume");
  lcd.setCursor(0,3);
  lcd.print("C = Start process");
  delay(4000);
  lcd.clear();
  beep(1,200);
}

void loop() {
  displaySettings();        // Show current settings
  delay(50);
  key = keypad.getKey();    // Check for key press
  switch(key){
   case 'A':                // Set dispenser flowrate
     beep(1,50);
     lcd.clear();
     lcd.print("Flow ml/hr = ");
     lcd.blink();
     lcd.setCursor(13,0);
    lcd.blink();
    lcd.setCursor(13,0);
    getNumber();
    delay(100);
    if(numVal >= 5 && numVal <= 15) { // Within range = 0.5 - 1.5 ml/hr
      flowRate = numVal;
      EEPROM.put(eeAddress, flowRate); // Store in E2PROM address 0
      beep(1,100);
      delay(500);
    }else{                  // Not within range
      lcd.clear();
      lcd.print("Error");
      beep(4,200);
    }
    lcd.noBlink();
    break;

  case 'B':                 // Set Dispense volume
    beep(1,50);
    lcd.clear();
    lcd.print("Volume ml = ");
    lcd.blink();
    lcd.setCursor(13,0);
    getNumber();
    if(numVal >= 10 && numVal <= 100) { // Within range = 1 - 10ml
      dispVolume = numVal;
      EEPROM.put(eeAddress+2, dispVolume); // Store in E2PROM address 2
      beep(2,100);
      delay(500);
    }else{                           // Not within range
      lcd.clear();
      lcd.print("Error");
      beep(4,200);
    }
    lcd.noBlink();
    lcd.clear();
    break;

  case 'C':            // Start the process
    beep(1,50);
    lcdLineClear(3);
    lcd.print("Started ...");
    startState = true;

    time_now = millis();
    digitalWrite(M0,LOW);      // 1/4 step
    digitalWrite(M1,HIGH);
    digitalWrite(M2,LOW);
```

```
      dispRate = map(flowRate,5,15,1350,380);  // 380, 1500
      Serial.print("Flow Rate = ");
      Serial.println(flowRate);
      // Calculate steps needed for volume dispense
      // 1ml = 4760 steps on stepper
      int vol = (int)dispVolume_f * 10;  // convert to integer
      stepCounter = map(vol,10,100,4760,47600);

      Serial.print("Dispense msec = ");
      Serial.print(dispRate);
      Serial.print(" | Steps = ");
      Serial.println(stepCounter);
      delay(1000);
      digitalWrite(EN_PIN, LOW);    // Enable stepper
      digitalWrite(DIR_PIN, LOW);   // Stepper turn direction, LOW = CW
      break;

    case 'D':           // Display Menu
      beep(1,50);
      displayMenu();
      break;

  case '*':
      initStepper();
    break;

  }
  delay(100);

  // Start the process -------------------------
  if(startState == true){
    if(millis() >= time_now + dispRate){
      time_now += dispRate;
      digitalWrite(STEP_PIN, HIGH);
      delay(stepPulse);
      digitalWrite(STEP_PIN, LOW);
      delay(stepPulse);
      if(stepCounter <= 0){
        startState = false;
        delay(50);
        digitalWrite(EN_PIN, HIGH);   // Disable stepper
        beep(1,300);
      }else{
        stepCounter--;
        Serial.print("Count = ");
        Serial.println(stepCounter);

  while(!digitalRead(SW_HOME)){
    digitalWrite(STEP_PIN, HIGH);
    delayMicroseconds(stepPulse);
    digitalWrite(STEP_PIN, LOW);
    delayMicroseconds(stepPulse);
  }
  digitalWrite(EN_PIN, HIGH);     // Disable stepper
  beep(1,200);
  delay(500);
}

void lcdLineClear(int row){
  lcd.setCursor(0, row);
  lcd.print("                    ");
  lcd.setCursor(0, row);
}

// Function to get numbers fron Keypad ---------------
void getNumber(){
  numVal = 0;
  //lcd.setCursor(0,1);
  key = keypad.getKey();
  beep(1,50);
  do{
   key = keypad.getKey();         // Read key pressed
   if(key >= '0' && key <= '9') { // Numeric keys pressed
      beep(1,50);
      lcd.print(key);
      numVal = numVal * 10 + key - '0';
   }else if(key == '*') {         // Clear '*' key pressed
      beep(1,50);
      numVal = 0;
      lcd.setCursor(13,0);
      lcd.print("     ");
      lcd.setCursor(13,0);
   }
  }while (key != '#');            // Enter '#' key pressed
   beep(1,50);
}

void beep(int rept, int del){
  for(int x=0; x<rept ; x++){
    digitalWrite(BUZZER, HIGH);
    delay(del);
    digitalWrite(BUZZER, LOW);
    delay(50);
  }
}
```

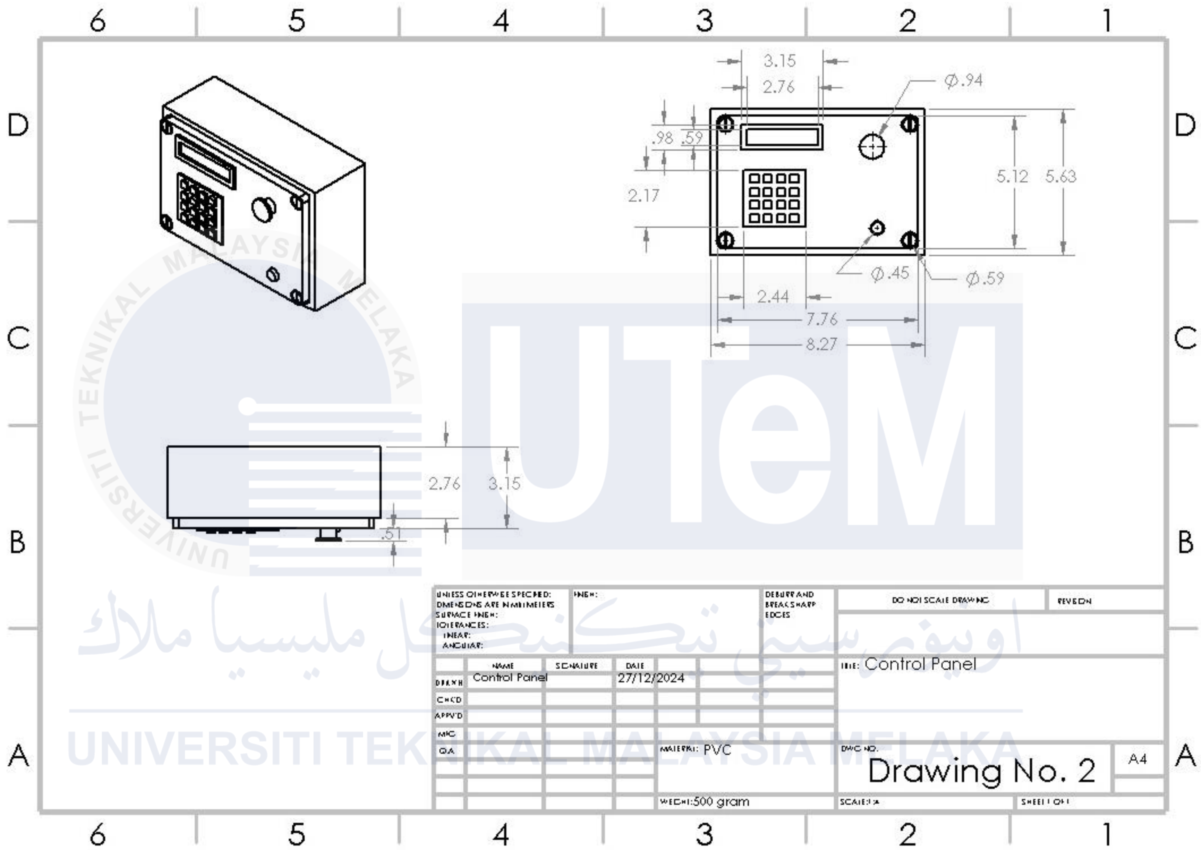
APPENDICES

APPENDIX C Isometric design of syringe pump



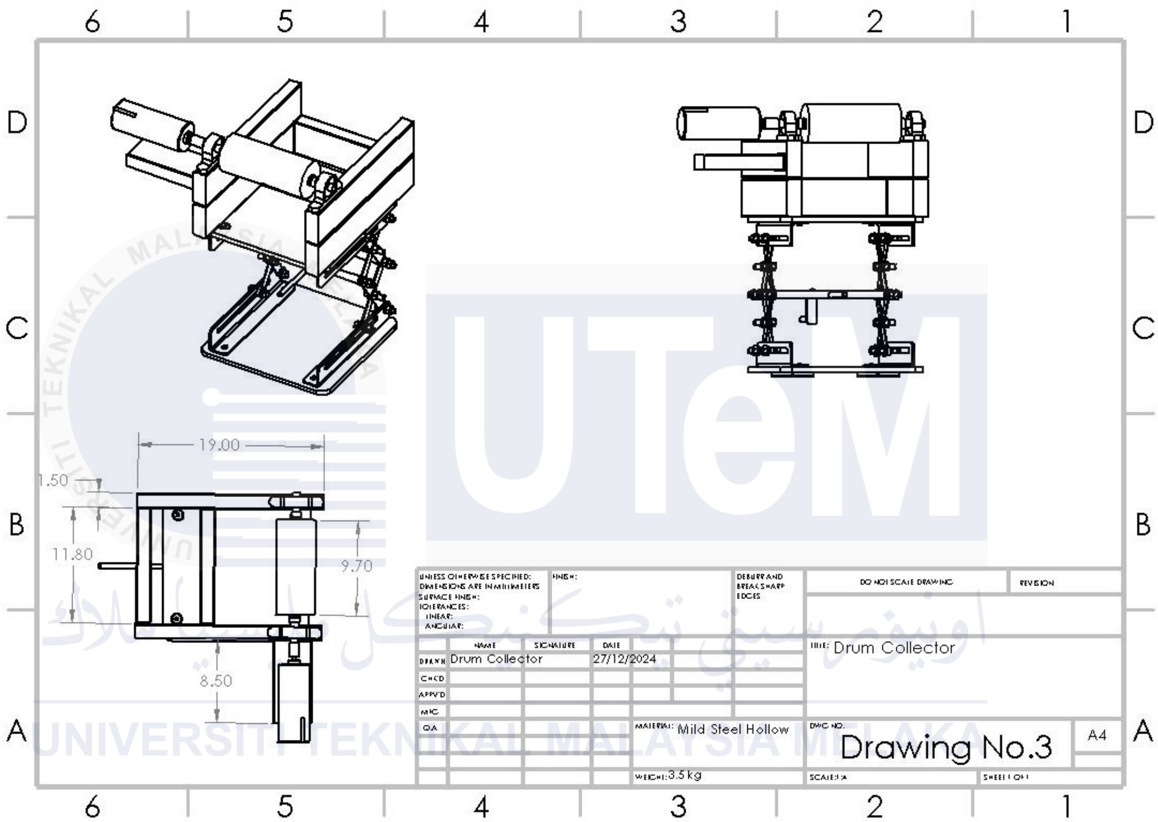
APPENDICES

APPENDIX D Isometric design of control panel



APPENDICES

APPENDIX E Isometric design of drum collector



APPENDICES

APPENDIX F Isometric design of speed regulator