MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING, DESIGN, ART, AND TECHNOLOGY

SCHOOL OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

FINAL YEAR PROJECT REPORT

DESIGN AND FABRICATION OF A 3D PRINTING THREADS EXTRACTOR FROM WASTE PLASTIC BOTTLES

BY

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DECLARATION

I, **SSEBULIME GONZAGA M** declare that this report is my original work and has not been submitted to any college, university or institution for any academic award.

Signed: Sebuline.

Date: 2/8/2023

We, the supervisors, have approved this report. It meets the examiners' requirements for the Bachelor of Science in Mechanical Engineering Degree of Makerere University.

Department-Supervisor

Dr. Hillary Kasedde

Signature:

Date: 2/8/2023

ACKNOWLEDGEMENT

This is to appreciate the people and organizations that helped me in making this possible.

I would like to thank Mr. Ntege Gonzaga who is the Managing Director of Zopah Uganda Limited and a professional Mechanical engineer. He was a very good teacher and boss to me during my time at the company where I did my industrial training which is where I got my project idea from.

I would like to thank the Department of Mechanical Engineering at Makerere University for the opportunity given to students to suggest project ideas from our surroundings and then use what we learn in class and go on to implement the projects which also offers us a chance to solve some problems around us.

Lastly, I thank Dr. Hilary Kasedde and Mr. Joseph Arineitwe who are the Department supervisor and Co-supervisor respectively that were given to me, for all the efforts they put in to see that my project was implemented successfully.

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ACRONYMS

DLP- Digital Light Process

DMLS- Direct Metal Laser Sintering

EBM- Electron Beam Melting

FDM- Fused Deposition Modelling

MJF- Multi Jet Fusion

PET- Polyethylene Terephthalate

PET G- Polyethylene Terephthalate modified with Glycol

SLA- Stereo lithography

SLS- Selective Laser Sintering

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ABSTRACT

3D printing is a form of additive manufacturing technology where a 3D object is created by laying down successive layers of material. As 3D printing is growing and boosting product development, the factories doing 3D printing need to continuously meet the printing requirements and maintain an adequate amount of inventory of the filament. 3D printing filament is manufactured through a process known as extrusion. Melted plastic is pushed through an extrusion die and is shaped into a long thin strand of plastic. The machines used for production of the filament are usually sized for industrial use, capable of creating hundreds of feet of filament a day. This filament is made in a few countries like the USA and this makes it expensive for users in countries that do not produce the filament to purchase due to the added cost of shipping, and many end-users also complain about delays in delivery and would therefore prefer to extrude their own filament, from plastic waste input. This project was therefore undertaken to provide 3d printer users with a machine that can help them produce PET filament from waste plastic bottles. The project also to a small extent solves the problem of poor disposal of plastic waste that endangers the environment. The machine was designed and manufactured to create filament that has the required ductility for spooling and use in a 3D printer. The machine worked well and was able to produce PET filament without completely melting the plastic bottles. The final filament product is dependent on the tension put on the filament as it exits the machine. At the moment, a human operator is required to consistently produce acceptable filament but an automated spooling system for the filament would greatly improve the consistency of the output and also ensuring continuous pulling of filament.

CHAPTER ONE: INTRODUCTION

1.1 Background

The 20th century saw a revolution in plastic production: the advent of entirely synthetic plastics. Belgian chemist and clever marketeer Leo Baekeland pioneered the first fully synthetic plastic in 1907. He beat his Scottish rival, James Swinburne, to the patent office by one day. His invention, which he named Bakelite, combined two chemicals, formaldehyde and phenol, under heat and pressure. Engineer Nathaniel Wyeth patented PET bottles in 1973 (Matjašič et al., 2021). The first plastic bottles able to withstand the pressure of carbonated liquids, they were a much cheaper alternative to glass bottles, lightweight for transport and safe in that they are virtually unbreakable. The increased use of plastics has seen environmentalists all over the world gather efforts against the continued use of the plastics due to their plus poor disposal that is harmful to the environment where among the worst offenders, along with polyethylene shopping bags and polystyrene food containers, is the PET bottle (Alabi et al., 2019). The PET polymer was developed specifically to contain pressurized carbonated drinks, though its popularity as a container for still beverages, above all water, has boomed in the 21st century. The economics of mass-produced, cheap plastic products have led to a single-use culture, and today around 500 billion PET bottles are sold every year. This figure is increasing, and the majority of these bottles end up in our oceans, degrading into micro plastics.

The focus of this project proposal is to design and fabricate a machine that can help in transforming the already used PET bottles into filament used in 3D printing. 3D printing is a technology where a physical 3D object is generated by successive formation of layers of material under a computer-controlled program. The earliest 3D printer originated in 1981, when Dr. Hideo Kodama invented one of the first rapid prototyping machines that created parts layer by layer, using a resin that could be polymerized by UV light (Shahrubudin et al., 2019a). Today, there are different types of 3D printing technologies which include; SLA, SLS, FDM, DLP, MJF, Direct Metal DMLS and EBM.

FDM is the most common of all the technologies listed above and it makes use of filament that is extruded through a nozzle of a given size most commonly 0.4mm and 0.6mm which is attached to a heating block set at a required temperature depending on the filament being used.

FDM makes use of different types of filaments which have different characteristics and therefore areas of application amongst which is PETG (Polyethylene Terephthalate modified with Glycol).

PETG (Polyethylene Terephthalate modified with Glycol) is a commonly used technical material, popular among 3D printer users for its low price and good printability. It’s tenacious, with good temperature resistance; PETG is most commonly used for printing various mechanical parts, holders, clamps, and waterproof parts owing to the great layer adhesion. PETG has a glossy surface, adheres greatly to a print sheet, and does not shrink or warp (it has very little thermal expansion), therefore it’s suitable for printing large models. Plus, its high tenacity and flexibility often prevent it from breaking. Due to good temperature resistance, PETG parts are suitable both for interior and most exterior use (with temperatures below 80 °C). The letter G in PETG means that it’s modified with glycol during the manufacturing process. Glycol makes PET less brittle, easier to print, and more transparent for translucent prints. Of course, one can print also with PET filaments without glycol. However, printing with only PET is challenging and does not offer any advantage whatsoever.

1.2 Problem statement

The need for cheaper and easily manufacturable materials has seen the demand of plastics grow all over the globe. One of the industries making use of plastic is the beverage industry which is replacing glass bottles with PET plastic bottles for packaging of their products. The plastic bottles come with several advantages for both the beverage companies and their clients one of which is the reduced cost of production for the companies and therefore reduced prices for the customers. However, the poor disposal of the plastic bottles after use has become a big threat to the environment with its grave effects that it has over the various environmental aspects for instance leaching out toxic chemicals into the soil (Okunola A et al., 2019), this therefore creates a need to reduce plastic waste in the environment and owing to the steady growth of the 3D printing technology and the expensive filament, PET bottles can be used for production of affordable 3D printing filament.

1.3 Objectives

1.3.1 Main objectives

- To develop a machine that extracts 3D printing filament from waste PET bottles.

1.3.2 Specific objectivities

- To design the machine.
- To construct a PET filament extracting machine.
- To assess the machine prototype against design requirements.

1.4 Scope of study

This study will focus on design of an extractor of 3D printing filament from waste PET bottles. The machine will be constructed from 3D printed parts while some will be purchased. The machine will be tested and then the filament produced by the machine will be used to print objects using a 3D printer and different aspects of the objects examined to assess the quality of prints. No additions will be made to the extracted filament and it will be used as produced by the machine.

1.5 Significance

The amount of plastic in form of PET bottles ending up in lakes, oceans and also getting buried into the ground is with no doubt increasing with the increasing production of the bottles which are poorly disposed of after use. Collecting these bottles and making rolls and rolls of PET 3D printing filament that will be used in prototyping and also production of various household items for design purposes will reduce on the number of these bottles ending up in waterbodies and also under the ground causing various sorts of harm to the environment. Production of this filament will also see the 3D printing technology steadily grow and adopted by different industries which will increase production rates and productivity.

1.6 Justification

Continued negligence of the poor plastic waste disposal in the environment will see greater harm inflicted onto the environment. This project proposal brings into focus a way that will see PET bottles being reused to serve another purpose and prevented from polluting the environment and also save the users of the 3D printing technology from the expensive costs of filament which involve the initial price and shipping of the filament.

CHAPTER TWO: LITERETURE REVIEW

2.1 Introduction

Plastics are synthetic polymer materials that have become ubiquitous in modern society due to their low cost, versatility, and durability. The widespread use of plastics, however, has also led to a number of environmental concerns, such as waste accumulation and ocean pollution. In response to these challenges, there is a growing interest in developing more sustainable and environmentally friendly plastic production and disposal practices.

One promising application of plastic is in the field of 3D printing. 3D printing, also known as additive manufacturing, is a process that involves building objects layer by layer using a computer-controlled printer. This technology has revolutionized the manufacturing industry by enabling the production of complex shapes and structures that are difficult to produce using traditional manufacturing methods. The use of plastic filaments as feedstock for 3D printing is increasing due to their low cost, ease of use, and versatility.

This literature review aims to provide a comprehensive overview of the developments and trends in plastic, 3D printing, filament production, and PET filament. The review will begin with a discussion of the properties and advantages of plastic, followed by a description of 3D printing and its applications. The review will then discuss the process of filament production and the properties of PET filament, which is a commonly used plastic filament for 3D printing.

2.2 Plastic

Plastic is a synthetic polymer material that can be molded into various shapes and sizes. It is made from a wide range of natural and synthetic monomers, including polyethylene, polypropylene, polyvinyl chloride (PVC), and polystyrene. Plastic has many advantages over traditional materials, including low cost, light weight, and durability. However, plastic also poses significant environmental challenges, such as waste accumulation and ocean pollution. There is a growing need for more sustainable and environmentally friendly plastic production and disposal practices (Pahlevi & Suhartanto, 2020).

2.3 3D Printing

3D printing, also known as additive manufacturing, is a process of producing three-dimensional objects layer by layer using a computer-controlled printer (Shahrubudin et al., 2019b). This technology has revolutionized the manufacturing industry by enabling the production of complex shapes and structures that are difficult to produce using traditional manufacturing methods. 3D printing has been used in various applications, including medical implants, aerospace components, and consumer goods (Shahrubudin et al., 2019c) The use of plastic filaments as feedstock for 3D printing is increasing due to their low cost, ease of use, and versatility (Kristiawan et al., 2021). Different types of thermoplastic filament are available each having various properties and characteristics that make it suitable for given applications and these include but not limited to PLA, ABS and PETG (Ngo et al., 2018)

PETG filament is a commonly used plastic filament for 3D printing. It is made from polyethylene terephthalate, which is a thermoplastic polymer with excellent mechanical strength, high-temperature resistance, and biocompatibility (Latko-Durałek et al., 2019). PET filament is also recyclable, making it a more sustainable option for 3D printing compared to other plastic filaments. Furthermore, PETG filament has good dimensional stability, making it ideal for producing precise and accurate parts (Szykiedans et al., 2017)

PETG filament is formed by addition of glycol in PET during the manufacturing process and this adds several properties to the PET for instance making it less brittle though PET can also be used for printing (Dupaix & Boyce, 2005a).

2.4 Filament Production

The production of plastic filaments for 3D printing involves melting the plastic material and extruding it into a continuous strand, which is then cooled and wound into a spool. Filament production can be done using various techniques, including melt extrusion and solid-state extrusion. The properties of the filament, such as its diameter, toughness, and stiffness, can be controlled by adjusting the extrusion conditions, such as temperature, pressure, and speed (Blanco, 2020).

2.6 Pet Bottle Recycling and Plastic Waste Statistics

Considering the environmental impact of plastic waste and the need for more sustainable practices in the plastic industry, research shows that PET bottles are one of the most common forms of plastic waste, with an estimated 500 billion produced globally each year. While PET is recyclable, the recycling rate for PET bottles remains low, with only 23% being collected for recycling globally (Halden, 2010). The lack of effective recycling programs and consumer education are major barriers to increasing the recycling rate of PET bottles (Rauwendaal, 2014).

To address this challenge, researchers and industry leaders are exploring new methods for the recycling of PET bottles, including chemical recycling and mechanical recycling (Gaikwad et al., 2018). Chemical recycling involves breaking down the PET polymer into its constituent monomers, which can then be used to produce new plastic products (Dizon et al., 2018). Mechanical recycling, on the other hand, involves grinding the bottles into pellets that can be used to produce new plastic products (Dupaix & Boyce, 2005b).

The properties of PET filament make it an attractive material for 3D printing. PET filament has high-temperature resistance, mechanical strength, biocompatibility, and is recyclable (Carneiro et al., 2015). These properties make it well suited for a variety of applications, including medical devices, packaging, and consumer products (Srinivasan et al., 2020). The increasing popularity of 3D printing and the development of more advanced technologies for filament production have made PET filament a promising alternative to traditional plastic products (Romeijn et al., 2022).

However, the widespread use of plastic and the accumulation of plastic waste remain major environmental challenges (Thompson, 2015). According to the World Bank, only 9% of plastic waste is effectively recycled globally, with the rest ending up in landfills or the natural environment (Worm et al., 2017). The accumulation of plastic waste can take hundreds of years to degrade and can harm wildlife and ecosystems (Halden, 2010).

This literature review has provided a comprehensive overview of the developments and trends in plastic, 3D printing, filament production, and PET filament. Plastic is a versatile material widely used in various applications due to its low cost, light weight, and durability. However, the widespread use of plastic has also led to a number of environmental concerns, such as waste accumulation and ocean pollution. In response to these challenges, there is a growing interest in developing more sustainable and environmentally friendly plastic production and disposal practices.

3D printing is a rapidly evolving technology that has revolutionized the manufacturing industry by enabling the production of complex shapes and structures. Plastic filaments, such as PET filament, are increasingly used as feedstock for 3D printing due to their low cost, ease of use, and versatility. PET filament, in particular, is a more sustainable option for 3D printing due to its biocompatibility, high-temperature resistance, and recyclability.

In conclusion, plastic and 3D printing have the potential to play a significant role in shaping the future of manufacturing and production. It is important to continue to develop more sustainable and environmentally friendly practices in plastic production and disposal, as well as to explore new and innovative applications for 3D printing.

CHAPTER THREE: METHODOLOGY

3.1 Determining specifications and designing of the machine.

3.1.1 Determining specifications.

Target specifications were obtained through extraction of the customer needs from the different statements that were collected through the two ways of gathering raw data and observation of similar machines. The customer needs included;

- The filament quality was on par with commercially available filament.
- The input material for the machine was virgin PET.
- Machine can be operated by unskilled workers.
- Machine was can be operated inn all environments.
- Plastic waste as the input material.
- Automated with little human interaction.

3.1.1.1 Determining final specifications.

The final specifications of the machine components and products were determined and recorded in order to meet the end users' needs as well as those of the project. Benchmarking was done on different machines like 3D printers which use parts similar to those that were intended to be used and the final specifications were arrived at, by comparing the target values with the best in market product. The benchmarking was also done on the filament that is produced on large scale through extrusion processes which is currently being used to determine the diameter of the filament that was to be produced. The final specifications are summarized in the table below.

Table 1: System requirements

METRIC	**VALUE**
Filament size	1.65 mm – 1.85 mm
Extrusion speed	100 mm/s
Extrusion temperature	210 degrees Celsius

Time to disassemble and clean	<5 min
Price	<UGX 300,000
Weight	<5 kg

3.1.1.2 Concept generation

Different concepts on which the machine could operate were be identified and recorded. These were obtained through research done over the internet on 3D printing websites and also literature review, which research was used to refine some of the concepts that had already been generated. From the concept generation process, two major concepts as listed below were picked and these were the ones to be subjected to the selection process.

- **Shredding and melting the plastic bottles**

This concept suggested shredding of the cleaned plastic bottles which would then be melted and extruded through a die prior to cooling and spooling as shown in the subsections of the process below. This concept was however abandoned due to various reasons as will be seen in the concept selection section.

Figure 1 Steps for extrusion process for concept 1

- **Cutting bottle into strap and extruding below melting temperature**

This concept on the other hand suggested that the bottles were cleaned and cut into a strap of uniform thickness and extruded at a temperature below the melting to give the strap a circular cross section area. This concept proved to be better than the previous one as regards the criteria that were used in concept selection and involved the following steps;

- The bottle was to be cleaned by washing it and then dried completely.
- The base of bottle was then to be cut off horizontally using a cutter.
- A cut of 10mm to the bottle at the bottom in a specific angle range between 20° to 40° was to be made.
- The pointed portion was the to be inserted into the cutter slot of 7mm and the pointed portion pulled from the other side of the cutter with a plyer.
- The strip would then be inserted into the extruder and pushed inside till it came out from the exit of the nozzle.
- The filament would then be left to cool and then slowly pulled with a plyer until it reached the winding spool.
- The filament would then be tied to the winding spool with help of a wire and then the filament would start winding automatically.

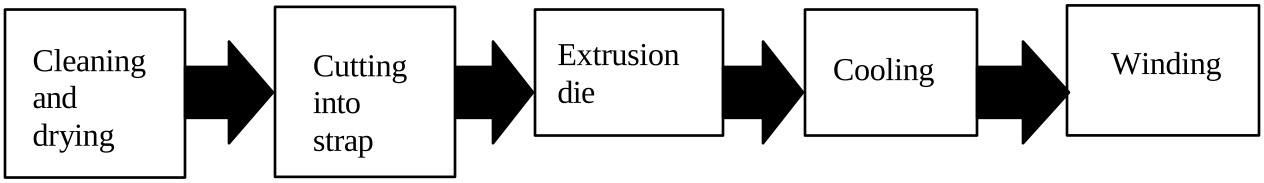


Figure 2 Steps for concept 2 process

3.1.1.3 Concept selection

Concept selection involved comparison between the two concepts that had been developed earlier basing on aspects from the customer requirements and also the project designer. The goal of concept selection was to identify the best concept basing on the customer requirements and other constraints so as to proceed with the best option.

Concept selection involved only concept scoring since only two concepts had been produced.

Table 2: Concept scoring matrix

Criteria	Weight	Melting concept		No melting concept	
			Weighted score		Weighted score
Price	0.5	30	15	70	35
Ease of use	0.3	20	6	80	24
Weight	0.2	10	2	90	18
Total			**23**		**77**

From the concept scoring matrix, the concept where there is no melting was carried on because it had a higher score.

3.1.2 System-level Sketch

The first step is to clean and prepare the material. The PET bottle is cleaned dried thoroughly, air is pumped into the bottle and with the bottle closed and compressed air inside, it is rotated above a flame along the axis normal to its cross section. This is done to remove designs that are on the bottle and therefore to make its surface uniform such that uniform filament is extracted. The air is then let out and the bottle cut into a uniform strap using a cutter. The device is then turned on, and the heating block heats up the extrusion die to the proper level. The strap is passed through the die and the filament is slowly pulled out by hand and tied to the winding spool after which automatic winding proceeds. The system level sketch of the extrusion process is shown in figure 2.

3.1.2.1 Functional Analysis

- Clean and dry plastic bottle: removes impurities.
- Cut bottle into uniform strap: ensures production of uniform diameter filament.
- Extrusion

Give the strap a circular cross-sectional area.

- d. Cooling

Lower temperature of filament as fast as possible: Fast solidification reduces crystallinity, which increases ductility.

Make filament safe to handle.

- e. Spooling

Maintain constant tension on finished filament to reach desired tensile properties.

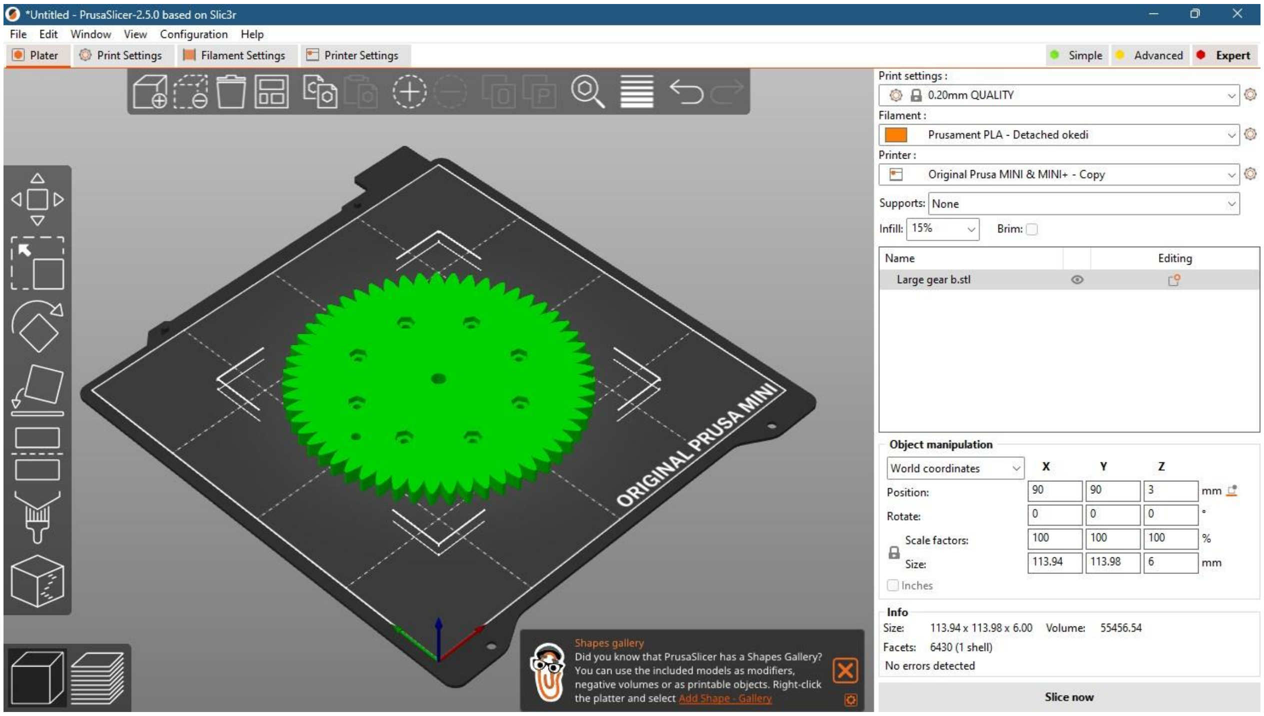
Collect filament for ease of use in 3D printer

3.1.2.2 Developing a detailed design for the machine.

Detail designing involved transformation of the information that was gathered from the system level design into a fully operating technical solution. This will therefore include determination of the different ways of interaction between the components of the machine. This stage involved use of several engineering techniques to design the components of the machine that took into account different factors like tolerances. It involved modelling of the different components of the machine using a design software where in this case, solid edge V16 was used.

3.1.2.2.1 Modelling components

The fabricable parts of the machine were to be made using 3D printers and were modelled using solid works. The gear system whose components' production drawings are included in the appendices were modelled and saved as ".stl" files so that they could be sliced to produce g-code for the 3D printers. The parts were then assembled as shown in the figure below to form the winding mechanism. The Prusa slicer software was used to slice the 3D models so as to produce g-code and the required settings were used so as to give the best prints.



Print settings : 0.20mm QUALITY

Filament : Prusament PLA - Detached okedi

Printer : Original Prusa MINI & MINI+ - Copy

Supports: None

Infill: 15%

Brim: ☐

Name	Editing
Large gear b.stl	

Object manipulation

World coordinates

	X	Y	Z	
Position:	90	90	3	mm
Rotate:	0	0	0	°
Scale factors:	100	100	100	%
Size:	113.94	113.98	6	mm

☐ Inches

Info

Size: 113.94 x 113.98 x 6.00 Volume: 55456.54

Facets: 6430 (1 shell)

No errors detected

Shapes gallery

Did you know that PrusaSlicer has a Shapes Gallery? You can use the included models as modifiers, negative volumes or as printable objects. Right-click the platter and select Add Shape - Gallery

Figure 3 Prusa slicer interface

Figure 4 Gear system

The parts were printed using PLA filament which is easy to print with and produces mechanically strong parts.

3.1.2.2.2 Power supply

A power supply model JJY 250W-12V was used since the heating block required a voltage of 12V to be able to heat up to the required temperature. It has input of 180-240VAC 50/60Hz and an output of DC 12V 20.8A.

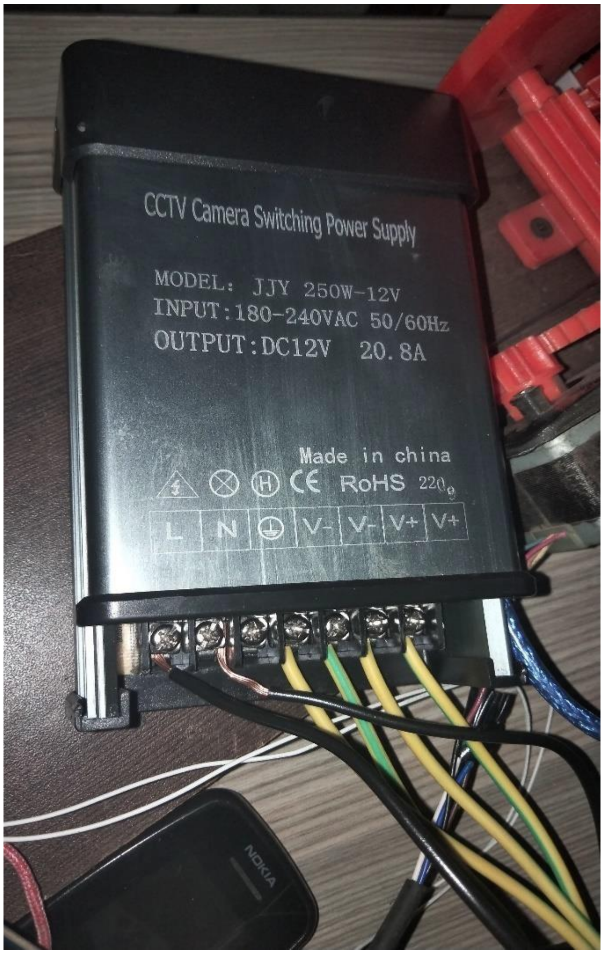


Figure 5 Power supply

3.1.2.2.3 Heating block

An Aluminum heat block was used with the following specifications;

Heating cartridge hole: 6 mm diameter

Thermistor hole: 2 mm diameter

Weight: 6g

Temperature range: -40 to 260 degrees Celsius

The thermistor attached to the heating block measures the temperature of the heating block and sends signals to the Arduino Mega board via the ramps shield 1.4 which turns the heater on or off accordingly so as to maintain the desired input temperature.

Figure 6 Heating block

3.1.2.2.4 Extrusion die

The extrusion die is a brass nozzle that was drilled to a diameter of 1.75 mm and has a weight of approximately 2g. It is attached to the heating block so that the plastic bottle strap entering from one end of it assumes its shape when exiting on the other side.

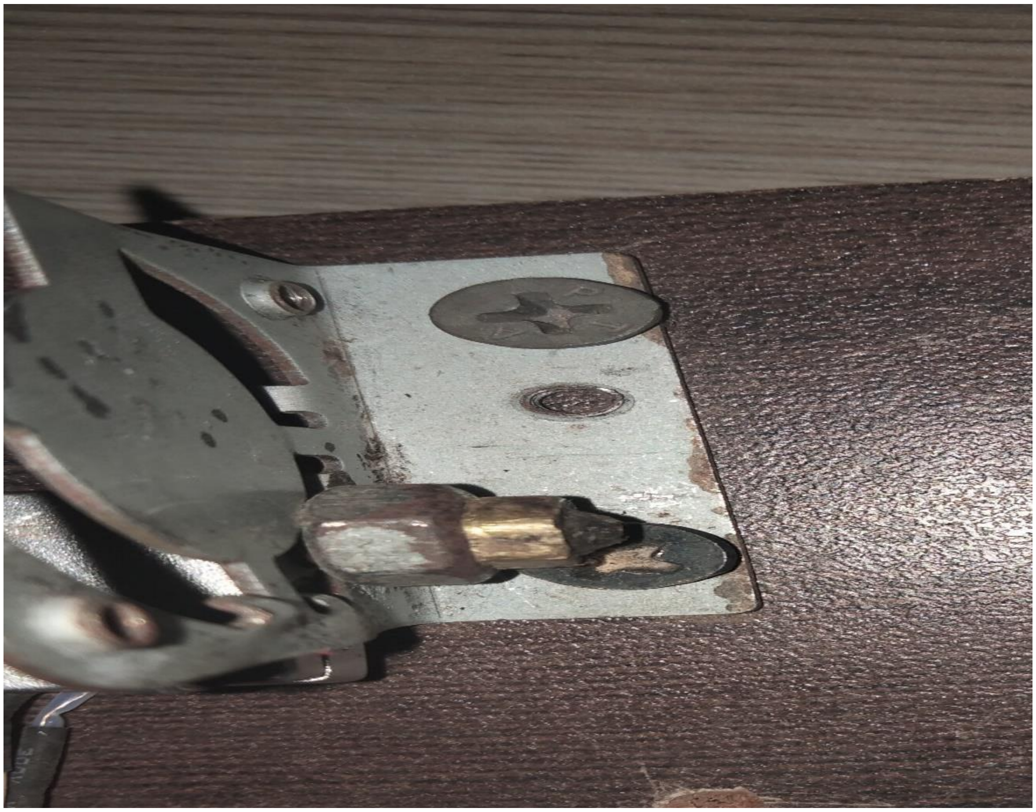


Figure 7 Extrusion die

3.1.2.2.5 Stepper motor and stepper motor driver

The stepper motor is responsible for driving the gear traction mechanism and its speed is controlled using the Arduino board. It is capable of moving hundreds of steps in a revolution. It is driven by the stepper motor driver which is attached to the ramps shield 1.4.

Figure 8 Stepper motor driver

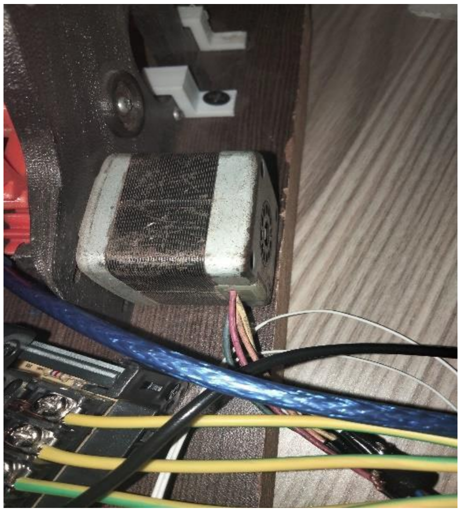


Figure 9 Stepper motor

3.1.2.2.6 Arduino Mega 2560 and Ramps 1.4 shield

The Arduino board is a programmable board and allows uploading and flashing of code several times. It uses 5V of the power supplied by the power supply via the Ramps 1.4 shield. The code that sets and maintains the temperature of the heating block and the motions of the motor was uploaded into the Arduino Mega 2560. The ramps board supplies power throughout the system and also its where most of the parts are connected like the thermistor, stepper motor and the motor driver.

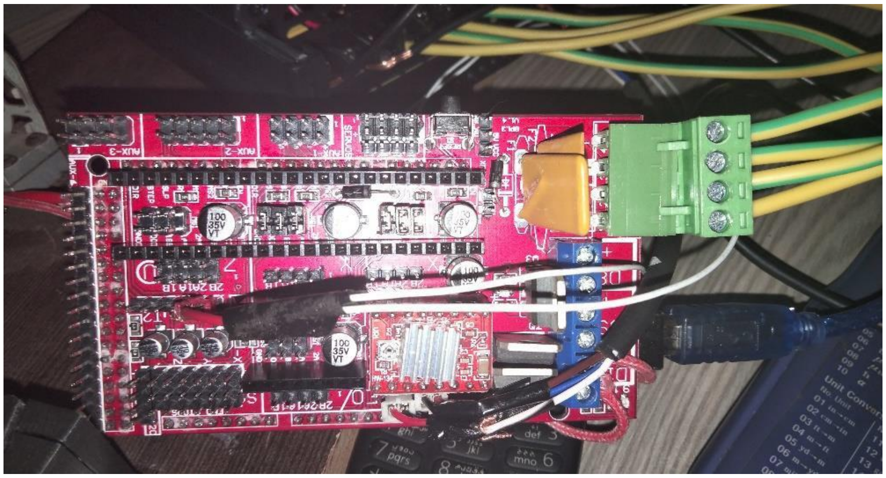


Figure 10 Ramps 1.4 shield

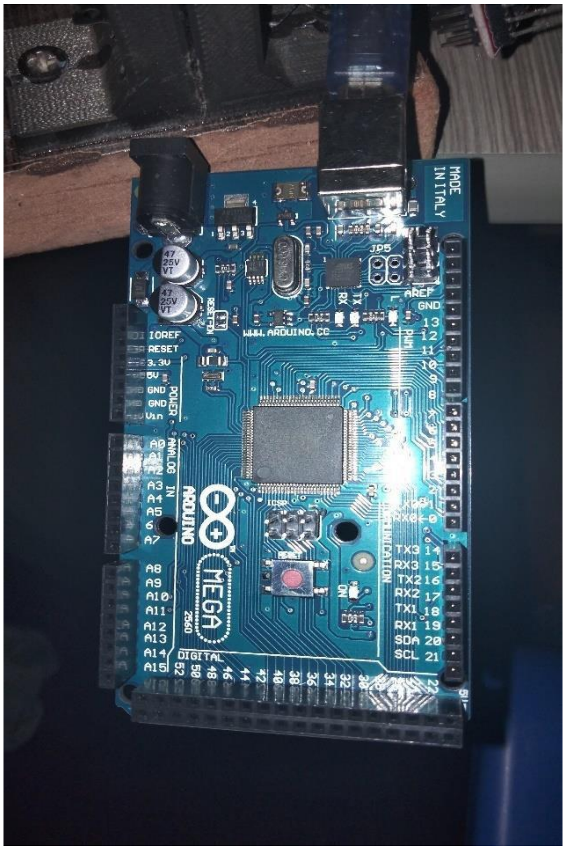
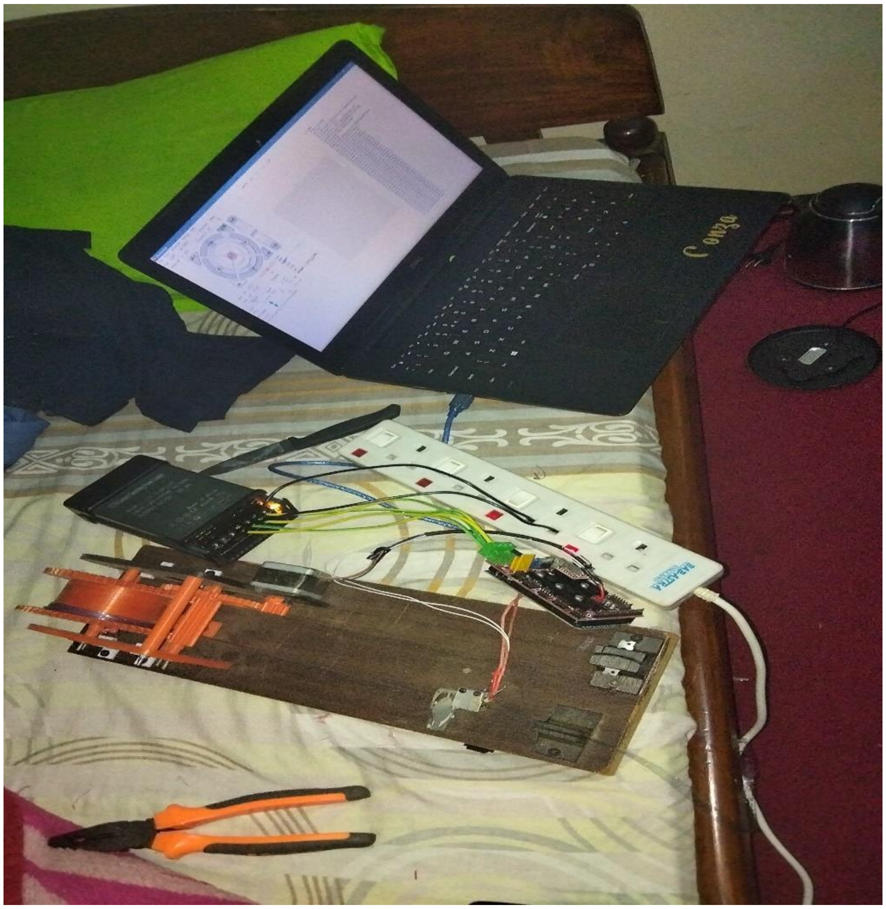


Figure 11 Arduino Mega 2560

3.2 Construction of the machine prototype

The parts above in section 3.2 were assembled and connections made using wires to come up with the machine as shown below. The code for the operation of the machine components in the appendices was uploaded onto the Arduino Mega 2560 board using a USB cable and Arduino software.



3.3 Assessment of prototype against design requirements

The assembled prototype was tested and assessed to ascertain whether it met the design requirements generated in section 3.1 above. This involved looking at the parameters that reflect the criteria that was used in concept selection i.e., price, ease of use and weight.

3.3.1 Production of filament

1. Cleaning and drying of bottles

The bottles that were used for the production of the first filament were two Hema mineral water bottles of 1.5 liters that were gotten from the dust bin. Shown in the figure below are the bottles after cleaning but before removing the labels.

Figure 12 Waste water bottles

2. Removing designs

The labels were then taken off the bottles and air pumped into the bottles after which they were rotated above a flame along the axis normal to their cross-section area to remove the designs such that we would get uniform filament and the figure below shows the result of the step.

Figure 13 Bottle with uniform surface

3. Cutting the bottle into a strap of uniform thickness

The bottom of the bottle was cut at a small angle between 20^0 and 30^0 to give a start for the cutter to generate a long strap of uniform thickness 10 mm.

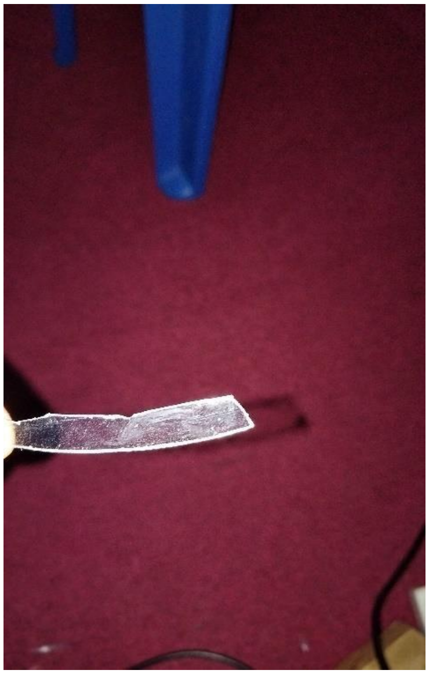


Figure 14 Part of the strap

4. Passing of strap through die

One of the strap ends was passed through the die from one end to the other before turning on the machine and tied to the gear traction mechanism. The machine was then turned on ie the heating block and stepper motor and the extrusion started.

Figure 15 Machine in operation

CHAPTER FOUR: RESULTS

4.1 Assessing the machine according to design specifications

On assessing the prototype based on the design requirements, all requirements were met except for the price being lower than UGX 300,000 since the project budget in Appendix A was over UGX 400,000. Other than that, the produced filament is of the specified size, and was also able to be excluded at 210 ^{0}C. The machine is easy to use and due to its modular setup, cleaning is very easy and can be done in less than 5minutes.

However, unlike the conventional manufactured filament, the filament produced is hollow as shown in the figure and therefore there are parameters that must be changed in the slicer software prior to printing in order to generate good quality prints.

Figure 16 Sample of filament produced

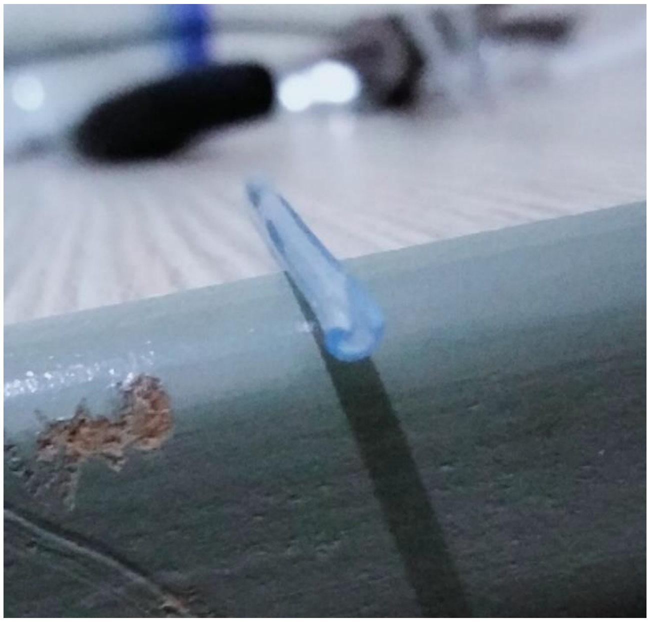


Figure 17 Filament with hollow cross section

3D printing filament does not need to meet precise technical requirements. The only requirement is that it can be used in a 3D printer. The ductility and diameter can have some variation and still be usable. If the produced filament can be spooled and fed like commercial filament, it is usable. Therefore, most of the testing was qualitative. The diameter of the produced filament was sampled at fixed intervals to determine the average diameter and tolerance.

Two meters of filament were obtained from one Hema water bottle (1.5l) and used to print a 20mm x 20mm x20mm calibration cube that was modeled using solid works and sliced using prusa slicer. The purpose of the calibration cube was to test the dimensional accuracy that could be obtained when using the filament and the results showed that the accuracy was high as the measurements taken on the printed cube were the exact measurements of the model.

4.2 Challenges faced during testing process.

On doing the first test of the machine, the process started smoothly but after some minutes, the nozzle got clogged and the extrusion process could not proceed. This was due to the nozzle being heated for a long time yet the traction mechanism was not turned on. The nozzle assembly was therefore disassembled and cleaned before restoring it and the process of testing proceeded and was successful.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The project was successfully implemented and all the objectives accomplished. This project has introduced the design and model of a filament machine and proposed an alternative way to acquiring filament but also reducing plastic bottles' pollution of waterbodies and land too. The machine has been tested and filament comparing with generally available filaments in simple tests. It was exciting and quite an achievement to receive filament that can be used in a regular 3D printer from waste plastic bottles. Creating and using the filament print parts on a 3D printer however requires some analysis and change of some parameters in the slicer software for the best prints owing to the filament being hollow. The product of this project is a prototype and several parts can be made better but also scaling it up. Making of PET filament from waste plastic bottles can be a solution to two problems i.e., high expenses of getting filament but also reducing pollution and other effects of littered plastics. Although making filament may help reduce pollution by plastics, poor disposal of printed parts may also lead to the same problem so everyone should take action to conserve the environment and save it for our grandchildren.

5.2 RECOMMENDATIONS

The machine produced from this project can be made better in terms of efficiency but also the cost of construction.

- Parts like the Arduino Mega 2560 board, ramps 1.4 shield and the power supply can be foregone and options like making a simple power supply put into action.
- Some additives can be added into the filament so as to enhance its properties like ductility.

APPENDICES

APPENDIX A: BUDGET OF THE PROJECT

PART	QUANTITY	COST PER UNIT(UGX)	TOTAL COST
12V 20A power supply	1	60,000	60,000
A4988 motor driver	1	7,000	7,000
Arduino Mega board	1	80,000	80,000
Arduino mega polulu shield	1	40,000	40,000
100K BTC with cable	1	10,000	10,000
Wiring set	1	20,000	20,000
Extruder E3D with thermistor and fan	1	75,000	75,000
Bicycle pump	1	50,000	50,000
Stepper motor	1	20,000	20,000
Operational expenses		100,000	100,000
Total			**462,000**

Table 3: Budget

APPENDIX B: ACTIVITY PLAN

The planned flow of activities until the completion of the project is shown below with the help of a Gantt chart.

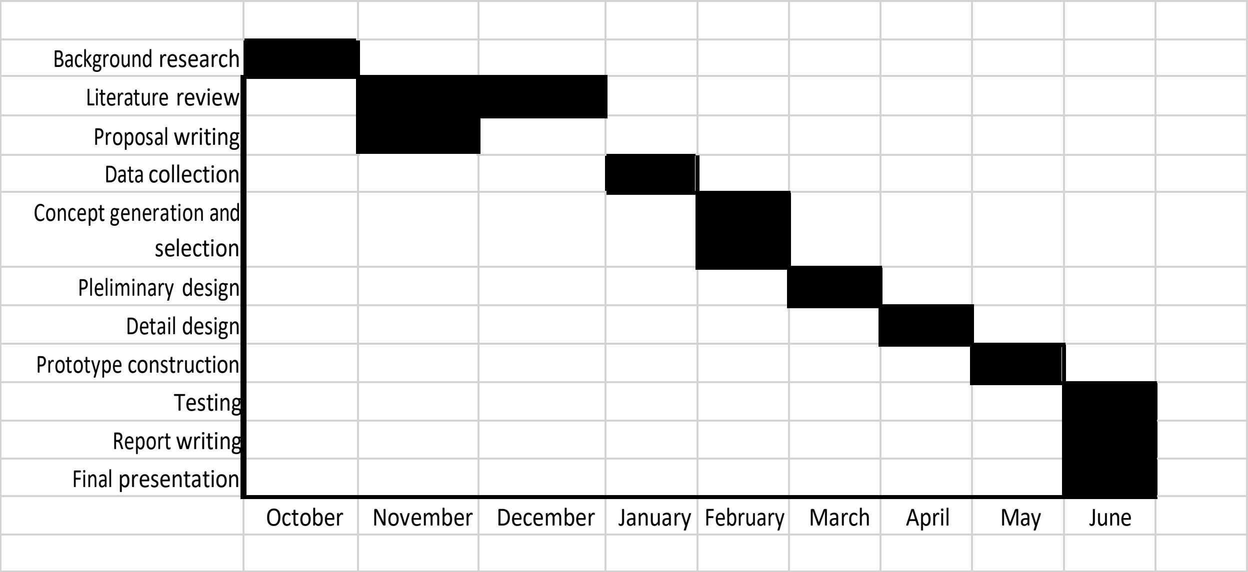
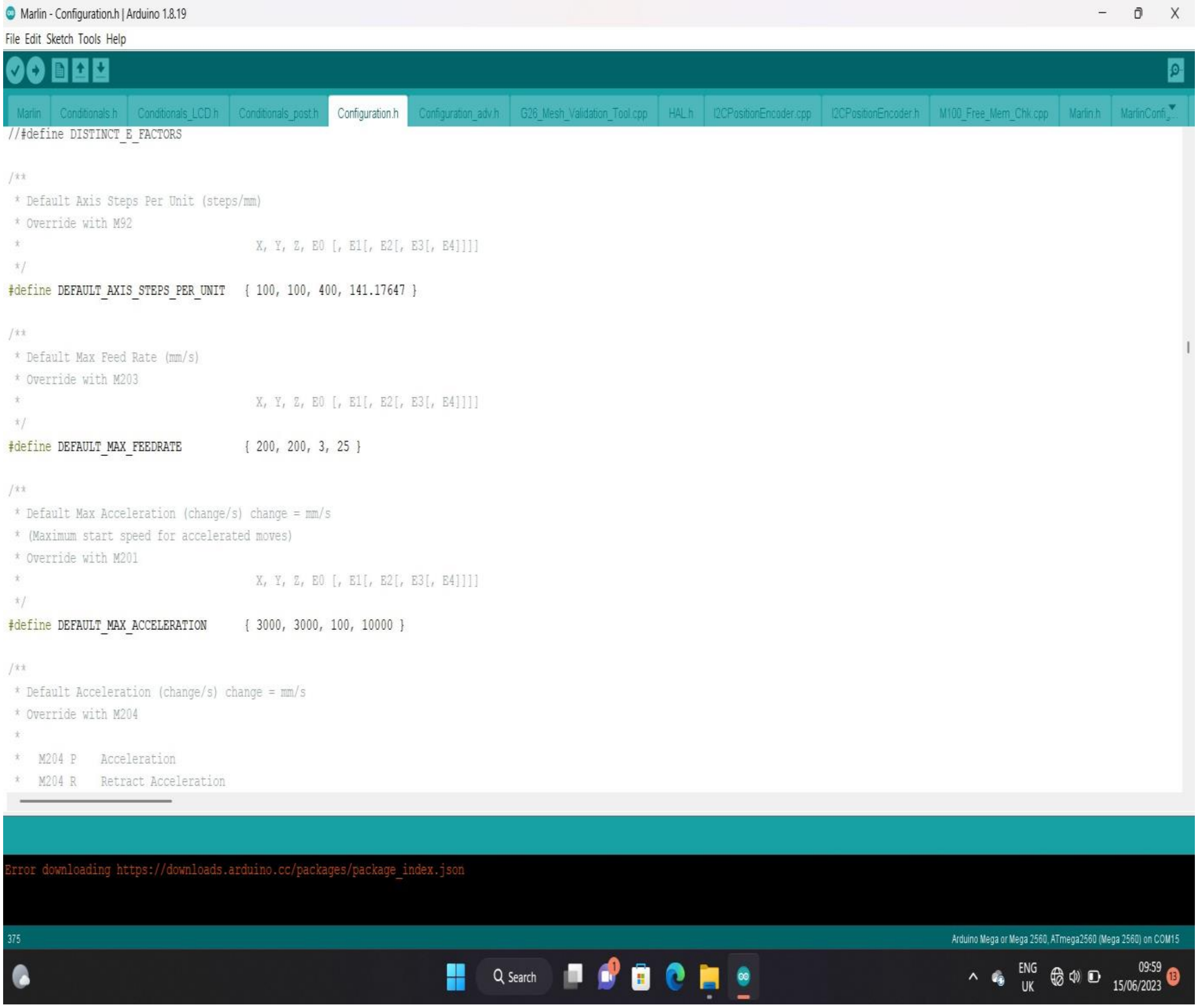


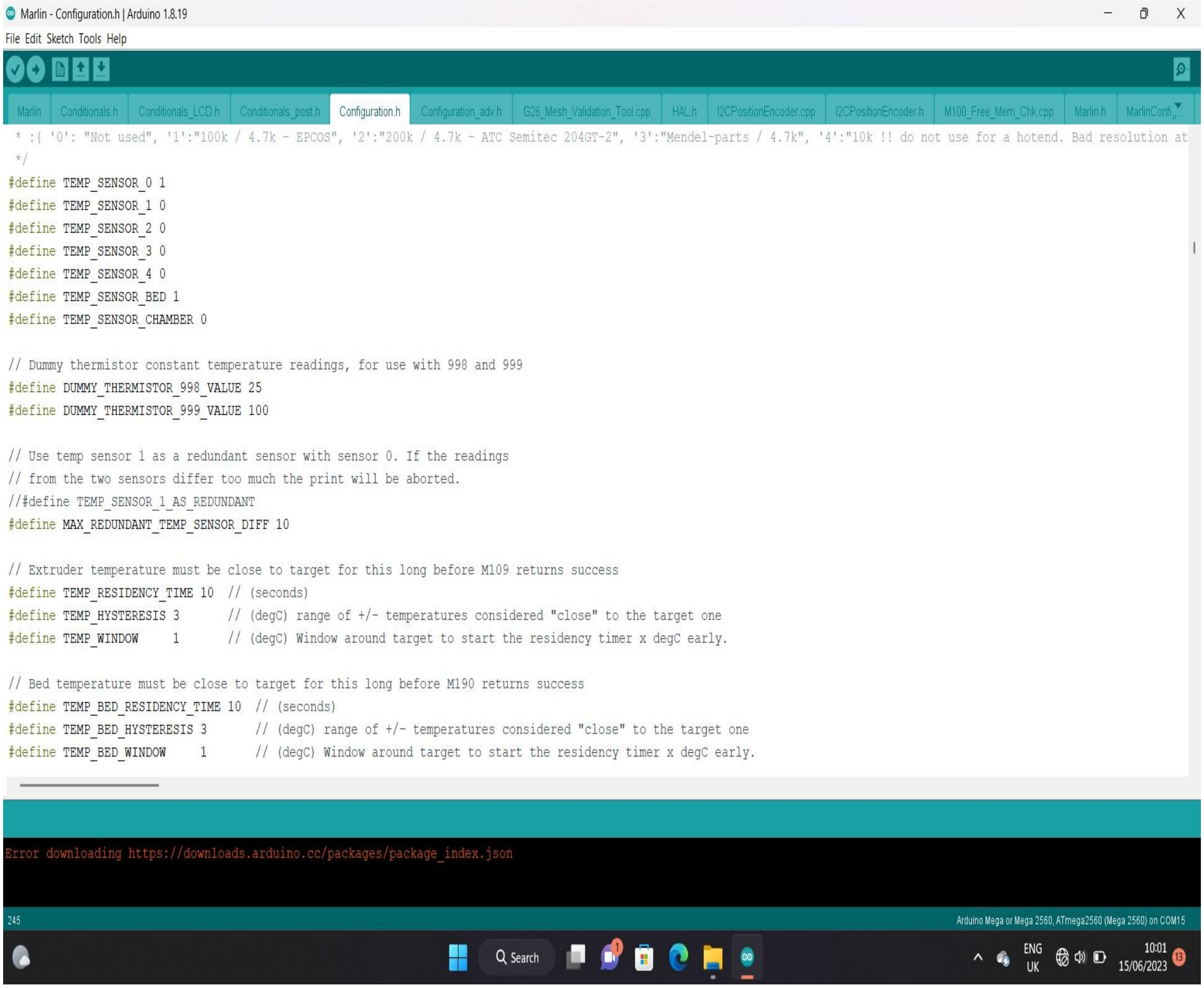
Figure 18 Gantt chart for project

APPENDIX C: CODE



```
//#define DISTINCT_E_FACTORS

/**
 * Default Axis Steps Per Unit (steps/mm)
 * Override with M92
 *                                      X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_AXIS_STEPS_PER_UNIT   { 100, 100, 400, 141.17647 }

/**
 * Default Max Feed Rate (mm/s)
 * Override with M203
 *                                      X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_MAX_FEEDRATE          { 200, 200, 3, 25 }

/**
 * Default Max Acceleration (change/s) change = mm/s
 * (Maximum start speed for accelerated moves)
 * Override with M201
 *                                      X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_MAX_ACCELERATION      { 3000, 3000, 100, 10000 }

/**
 * Default Acceleration (change/s) change = mm/s
 * Override with M204
 *
 *   M204 P    Acceleration
 *   M204 R    Retract Acceleration
```

```
Error downloading https://downloads.arduino.cc/packages/package_index.json
```



```
 * :{ '0': "Not used", '1':"100k / 4.7k - EPCOS", '2':"200k / 4.7k - ATC Semitec 204GT-2", '3':"Mendel-parts / 4.7k", '4':"10k !! do not use for a hotend. Bad resolution at
 */
#define TEMP_SENSOR_0 1
#define TEMP_SENSOR_1 0
#define TEMP_SENSOR_2 0
#define TEMP_SENSOR_3 0
#define TEMP_SENSOR_4 0
#define TEMP_SENSOR_BED 1
#define TEMP_SENSOR_CHAMBER 0

// Dummy thermistor constant temperature readings, for use with 998 and 999
#define DUMMY_THERMISTOR_998_VALUE 25
#define DUMMY_THERMISTOR_999_VALUE 100

// Use temp sensor 1 as a redundant sensor with sensor 0. If the readings
// from the two sensors differ too much the print will be aborted.
//#define TEMP_SENSOR_1_AS_REDUNDANT
#define MAX_REDUNDANT_TEMP_SENSOR_DIFF 10

// Extruder temperature must be close to target for this long before M109 returns success
#define TEMP_RESIDENCY_TIME 10  // (seconds)
#define TEMP_HYSTERESIS 3       // (degC) range of +/- temperatures considered "close" to the target one
#define TEMP_WINDOW     1       // (degC) Window around target to start the residency timer x degC early.

// Bed temperature must be close to target for this long before M190 returns success
#define TEMP_BED_RESIDENCY_TIME 10  // (seconds)
#define TEMP_BED_HYSTERESIS 3       // (degC) range of +/- temperatures considered "close" to the target one
#define TEMP_BED_WINDOW     1       // (degC) Window around target to start the residency timer x degC early.
```

```
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```

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