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Design and Implementation of a Low-Cost Open-Source Syringe Pump Using Stepper Motor Technology

تطوير وتصميم مضخة حقن منخفضة التكلفة ومفتوحة المصدر باستخدام تقنية محرك خطوي

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A graduation project report submitted to the Department of Engineering in partial fulfillment of the requirements of a bachelor's degree in biomedical engineering.

Abstract

This study presents the design and development of a cost-effective syringe pump tailored for laboratory and research applications. Conventional syringe pumps are often financially prohibitive for small-scale laboratories or educational institutions, limiting accessibility. To bridge this gap, the proposed system utilizes an Arduino microcontroller paired with a stepper motor and linear actuator to precisely control the movement of the syringe plunger. Users can adjust fluid delivery parameters via a potentiometer, while real-time feedback on flow rates and volumes is displayed on an integrated LCD screen. By combining affordable hardware with open-source programming, this project showcases a reliable, user-friendly solution capable of supporting diverse scientific workflows without compromising precision or affordability.

The primary goals of this project are threefold. First, to develop a locally manufactured syringe pump that delivers high-quality performance, precision, and accuracy at a fraction of the cost of commercial alternatives. Second, to break the barriers of imported commercial devices in times of difficulties of wars and blockage in Yemen, such as difficulties in finding spare parts and difficulties of maintenance and calibration. Where manufacturers can't afford their services in this satiation. Third, to enhance the standard syringe pump device by adding new features, such as central monitored alarms and alerts, Auto detection of solute volume inserted in the syringe.

Abstract

The results of our work weren't a final product that can be marketed yet, but very promising. Where we manage to create a light and portable open-source device that can use all syringe sizes of (10mL, 20mL and 60mL), and has accuracy of over 98% for all tested speeds between the range of 1 to 400mL/h, and it worked for around 6h in battery.

Even though we managed to create a device that meets global health standards, we couldn't achieve all our goals yet, specifically the central monitoring protocol. And the chassis assembly used was derived from a different device that was out of service, we as well used the Arduino microcontroller to reduce the time required to create a full final circuit. And even though the battery can last 6h straight, it's still not efficient enough. Our next goal is to limit all these week spots to create a marketable device that can help serve the goal this project was created for.
However, the estimated price for the final product is around the quarter of the average price of syringe pumps, where we can sell our device for as low as 300$ with profit of 100$ for each product sold, which is our main goal. And services will be delivered by us as manufacturers allowing a longer life span for our product than average life span in the market.

Dedication

Praise be to Allah who has guided us to this, and we would not have been guided had Allah not guided us. O Allah, all praise is due to You until You are satisfied, all praise is due to You when You are satisfied, and all praise is due to You after You are satisfied.

To the beloved of Allah, to the master of prophets and messengers, Muhammad ibn Abdullah, the truthful and trustworthy, may the prayers and peace of my Lord be upon him, his family, and all his companions. To our mothers, fathers, brothers, and sisters, to our fellow students and colleagues in our university journey, and to our dear professors in the Department of Biomedical Engineering at the United Arab Emirates International University, we extend our special thanks and respect to Professor Waleed Al-Talabi, and express our deep gratitude for the advice and guidance he provided us, and for the efforts he exerted in completing this work. We also extend our gratitude to the project discussion committee, our dear professors, and to our beloved Yemen, Palestine, and our Arab and Islamic nation.

We dedicate this research to you.

Acknowledgment

With profound humility and boundless gratitude, we first turn our hearts to Allah, the Most Merciful, whose infinite wisdom, unerring guidance, and steadfast support have illuminated every step of this journey. It is by His gracious decree that we found the courage to overcome challenges and the fortitude to bring this endeavor to fruition.

Our deepest thanks go to our families, whose constant love, unwavering faith, and uplifting encouragement have been the bedrock of our perseverance. Their patience in moments of strain, their belief in our potential, and their innumerable acts of kindness have sustained us, inspiring us to reach ever higher.

We are especially indebted to Associate Professor Waleed Al-Talabi. His exceptional mentorship marked by insightful critique, generous sharing of expertise, and patient guidance has shaped our scholarly growth and guided us toward the highest standards of excellence. We remain forever grateful for his dedication to our development and their invaluable contributions to this work.

Our sincere appreciation also extends to our peers and colleagues, whose collaborative spirit and thoughtful dialogue have enriched every phase of our research. Through their constructive feedback, lively debate, and genuine camaraderie, they have fostered an environment of shared learning and collective progress.

Lastly, we wish to acknowledge all those, seen and unseen, whose support whether through a word of encouragement, a timely suggestion, or the gift of their time has propelled this project forward. Your generosity and kindness have left an indelible mark on our efforts, and we pray that Allah rewards each of you abundantly for your contributions.

Finally, we, the members, wish for everyone good health and wellness.

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Introduction

1. Chapter 1: Introduction

1.1. Overview

A syringe pump is an advanced medical and laboratory device used to precisely control the flow of fluids through a syringe fixed within a mechanical drive system. These pumps are widely used in medical fields, such as intravenous drug delivery, anesthesia, and drug research, as well as in industrial and research applications, such as biochemistry and microfluidics [1].

1.1.1. Syringe Pump

A syringe pump is a mechanical medical equipment used to precisely inject fluids, medications, or nutrients into a patient's body. Unlike traditional methods of injection, syringe pumps deliver a controlled and steady amount of fluid over a specific period. This device is mainly used in critical care environments, such as operating rooms, intensive care units (ICUs), and hospitals. It helps manage small doses of medication, ensuring that patients receive the right amount at the right time.

The device operates through a precise electric motor that controls the movement of the syringe plunger, allowing continuous or intermittent fluid flow at a specified rate. This rate can be finely adjusted according to application requirements, making it an essential tool in experiments that require high-precision control over volume and flow rate [1].

1.1.2. Uses and Cases of Syringe Pumps

Syringe pumps are versatile devices used across various fields, including medical applications, scientific research, and industrial processes. Below are the key uses and real-world **cases** where syringe pumps play a critical role.

1- Medical Applications

Syringe pumps are widely used in healthcare settings to deliver precise amounts of fluids, medications, or nutrients to patients over a controlled period [1].

A. Drug Delivery in Hospitals

- Intravenous (IV) Medication Administration**:** Used in Intensive Care Units (ICU), operating rooms, and emergency departments for delivering controlled doses of drugs such as insulin, heparin, and painkillers (morphine, fentanyl)**.**
- Chemotherapy Infusion**:** Ensures slow and accurate administration of cytotoxic drugs to minimize adverse effects.
- Anesthesia and Sedation**:** Provides propofol or midazolam in surgeries and ICUs for patient sedation.

B. Neonatal and Pediatric Care

- Used in neonatal incubators for administering small, precise doses of fluids or medications to premature babies.
- Commonly used for TPN (Total Parenteral Nutrition)**,** where nutrients are delivered directly into the bloodstream.

C. Pain Management (PCA - Patient-Controlled Analgesia)

- Allows patients to self-administer pain relief medications (such as opioids) at controlled intervals, reducing discomfort while preventing overdose.

D. Infusion Therapy for Chronic Diseases

- Diabetes Management**:** Used in insulin pumps for continuous subcutaneous insulin infusion (CSII).
- Cardiovascular Treatments: Administers vasoactive drugs like dopamine and epinephrine for managing blood pressure.

Medical Condition	**Solution Used**	**Typical Dosage**	**Flow Rate**	**Duration**
Intravenous Drug Administration in ICU	IV Insulin Infusion	0.05-0.1 units/kg/hour	0.5 - 5 mL/hour	Continuous until blood sugar stabilizes
	Heparin for Clot Prevention	12-15 units/kg/hour	1-10 mL/hour	Until coagulation stabilizes
Anesthesia and Sedation in Surgeries	Propofol Infusion	25-200 mcg/kg/min	5-50 mL/hour	Throughout the surgery
	Morphine or Fentanyl for Pain Relief	1-10 mcg/kg/hour	2-10 mL/hour	As needed
Total Parenteral Nutrition (TPN)	Glucose, Amino Acids, and Lipid Solutions	Based on patient weight	50-150 mL/hour	12-24 hours daily
Chemotherapy Infusion	Cisplatin, Doxorubicin, Methotrexate	Based on cancer type and patient weight	2-20 mL/hour	Several hours to days
Patient-Controlled Analgesia (PCA)	Morphine or Hydrocodone	0.5-2 mg/dose	0.2-2 mL/hour	Until pain subsides

table 1-1: Medical Applications

2- Research and Laboratory Applications

Syringe pumps are essential in scientific experiments and biomedical research**,** ensuring precise liquid handling and controlled flow rates [2].

A. Microfluidics and Lab-on-a-Chip Technologies

Syringe pumps control the movement of tiny liquid volumes in biochips used for DNA sequencing, disease diagnostics, and drug screening**.**

B. Cell Culture and Tissue Engineering

Used in bioreactors to supply nutrients to growing cells or deliver drugs in studies related to cancer therapy, stem cell research, and regenerative medicine**.**

C. Analytical Chemistry and Spectroscopy

- Ensures consistent flow of reagents in High-Performance Liquid Chromatography (HPLC) and Mass Spectrometry (MS) for chemical analysis.
- Used in electrochemistry for delivering controlled amounts of electrolytes.

Research Application	Solution Used	Typical Dosage	Flow Rate	Duration
Analytical Chemistry (HPLC, MS)	Organic Solvent (Methanol, Acetonitrile, Water)	10-100 µL	0.1-5 mL/hour	30-120 minutes
Nutrient Supply in Cell Culture	DMEM or RPMI with Glucose & Serum	2-10 mL	0.5-2 mL/hour	24-72 hours
Microfluidics and Biochip Applications	Biological Buffers, Blood Samples, or Analytical Fluids	10-100 µL	0.01-1 mL/hour	Minutes to hours

table 1-2: Research and Laboratory Applications

3- Industrial and Manufacturing Applications

Syringe pumps are also used in precision manufacturing, quality control, and automation systems [3].

A. Pharmaceutical and Drug Development

Helps in automated drug formulation, ensuring precise mixing of active ingredients.

Used in stability testing for controlled drug release studies.

B. Chemical Processing and Material Science

Delivers precise amounts of reactants in polymer synthesis, coatings, and nanomaterials research.

Used in inkjet printing and 3D bioprinting for printing biological tissues.

C. Environmental and Agricultural Applications

Syringe pumps are used in water quality testing and automated pesticide delivery systems in precision agriculture.

Research Application	Solution Used	Typical Dosage	Flow Rate	Duration
Pharmaceutical Drug Production	Active Pharmaceutical Ingredients (APIs) for Injectables	As per formulation	5-50 mL/hour	Per production requirements
3D Bioprinting	Hydrogel with Living Cells	10-500 µL	0.05-5 mL/hour	Several hours
Precision Chemical Spraying	Coating Solutions for Electronics & Materials Science	1-50 mL	1-10 mL/hour	Based on industrial process

table 1-3: Industrial and Manufacturing Applications

1.2. Problem Statements

A. The cost of Syringe Pumps provided by merchants is relatively high. Where new devices range between 800$ to 2000$. Where used devices are between 400$ to 600$. Other syringe pump providers for lower doesn't offer many features like open-source syringes, accuracy and software interface, therefore they are not a good choice for most cases.

B. Difficulty of Troubleshooting, making syringe pumps frequently replaced after simple malfunctions duo to the following fact that repairing most syringe pump problems requires trained technicians to repair duo to the complexity of its software and hardware, difficulties of calibration if even possible by the provider, electronic malfunctions are hard to diagnose and it's hard to find spare parts and slow response from manufacturers, and in most of the time technicians suffer of documentation issues (service manuals are not provided or not written properly to help them do their job), especially in the situations our country is going through.

C. Monitoring Issue in some healthcare organization duo to lack of nurses or other reasons, and difficulty in finding out what went wrong sometimes where devices mostly doesn't provide history of usage and doses, or does not provide reading for dose delivered so far.

D. In some provided syringe pumps, if syringe is not used to the full (etc. a syringe of 20mL is half filled to 10mL) the used must insert value of solute volume manually to allow syringe pump to calculate the dose delivered.

1.3. Project Objectives

1- To provide a local made syringe pump device of high quality, precision and accuracy for a lower cost than market, were both healthcare providers in particular and our nation in general are benefited financially.

2- To create a syringe pump with an open source, where the device is capable of determining the size of syringe (10, 20 and 50mL) and the proper speed for motor in return for accurate flow rate.

3- Add an extra advantage of wireless control of syringe pump through software application. Allowing the user to control many syringe pumps from a long distance and monitor their alarms all at the same time. And adding software features for storing history and customized settings.

4- Automatic calculation of solute injected to the patient by detecting initial position of syringe and detecting distance travelled by the plunger.

5- Allowing for storage of customized frequent values of injection by the user to spare time and sometime prevent error caused by lack of knowledge of the user of the doses needed for some injections. And storage of history for the doses delivered and values inserted previously to provide a reference for the history of injections for patients if needed.

6- Easy access to patient information through the application and the extent improvement in health deterioration.

1.4. Project Scope and Limitations

The scope of our design is focused in the software and calibration, structure design, main PCBs design for sensors, driver and power supply. And does not include design for chassis assembly design and processor circuits for now. Where a spare part is used for chassis assembly, and Arduino Mega board used for processing as a temporary solution, and will be designed later in our next prototype.

1.5. Project methodology

To achieve the desired standards that was mentioned before, we started trying some common methods [4].

1- Accuracy:

Using a stepper motor with a linear shift assembly that turns the rotating motion to linear motion, and a couple of sensors to track the speed of motion and the current location of the syringe plunger. A motor driver circuit and a microcontroller are needed to control each step of the stepper motor accurately with counting steps.

2- Safety and smart sensory:

Using LED transmitter and photodiode receiver was the most affordable, yet the most efficient method to detect the flowrate and speed, position and even the size of the syringe placed. This is the most common method in modern syringe pumps for this function. A strain gauge attached to a bearing attached to the linear shift is used to detect the stress applied on the syringe plunger and is used to detect occlusion in tube or patient's veins.

3- Power Backup and Portability:

Six lithium-ion battery of 3.7 v and 2200mA/h capacity are set to make an 11.1V battery with capacity of 4400mA/h to power the device in case of disconnection from the main source. The light weight of PLA material used to print the structure allows the syringe pump to be light and easily portable.

4- Interference and wireless control and monitoring:

The library and customization mentioned before, along with other features for interference with the user are programmed using Micro C/Arduino Language. A Microchip for WIFI connection is used for the wireless functions to allow the syringe to be controlled and monitored by a phone or a personal computer.

1.6. Document Structure

This document provides a detailed explanation of the working principles of syringe pumps, their design, and control methods, along with an overview of the latest technological advancements and future trends in this field.

Chapter 2

Background and Literature Review

2. Chapter 2: Background and Literature Review

2.1. Background

Why Syringe Pump?

As we happen to practice maintenance of biomedical devices in local hospitals, such as science and technology hospital and republican hospital, we couldn't help but to notice the huge amounts of syringe pumps and infusion pumps thrown away in workshops duo to lake of spare parts, difficulties of calibrations and maintaining electric circuits (most service manuals doesn't provide block diagram for electric circuits). Therefore, we decided to take advantage of this gap in our graduation project, were we found it's possible to provide these devices for a lower cost and easier maintenance, starting with syringe injection pumps [7].

2.1.1. Properties

1- Portability

Many syringe pumps are compact and lightweight, making them easy to transport and use in various settings, including hospitals, clinics, and research labs.

2- Programmable Settings

Advanced syringe pumps often feature programmable protocols, allowing for customization of infusion rates and volumes, which can enhance efficiency in treatment.

3- Multi-Syringe Capability

Some models can accommodate multiple syringes simultaneously, enabling concurrent infusions of different medications or solutions.

4- Battery Operated Options

Many syringe pumps come with battery backup, allowing for use in emergency situations or in environments without direct power supply.

5- Integration with Other Systems

Some syringe pumps can integrate with electronic health record (EHR) systems for seamless tracking and documentation of medication administration.

6- Reduced Risk of Contamination

The closed system design of syringe pumps minimizes the risk of contamination, which is crucial for maintaining sterility in medical applications.

7- Real-Time Monitoring

Many advanced models offer real-time monitoring of flow rates and volumes, providing immediate feedback and enhancing patient safety.

8- User Training and Resources

Reputable manufacturers often provide comprehensive training resources and support, ensuring that healthcare professionals can use the devices effectively and safely [6,7].

2.1.2. Software and Hardware Problems

1- Inoperable Pump Error: An error message indicating the pump is inoperable without a clear cause.

2- Key Bounce Issue: A single keystroke is misinterpreted as multiple inputs (e.g., 10 mL/hour registered as 100 mL/hour [6,7].

Alarm Errors

1- Missing Audible Alarms: Failure to alert users of critical problems (e.g., occlusions or air in tubing)

2. False Alarms: Generating alarms without actual occlusions or issues [6].

User Interface Design Issues

1. Confusing Screen Design: The interface does not guide users properly, leading to incorrect data input.

2. Unclear Measurement Units: Lack of clarity on required units (e.g., pounds vs. kilograms).

3. Damaged Labels or Components: Routine handling or cleaning can damage the pump, affecting reliability.

4. Inadequate Setup Instructions: Vague instructions for mechanical setup can lead to clamped tubing and under-syringe.

5. Poor Alarm Functionality: Alarm systems may be poorly designed, leading to missed critical alerts or alarm fatigue.

6. Confusing Key Layout: Misplacement of keys (e.g., "Start Syringe" near "Power") can result in accidental shut-offs.

7. Unclear Warning Messages: Warnings that do not clearly communicate the necessary actions can confuse users.

8. Outdated or Confusing Manuals: User manuals that are unclear or not updated may hinder effective use [6].

Recommendations

• Software Updates: Address software errors and ensure accurate keystroke recognition.

• Alarm System Redesign: Improve alarm reliability and reduce false alarms.

• User Interface Redesign: Simplify the interface, clarify measurement units, and enhance navigation.

• Clear Instruction Manuals: Update manuals and include specific, clear instructions for setup and operation [6].

Factors to consider when buying syringe pump

When buying a syringe pump, here are some important factors to keep in mind:

• Accuracy: Ensure that the pump delivers the precise volume and rate needed.

• Ease of use: Look for user-friendly controls and display interfaces.
Capacity: Choose a syringe pump that meets your specific volume and flow rate requirements.

Compatibility: Ensure that the pump is compatible with the syringes you plan to use.

Warranty and service: Make sure the pump comes with a warranty and adequate customer support [6].

2.2. Literature Review

Continuous scientific development in the units of medical monitoring devices, and competition in creating new methods that contribute to increasing the reliability and accuracy of reading medical information, and reducing costs as well, to reduce the difficulties resulting from some measurement methods [5].

2019: Smart pumps were introduced, featuring wireless connectivity, drug libraries, care area profiles, and soft and hard borders, enhancing the safety and efficiency of drug delivery.

New Millennium: Smart pumps emerged, providing highly accurate dose control, connecting to electronic health systems, and providing automatic alerts and warnings.

Mid-2000s: Insulin pumps evolved to become more integrated with glucose monitoring devices, leading to the development of artificial pancreas systems.

Syringe pumps are vital tools in both medical and research fields, and many scientific studies have examined their development, performance, and safety. Below is a summary of key studies and their findings:

Evaluation of a Newly Developed Syringe Pump for Continuous Drug Infusion

Summary: The study evaluated the performance and safety of a new syringe pump called "Neo" for clinical use. Results showed that it provides precise and appropriate drug infusion, making it a promising device in dental anesthesia**.**

Performance Comparison: Flow-Controlled Infusion Pump vs. Conventional Pumps

Summary: A novel syringe pump with flow-control features was compared to a traditional syringe pump, especially during startup and vertical movement. The new design significantly reduced delays and flow irregularities, improving drug plasma concentration stability**.**

Clinical Tips to Enhance Patient Safety During Syringe Pump Use

Summary: Experts proposed ten clinical tips to improve patient safety when using syringe pumps for IV therapy. Key recommendations included avoiding vertical movement during infusion and limiting ultra-low flow rates.

Accuracy and Reliability of Infusion Pumps in Hospitals

Summary: A systematic review of studies over a 10-year period assessed the accuracy and reliability of hospital infusion pumps to support better maintenance and device management strategies.

Impact of Syringe Pump Pulsation on Cell Separation in Microfluidic Devices

Summary: This study explored how pressure pulsations from syringe pumps affect the width of cell-free zones in microfluidic separation devices, which in turn impacts separation efficiency.

Pneumatic Soft Actuator Control Using Approximate Dynamic Modeling

Summary: Researchers proposed a full system model combining a syringe pump with pneumatic actuators and implemented a Linear Quadratic Regulator (LQR) for fast, accurate actuator control.

Performance of Modern Infusion Pump Sets at Low Flow Rates

Summary: The study evaluated how modern infusion pumps perform at low flow rates and the implications for drug concentration consistency and safety.

Impact of Lowering Syringe Pumps on Flow Rate Accuracy

Summary: This study examined how lowering the position of a syringe pump and changes in external pressure affect the accuracy of infusion flow rates.

Chapter 3
Requirements Analysis and Modeling

3. Chapter 3: Requirements Analysis and Modeling

3.1. Introduction

Syringe pumps, along with infusion pumps, are classified as class IIb medical device according to EU union [1,2], meaning that it has a moderate high risk in using them duo to the invasive injection of solutes. The result of an underdoes might cause a serious problem, and injection of an overdoes can be disastrous depending on the condition and the solute used. This implies a set of standards that must be met according to Science Arena's paper [2]:

1- Advance Dosing Accuracy:

The accuracy of flowrate control is crucial point for the design of a syringe pump, where an accuracy between 1% to 3% [3]

2- Battery backup and portability:

A syringe pump must have a battery to allow it to function for long time in case needed in portable applications. And to ensure it continue to function in case of power cutoff or where power plugs doesn't exist. The syringe pump weight must be light to make it more portable.

3- Smart Alarm system:

For safety requirements, a fail-safe system of a set of visual and audible alarms is used to alert medical staff of the existing issue to prevent any unexpected problem, like motor malfunction, battery drain, occlusion or solution depletion.

4- Drug Delivery Profiles:

Some syringe pumps may contain a set of settings for flowrate for commonly used drugs. This could save experts time and prevent some new staff from selecting wrong volumes.

5- Integrated safety Features:

To enhance patient safety, safety features like does calculation checks and infusion rate limits for each common drug may reduce the risk of harm in treatment.

6- Open-Source:

It's very useful for a syringe pump to be able to determine the size of syringe automatically and set the speed as needed for each syringe depending on its diameter length, instead of being limited to one size only.

7- Wireless Connectivity:

A wireless communication would be useful to allow control from a distance and to make alarms attached to a central monitoring system.

8- Storing History:

this functionality is provided to view doses delivered for patients to prevent errors caused by user. And provide an overview for doses history in case of legal accountabilities.

3.2. Block Diagram

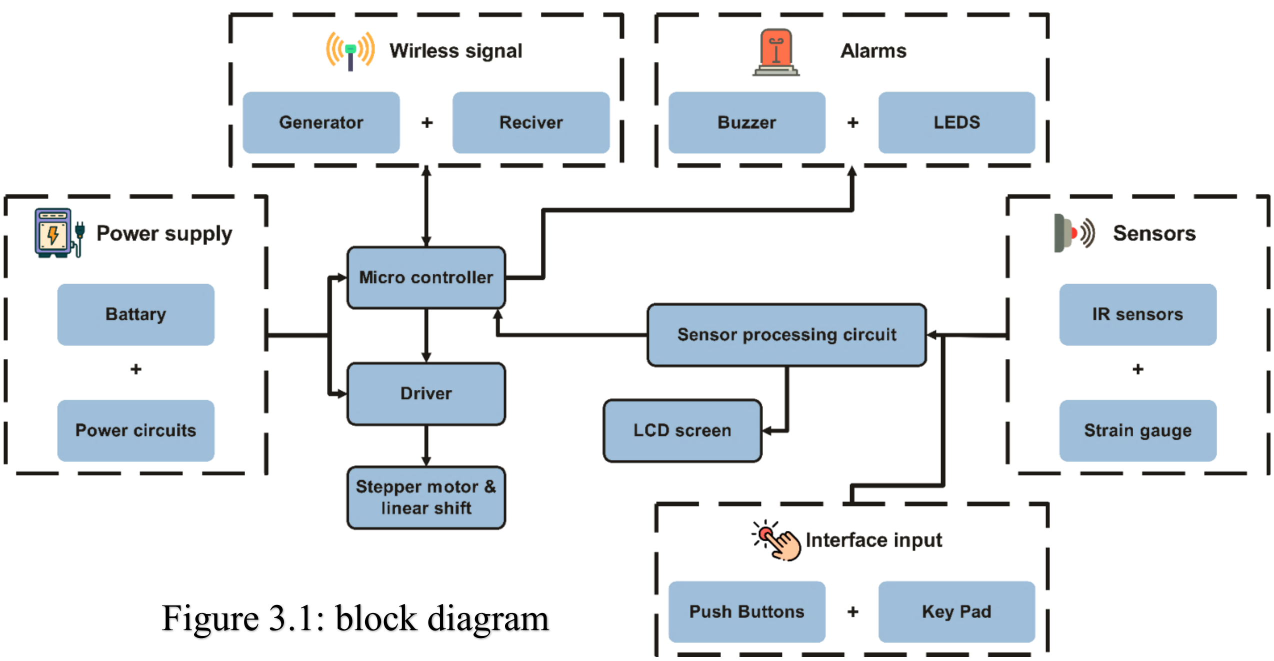

Figure 3.1: block diagram

Chapter 4
Project Design

4. Chapter 4: Project Design

4.1. Structure Design

We used 3D design software to create our structure design, using SolidWorks we came out with the front and back main structure, the syringe holder, syringe plunger assembly and battery lid. We used a 3D printer to print each part separately of PLA material

The only part that was not designed by our team was the motor assembly duo to the lack of proper material that was needed to handle the fraction and stress of motor and assembly motion and lack of time for designing this complex part. We got this assembly eventually from an old syringe pump that was beyond repair, model Atom S-1235[].

We decided to leave designing this part for our next prototypes after we assure that everything else works properly.

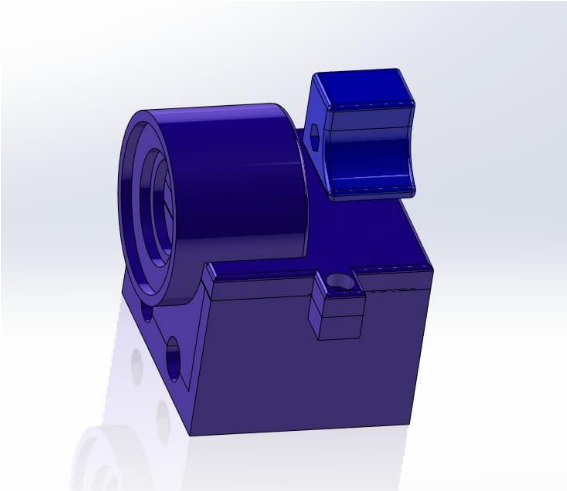

figure 4-1: Syringe plunger 3D structure

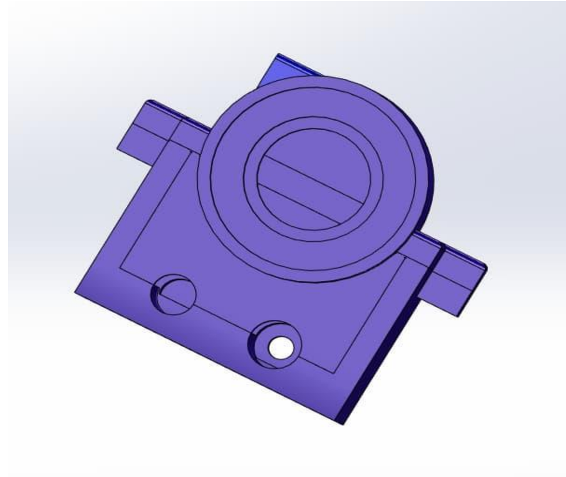

figure 4-2: Syringe plunger 3D structure

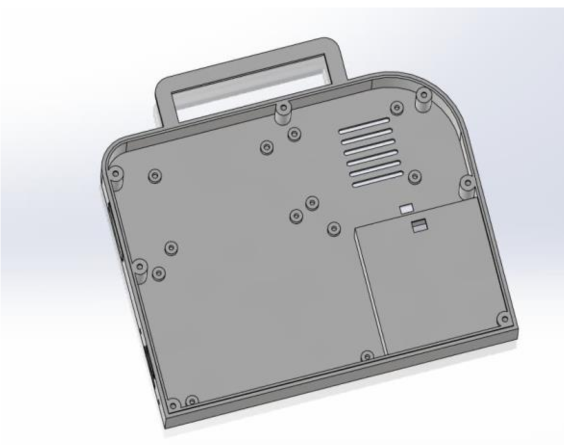

figure 4-1: Syringe plunger - Inside View

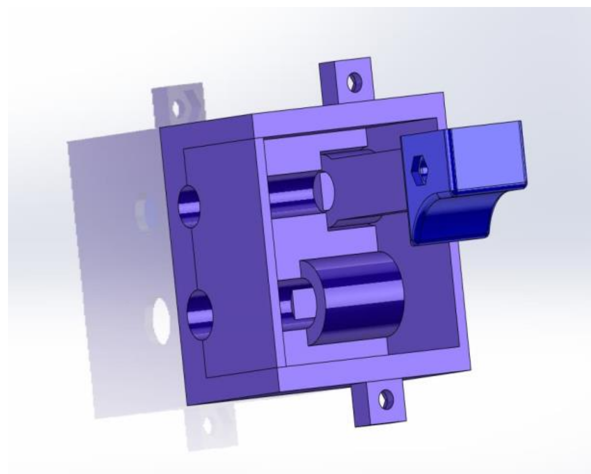

figure 4-2: Back Structure -Inside View

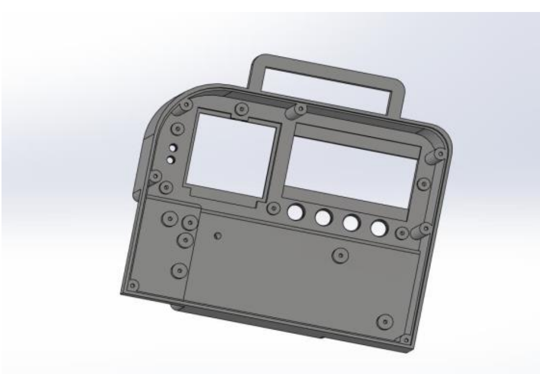

figure 4-3: Front Structure -Inside View

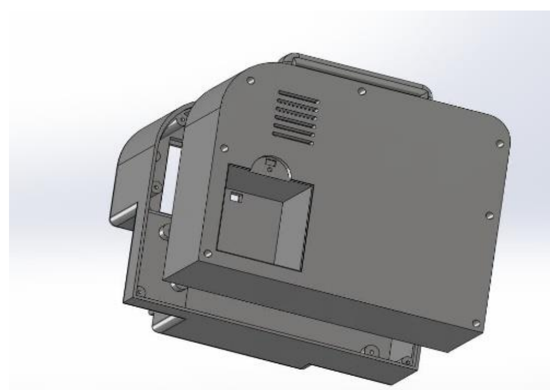

figure 4-4: Syringe Pump Structure -Rear View

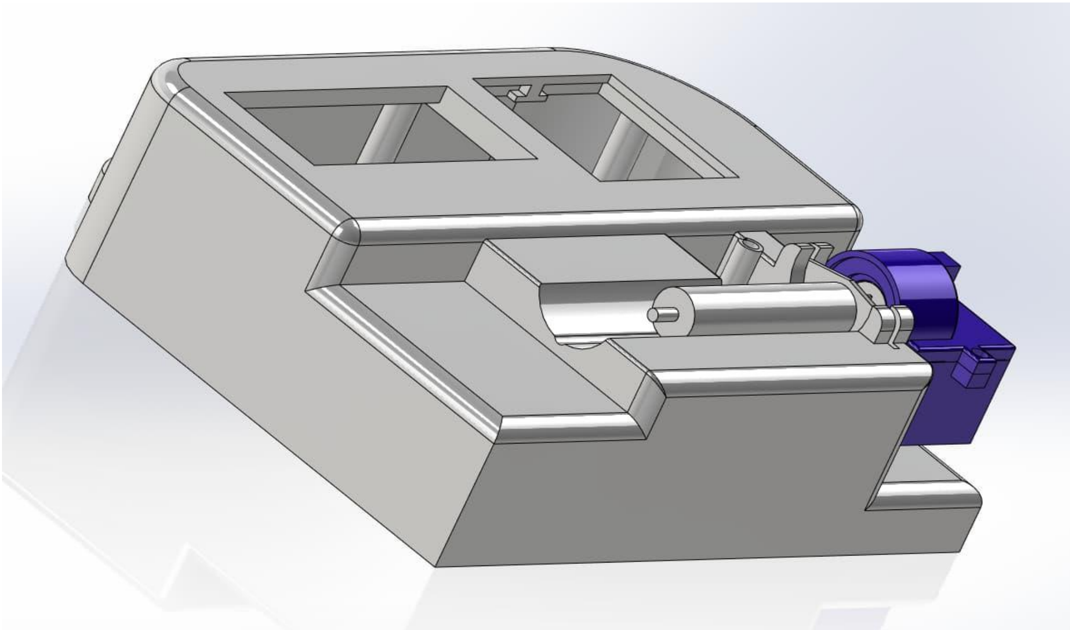

figure 4-5: Syringe Pump 3D Module - Front View

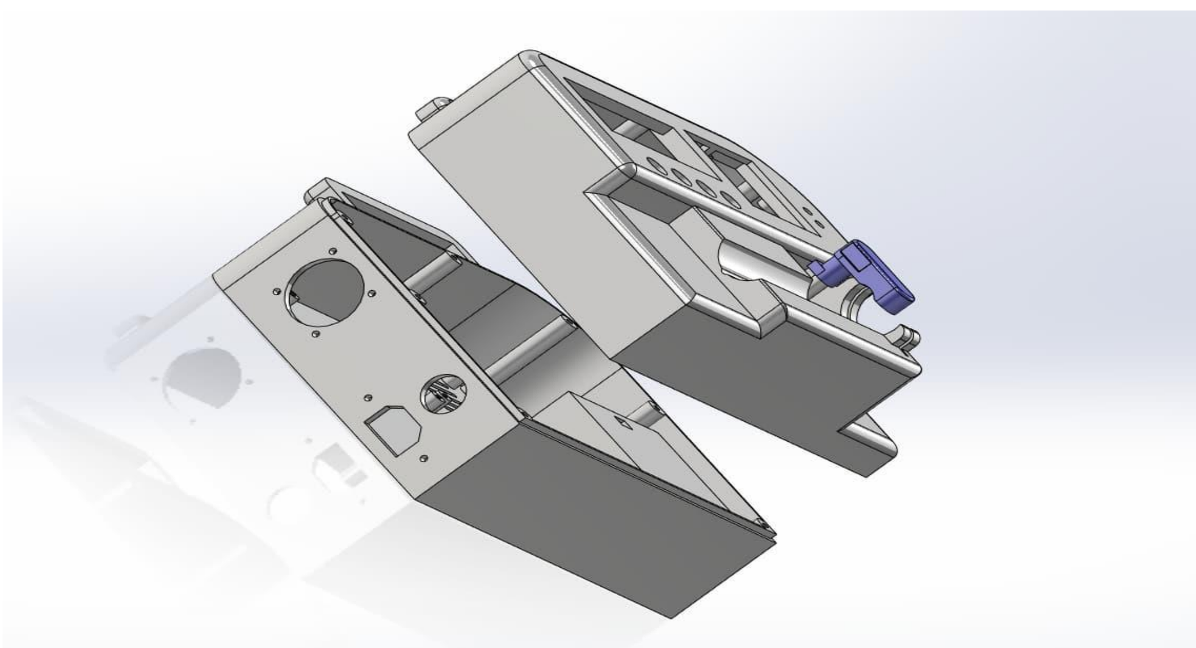

figure 4-6: Syringe Pump 3D Module - Side View

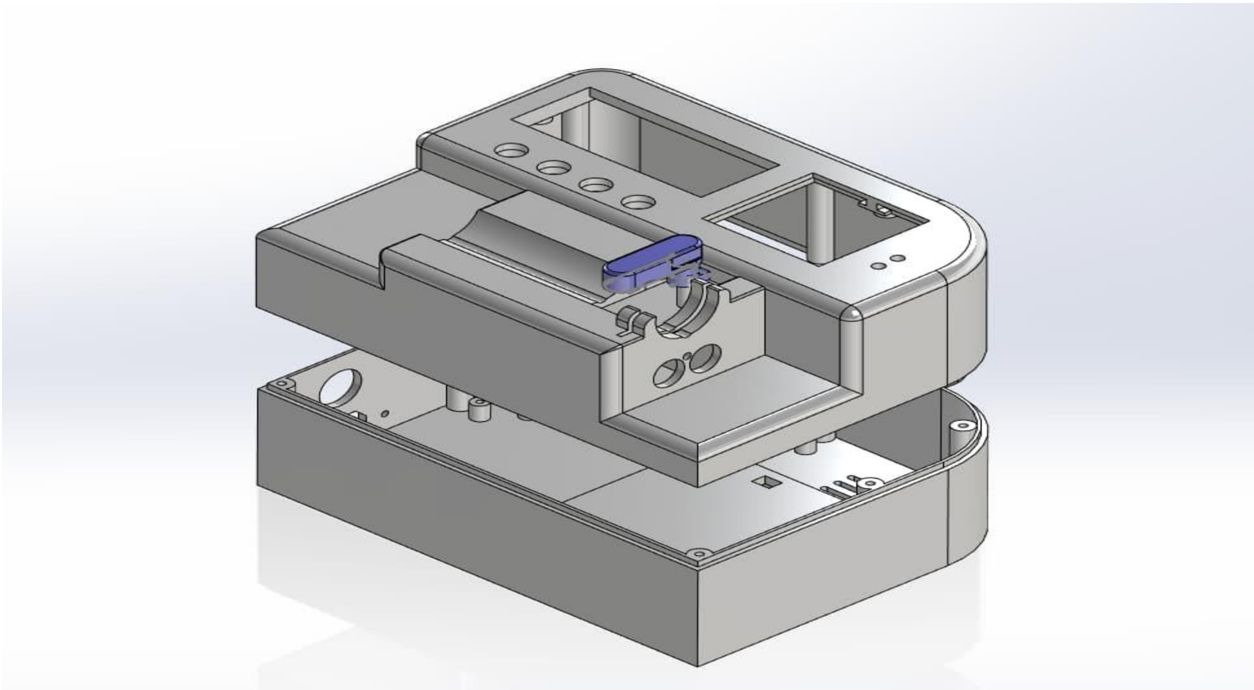

figure 4-7: Syringe Pump 3D Module - Front View

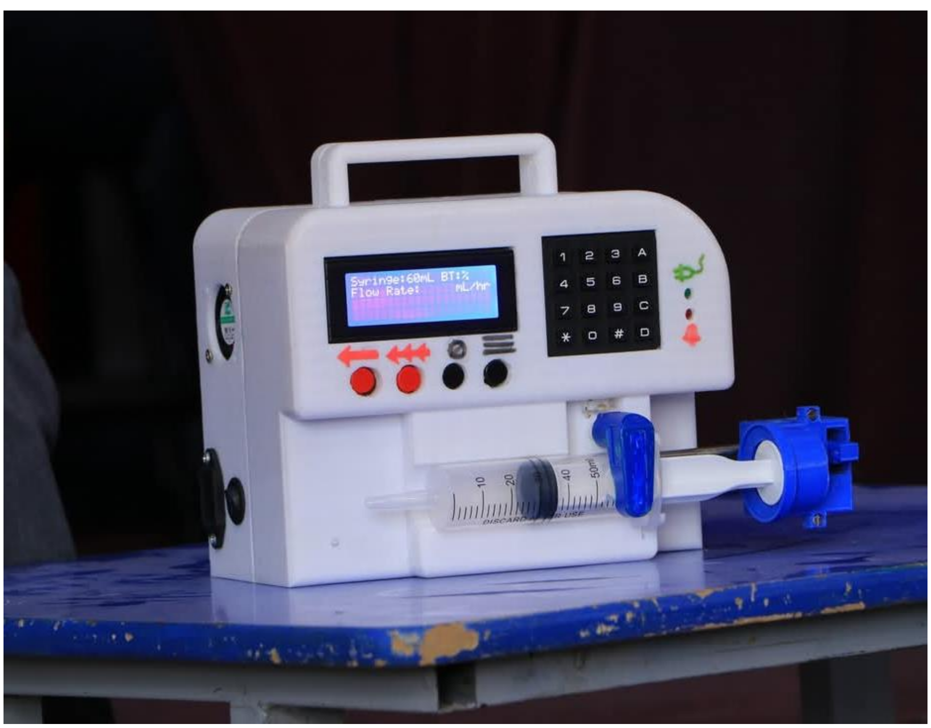

figure 4-8: Syringe Pump Module - Final

4.2. Electric Circuitry

There are 4 different circuits used for our project

1- Power Circuit:

The circuit used to convert 220V 50hz AC power source to three lines of DC power. 12V DC power line for the stepper motor supply and its driver, 5V DC supply for the microcontroller and smart sensors along with their boards, and battery charger adjustable power line to allow battery to safely charge without over charging which may cause an explosion or cause a fire.

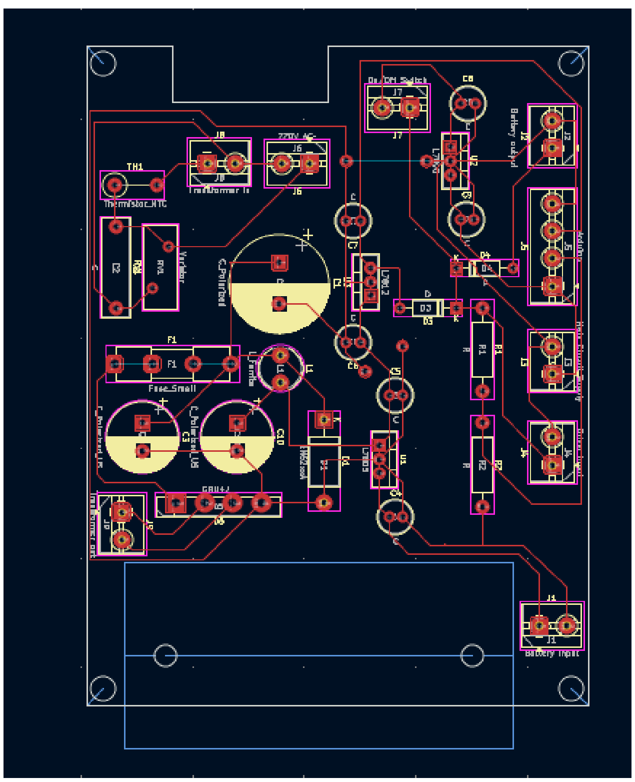

figure 4-11: Power Supply PCB layout

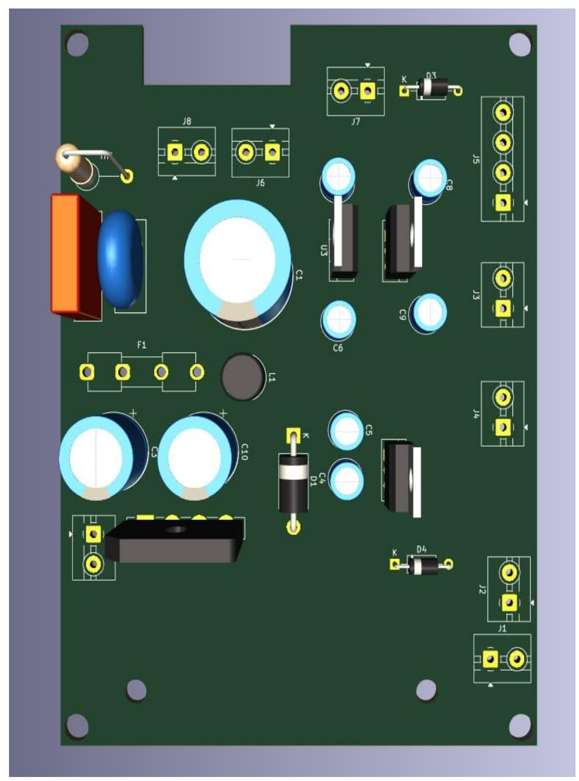

figure 4-12: Power Supply 3D Module

2 - Microcontroller board:

For this application, we choose to start our very first prototype with a PIC controller, that was the previous year for embedded systems subject project. This choice didn't achieve the desired results for our first prototype, therefore we decided in this prototype to use Arduino Mega controller, as it will help us achieve the desired features we aim for. This is not a perfect fit for the project for a microcontroller as it's over qualified for this use and is an educational product and not a commercial microcontroller that we can use for our final product, but it was the only good choice duo to the lack of options when it comes to microcontrollers found with local merchant. This will be replaced later on in the final product after ordering the prober fit controller for this application.

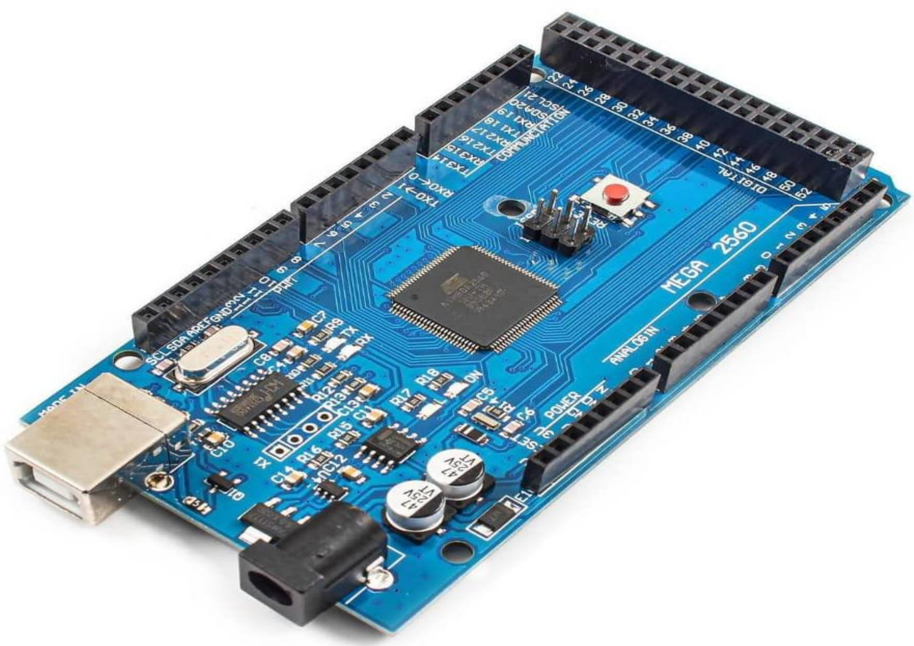

figure 4-13: Arduino Mega 2560

3- Sensors and interference board:

This board was designed using PCBs designing software to be later printed using a CNC machine to draw the copper lines between components, this board contain the main connections for LCD screen, keypad, LEDs and push buttons used in interference with the user. As well as the sensors circuits for processing the signals that are connected to the Arduino microcontroller.

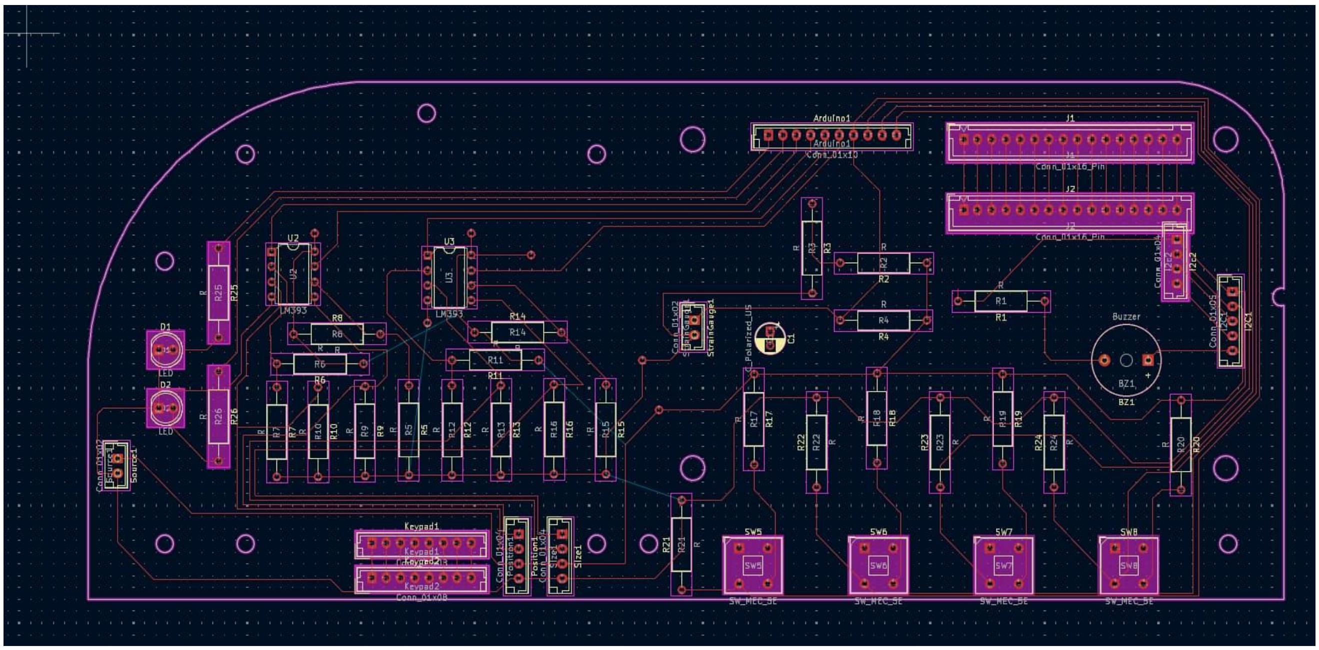

figure 4-14: Main Circuit PCB Layout

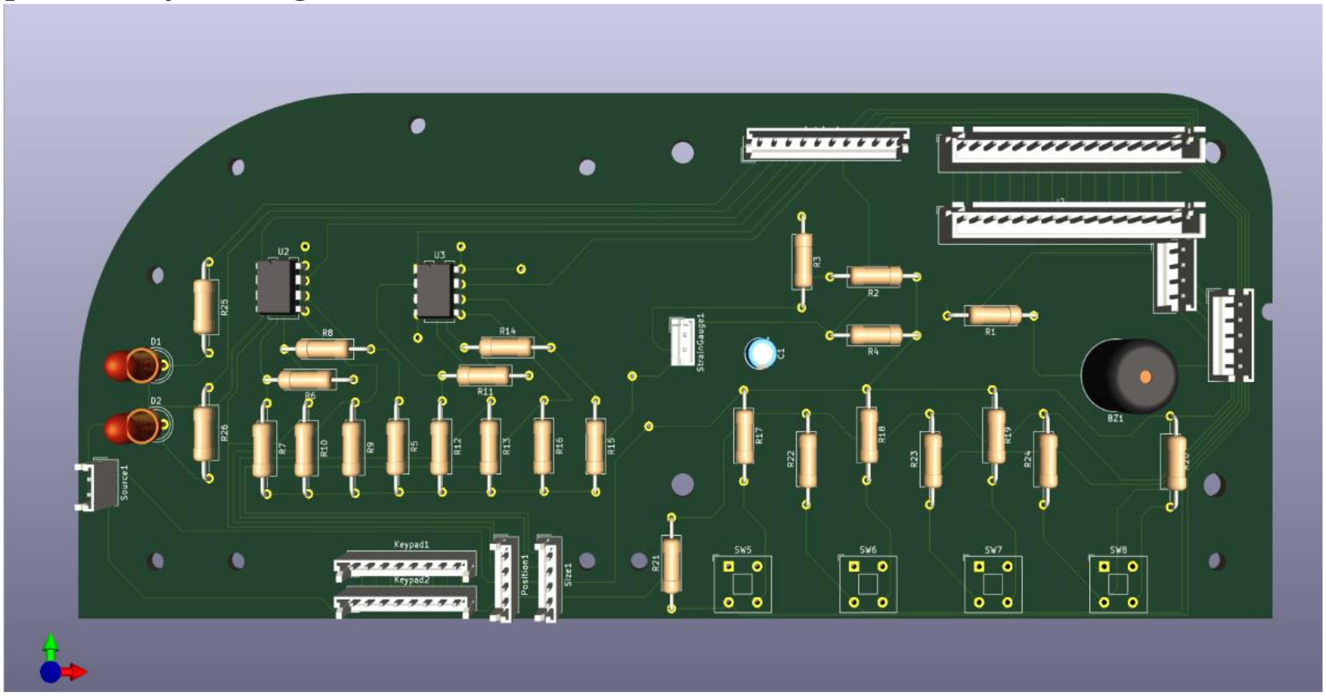

figure 4-15: Main Circuit 3D module

figure 4-16: Strain Gauge

figure 4-17: IR Sensors

4-Motor Driver:

A small simple circuit using a set of MOSFETs connected to the controller to deliver power separately for each phase. Each couple of MOSFETs control one phase of the motor in one direction. The motor has 2 phases, meaning that we will need 8 MOSFETs, two for each direction of rotating of each phase. The MOSFETs work as a barrier between the 5V controller signal and the 12V motor source, as the controller power is not enough to feed the motor.

4-18: Stepper Motor

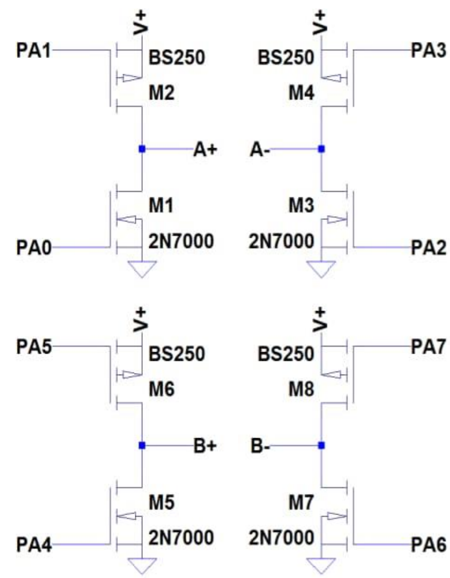

figure 4-19: Driver Circuit

Chapter 5

Implementation and Testing

5. Chapter 5: Implementation and Testing

5.1. 3D Design

The structure of the syringe pump was properly fit for most pieces, however, there war some miss calculations, such as the battery room, which was right behind syringe size sensor, preventing the structure to close properly. It needs to be moved to the other side to allow for more room for the sensor in the future. The plunger is designed to push the syringe but not hold it as in most devices, duo to the complexity of holder in syringe plunger.

5.2. PCBs

the electrical circuits of sensors and power were tested in a test board, and the results where good, they are not yet printed by the time this paper was written.

The driver circuit worked just fine at the beginning, but no control of current flowing throw MOSFETs caused them to heat up and eventually some of them burnt out. Causing the motor to rotate to one direction without the other or completely stop. The circuit need more work in current control for the motor, duo to the lack of time, we had to make the decision of using a driver circuit provided by a different manufacturer for this second prototype. This circuit will be edited as needed if we had enough time for it, or left for future work.

5.3. Software and Calibration

Arduino makes it easy to program the different complex sensors duo to the open-source programing environment and libraries, and the different advantages of analog input and outputs and the EEPROM provided within. Using the pins as output for stepper motor pulses (pulse width module PWM) was perfect for controlling speeds of the syringe pump. This was by applying a high voltage to the stepper motor and turn it off with certain delay in between the two operations.

Using this formula to find the total delay needed in a loop (Td), we managed to control the speed of a motor almost perfectly

Td= 3600000000 / (S*SpmL)

Where 3600000000 is the microseconds in one hour, S is the speed selected in mL/h, SpmL is the steps needed to achieve one milliliter in a syringe. However, more correctness was needed for delays caused by delay function error and other sensors processing in the loop, unwanted delay reduced by subtracting total extra delays in the loop after calculating them by micro() function in arduino.

Td= (3600000000 / (S*SpmL)) – Delay of the processing

Even after this formula the accuracy needed was not yet achieved for reasons that are still ununderstood for us, so an error correction variable was added to reduce it.

Td= (3600000000 / (S*SpmL)) – (Delay of the processing + Error Correctness)

Where Error Correctness is calculated throw another formula, EC = Constant1 – Speed/Constant2

Where constant 1 and 2 are calculated by finding the highest and lowest speed's EC by trial and filling them with different values that fit the equation.

Chapter 6
Results and Conclusion

6. Chapter 6: Results and Conclusion

6.1. Results

1- The accuracy achieved was as desired, which is more than %98 in all speed we examen.

2- The Sensors worked as desired, the sensitivity of the strain gauge was better than we expected for the application, the alarms for all possible malfunction known for syringe pump was added and worked perfectly.

3- The 3D print was light and strong as needed for the application, but needs some farther editing so parts fits more easily.

4- The electrical circuits where functioning as we hoped they will be, for both sensors circuit and power circuit.

5- The battery lasted 6-8h of continuous work, which is less than we hoped for, but was yet accepted.

Size	Speed (mL/h)	Accuracy	Speed (mL/h)	Accuracy	Speed (mL/h)	Accuracy
20mL	180	98.8%	150	98.5%	120	98.7%
	80	99.2%	60	98.3%	40	98.6%
	20	98.8%	10	98.4%	5	98%
60mL	400	98.4%	300	98.1%	200	98.3%
	150	99%	100	98.7%	50	98%
	25	98.8%	10	98.2%	5	98.5%

Table 6.1: results of flow rate accuracy trials

6.2. Conclusions and Recommendations

We managed to create a syringe pump prototype with all needed operation and safety systems from scratch. We couldn't deliver all the promised advantages, specifically wireless control for syringe pump and alarms, duo to the overwhelming work and the lack of time, but we managed to deliver a prototype within accepted criteria that deliver doses with error of less than 2%, and operating alarms, battery and user interface, the project is not a complete product yet, but it was successful prototype and a huge upgrade from our first prototype of the last year. To reach what we can call product, some editing is needed in 3D design, higher battery capacity and most importantly redesign the electrical boards to merge the processor to the main board and merge the driver to the power circuit to reduce the wires withing the device and the complexity. Furthermore, we recommend that a separate microcontroller is used for stepper motor control, where one controller may not be enough to process all sensors, LCD, keypad and control the stepper motor all together, where in our prototype, the LCD cannot be refreshed and keypad is stopped while the motor is running. This will allow for smoother interference with the user, and perhaps even better accuracy.

6.3. Future Work

Alot of work of our project is not finished yet to start marketing our product we need to work on many things before calling it our final product, this includes:

1- Designing the linear-shift chassis assembly from scratch, using proper material.

2- Designing specialized processor circuit to replace Arduino board that fits for the application of the project and reduce the number of boards by merging processor board with driver board or sensors board.

3- Redesigning driver board to control and limit current flow, reducing power consumption and protect motor and MOSFETs from overheating.

4- Further testing to discover other structure and circuit errors and solve them until the project is safe and efficient to be marketed, and making a proper user manual and service manual for our product.

Other features and ideas we might include in future products:

1- Adding the advantage of adding dual syringe to our design, which allow user to use two different solutes with two different settings at the same time with one syringe pump.
2- Insulin Pump mode that allows the syringe pump to connect wirelessly to CGM (continuous glucose monitor), allowing the syringe to inject proper amount of insulin to the patient as needed after inserting variables like gender, age and weight automatically using smart algorithms and calculations.
3- Allowing the syringe pump to be connected to vital monitors or other monitoring sensors to calculate doses needed for some conditions with some solutes by using similar smart algorithms.

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