3D Printer

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Abstract—Although 3D printing was invented decades ago, it is in this century that it has had a big impact and there have been many improvements. It is now used professionally in many fields, and even for personal use. It is particularly useful when producing prototypes without having to make a mould or for printing parts for old objects that are not being produced any more, like a gear of an old watch, among other uses. In this work, a FFF (Fused Filament Fabrication) 3D printer has been designed and developed to deepen the understanding of this technology and explore its potential applications, ultimately benefiting industries, education, and hobbyists.

Index Terms—3D Printer, Raspberry Pi Pico H, Fused Filament Fabrication, Cortex M0.

Resum— Tot i que la impressió 3D es va inventar fa dècades, és en aquest segle que ha tingut un gran impacte i hi ha hagut moltes millores. Ara s'utilitza professionalment en molts camps, i fins i tot per a ús personal. És especialment útil a l'hora de produir prototips sense haver de fer un motlle o per imprimir peces d'objectes antics que ja no s'estan produint, com un engranatge d'un rellotge antic, entre altres usos. En aquest treball, s'ha dissenyat i desenvolupat una impressora 3D de FFF (Fabricació per Filament Fos) per aprofundir en la comprensió d'aquesta tecnologia i explorar les seves aplicacions potencials, beneficiant finalment les indústries, l'educació i els aficionats.

Paraules Clau—Impressora 3D, Raspberry Pi Pico H, Fabricació per Filament Fos, Cortex M0.

1 Introduction

While the inception of 3D printing dates back several decades, it is within the current century that its substantial impact and numerous enhancements have become evident. Presently, 3D printing finds extensive professional applications across various fields and is also widely utilized for personal endeavors. Its significance is notably pronounced in the efficient creation of prototypes without the need for moulds, as well as in the replication of components for discontinued items, such as an antique watch gear, among other versatile applications.

There are currently several kinds of 3D printers in the market. The most used criteria to differentiate the 3D printers is the technology they use to print objects. The most common one is the FFF (Fused Filament Fabrication) and the object of this project. It prints objects, melting a thermoplastic filament and depositing it, forming layers that will become the printed object. There are also other printing technologies like the SLA (Stereolithography), for example, which uses mirrors to lead a laser forming the shape of the object that is being printed in different layers onto a resin tank which solidifies in contact with the beam. [1]

When designing a 3D printer there are a few things to bear in mind. For an FFF 3D printer, it is important to be able to lead the extruder to different parts of the bed to be able to form the object that needs to be printed.

The way this paper is organised is, in the first instance, we will be looking the components that are needed for developing a 3D printer and how they work. The electrical components will appear first and then the mechanical ones and finally the user interface.

Then we will take a look at the objectives of this project, then the methodology followed to conduct this project and then the design where the components and decisions taken will be discussed in depth. Lastly, we will see the results of this project, the conclusions, and possible improvements in the future.

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2 Components

A 3D printer to work needs a combination of both electronic and mechanical components. The electronic components will be the ones responsible of controlling all the processes that are to be executed within the 3D printer and the mechanical components will be the ones responsible of transmitting the movement generated by the motors to make something useful.
In this section, the main components are going to be shown but will be discussed in more detail in the design section.

2.1 Electronic components

The electronic components that have been used in this project are the ones shown in figure 1.

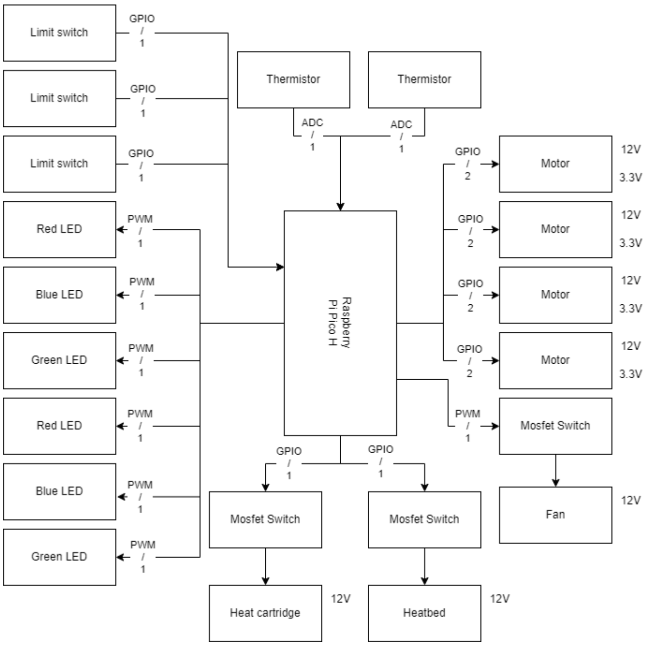

Figure 1. Block diagram

Microcontroller:
The most important component of a 3D printer is the microcontroller, which acts as the brain of the 3D printer. It will be controlling and coordinating all the components that form the 3D printer. The microcontroller used on this project will be the Raspberry Pi Pico H, which is the first low-cost microcontroller designed by Raspberry Pi and has a Dual-Core ARM Cortex M0+. [2]

Limit switches:
When the printing process is started, it is mandatory to know the position in all the axis. That's where limit switches come in handy. A limit switch is a device that changes its signal when it detects an object. There are four kinds depending on the way of detecting the objects:
A mechanical switch is basically a button, it needs to be pressed to detect the objects. Because of the physical contact it is less durable than the other kinds, but it is more simple and cheaper. An optical switch consists of a LED and a phototransistor. When an object blocks the path of the light, the signal it emits changes. It is contactless making it more durable than mechanical switches but needs an extra pin to supply the LED. Ambient light can affect it. A magnetic switch is also a contactless switch, and it detects changes on the magnetic field. For that, a magnet has to be attached to the carriage. It also needs an extra pin but as a reference voltage. Finally, the force sensitive switch is a switch that changes its resistance based on the force applied to it. It needs an extra controller board to measure the changes of the resistance and since it needs a force to be applied to it the carriage has to touch it as with the first limit switch. [3]

2.2 Mechanical components

Frame:
To generate a linear motor system to move the components around, there can be used both linear rails or rods:
A linear rod is basically a cylinder (fixed part) with another cylinder (movable part) with a bigger diameter and a hole in the middle for the inner cylinder to fit in. The outer cylinder is way shorter and travels alongside the inner cylinder carrying the components that need to be moved (like the extruder). Cylinder rods are cheaper than linear rails because their shape is simpler and easier to manufacture, but they have an issue: It has too many degrees of freedom. In a linear rail, the movable part can only move back and forward, but on a linear rod it can also spin around. In 3D printing where accuracy is key, this is disastrous because an extruder spinning around the rod will not be able to print any object. This is solved by adding an extra cylinder rod with another linear bearing.
In what it refers to linear rails there are two main kinds: the traditional and the V-rail.
The traditional rail is similar to the linear cylinder but instead of being round shaped it is shaped like a rectangle, making spinning around it impossible. With that said, both of these methods have a common con which is that a frame is needed for them to be attached to, which is solved by the last kind of rail, the V-rail. The V-rail is a square-shaped bar which has holes on its sides shaped like a V. A particular wheel shaped

like a V can be attached to those holes and move there back and forward. At least one wheel has to be attached to each side, so they do not fall off, and they need to be connected to form a carriage where the components can be attached to. A drawback of the V-rails is the lifespan of its wheels, which break quicker than the ball bearings used on traditional rails.

Transmission:
Once we have the rails, we need a method to transmit the movement of the motors to the carriages. There are two main methods:
The belt-driven transmission and the lead screw-driven transmission.
For the belt-driven transmission, a timing pulley is attached to the tip of the motor and both sides of the belt are attached to both sides of the carriage. Moving the motor pulls the belt moving the carriage.
For the screw-driven transmission, a screw is attached to the tip of the motor and as the rotor rotates, the screw spins. Then a nut block is attached to the screw and goes back and forth if the screw is held in place.
The belt-driven transmission is cheaper and faster than the screw-driven one, but it is less accurate. Another factor to keep in mind is that the screw is less likely to spin by itself when the power is cut off than the belt, making it more suitable for the Z axis, so the extruder does not fall and crash on the bed.

Filament:
The main characteristic of the FFF printers is the use of filament to print the objects. There are many filaments used in 3D printing but here are a few:
PLA is a filament made out of corn, which makes it biodegradable and non-toxic. It does not need a heat bed to be printed. It is one of the most commonly used filaments and it comes in many colours.
ABS is one of the most used filaments in 3D printing along PLA, it is cheaper and more resistant than PLA, but it is derived from petrol making it toxic and not biodegradable.
PVA is derived from petrol. It can be diluted in water, making it ideal for the support parts in combination with other filaments, making it possible to put the objects inside of water after printing them getting the desired objects without having to remove the supports manually.
There are many other filaments suitable for different purposes but those are the most used ones. [1]

2.3 User interface

User interface:
There is a green LED within the microcontroller which indicates when the 3D printer is on or off.
There are also 6 other LEDs that indicate the temperature of both the hotend and the heatbed (green indicating right temperature, blue indicating a temperature too low and red indicating a temperature too high).
The way to add a gcode file for the printer to interpret is uploading it onto the microcontroller and changing the line 6 of the file called *gcodeParser.py* with the name of the file.

3 Objectives

The main objective of this project is to design and develop an FFF (Fused Filament Fabrication) 3D printer. Also, to learn how are the printed objects made and unravel the mysteries behind this technology, deepening its understanding and to see its possible applications.
Another objective of this project is the use of a microcontroller based on the Cortex-M0 architecture, which is designed to operate with minimal power consumption and to occupy a reduced amount of space due to the size of its footprint.
The microcontroller used on this project as mentioned before, will be the Raspberry Pi Pico H.

4 Methodology

The methodology used in this project consists of a hybrid methodology that mixes elements of different methodologies. In this case a waterfall method is combined with an agile method splitting the project in more simple tasks, and depending on the tasks there could be a dependency or not among them allowing tackling the tasks in the preferred order in case of there not being any dependency.
The planning is in the appendix.

5 Design

5.1 Electronic components

The connections are shown in figure 2.

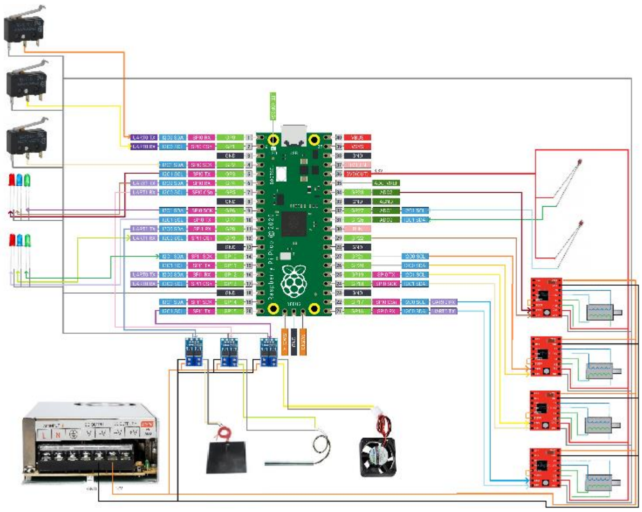

Figure 2: Connection map

The resulting 3D printer is shown in figure 3.

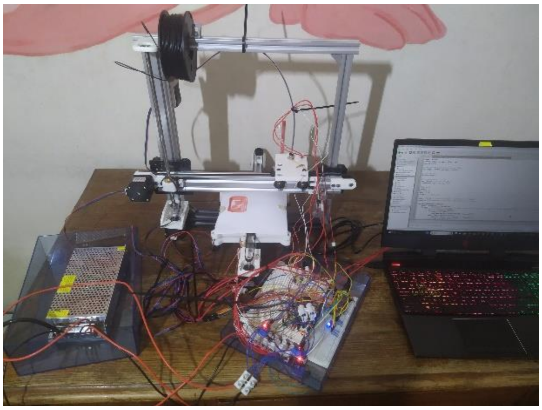

Figure 3: 3D Printer

Microcontroller: To control all the electronic components.
Raspberry Pi Pico H.

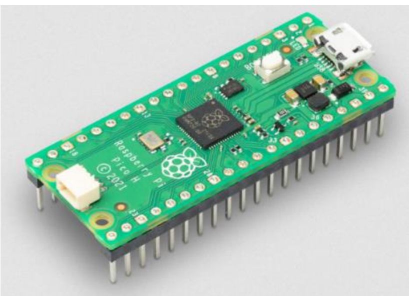

Figure 4: Raspberry Pi Pico H

Microcontroller RP2040 Dual-Core ARM Cortex M0+.
20 pins on each side already soldered.
USB 1.1 for programming and support (device or host).

2 ADC modules will be used to control the thermistors to control the heat of both the hot end and the heatbed.

8 PWM modules will be used to control the 7 LEDs (1 indicates that the printer is on (LED integrated in the microcontroller) and the other 6 indicate the relative temperature of the hot end and the heatbed, being blue, a temperature too low, red a temperature too high and green a right temperature). And lastly, the fan that cools down the cold end so the filament does not melt too quickly making it hard to control it.

3 GPIO input modules to control the limit switches so the 3D printer can start printing at a known position.

10 GPIO output modules to control the 3 motors of each axis plus the motor for the filament (2 pins per motor (direction + steps)) and to control both the hot end and the heatbed.

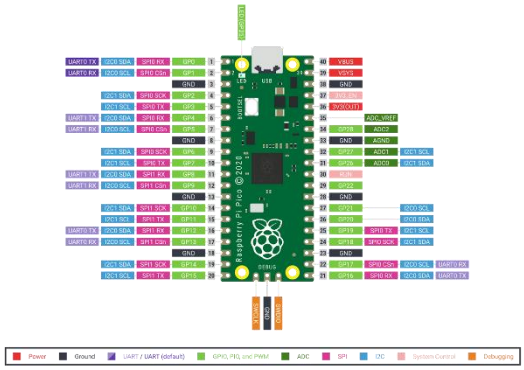

Figure 5: Raspberry Pi Pico H's pins

- **4 stepper motors of 16 steps** (1 for each axis (X, Y, Z) and 1 for the extruder (to pull down the filament)).

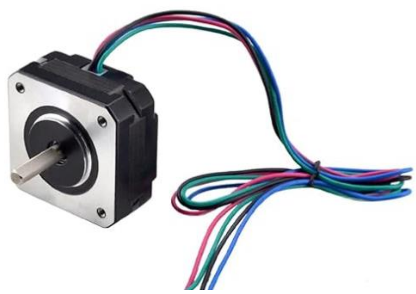

Figure 6: Stepper motor

It has 4 pins:
Black and green are connected to one phase and red and blue are connected to the other.
All four pins are connected to a stepper driver resulting in a total of 0 pins connected to the microcontroller.

4 stepper drivers: To control the pulses of the stepper motors.

It takes 3-5.5V
Pins:
Enable: Enables the driver. It's enabled by default. It's disabled with a logic 1.
MS1: Pin to select microstepping.
MS2: Pin to select microstepping.
MS3: Pin to select microstepping.
RESET: Ignores all inputs to the step pin when activated. It's activated with a logic 0. To keep it high it can be connected with the sleep pin.
SLEEP: Minimises power consumption when the motor is not in use.
STEP: When activated advances the motor 1 step according to the microstepping setting. It's activated with a change from low to high.
DIR: Defines the direction of the rotation.
VMOT: Input of the voltage to the motor (8V-35V).
GND: Must be connected to ground.
2B: Output pin connected to the stepper motor.
2A: Output pin connected to the stepper motor.
1B: Output pin connected to the stepper motor.
1A: Output pin connected to the stepper motor.
VDD: Power's the driver (3V-5,5V).
GND: Must be connected to ground.

MS1	MS2	MS3	Microstep Resolution
Low	Low	Low	Full Step
High	Low	Low	Half Step
Low	High	Low	Quarter Step
High	High	Low	Eighth Step
High	High	High	Sixteenth Step

The current limit control must be adjusted to match the value of the stepper motor's current (1'7A in this case) divided by 2'5 Ω: 1'7A / 2'5 Ω = 0'68V.
The driver must be enabled, set to full step mode and must not be sending steps. The reference voltage is measured between the potentiometer screw and GND. The value depends on VDD.

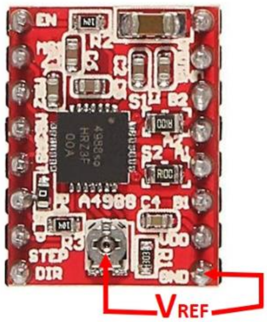

Figure 7: Stepper driver

VMOT and GND are connected to the power supply.
2B, 2A, 1A and 1B are connected to the stepper motor.
Reset is connected to Sleep.
VDD, GND, STEP and DIR are connected to the microcontroller.
This makes for a total of 2 output pins and 0 input pins per stepper driver connected to the microcontroller.
There is a total of 4 stepper drivers resulting in a total of 2 pins / driver * 4 drivers = 8 output pins.

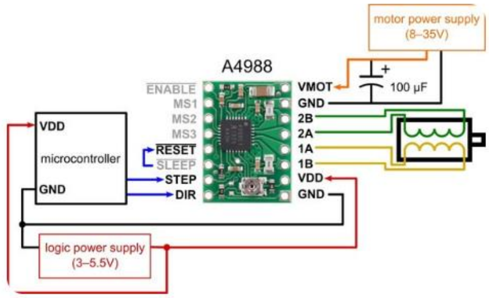

Figure 8: Stepper driver's pins

- **Power supply:** To power all the components. It supplies up to 12V and 15A.

- **3 limit switches:** To determine the position (0, 0, 0) at the beginning of the printing

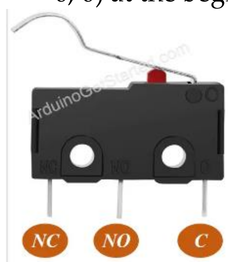

Figure 9: Limit switch

I chose the mechanical limit switch because despite being less durable it is cheaper and would still last enough to complete this project.
Each limit switch has 3 pins where C is connected to NC when the limit switch remains untouched and to NO when touched:

- NC: Normal closed pin. (Input pin)
- NO: Normal open pin. (Input pin)
- C: Common pin. (Output pin)

Normally only 2 pins are used (C and any of the other two) having the following possibilities:

If C is connected to GND:
    If switch is untouched:
        NC = LOW
        NO = HIGH
    else
        NC= HIGH
        NO = LOW
If C is connected to VDD:
    If switch is untouched:
        NC = HIGH
        NO = LOW
    else
        NC= LOW
        NO = HIGH

(A pull-up resistor is used when C is connected to GND and a pull-down resistor is used when C is connected to VCC).

- **1 cartridge heater:** To warm up the filament on the extruder.
  Voltage: 12V.
  Power: 40W.
  It has two terminals, one for the power and the other for ground.

- **1 thermistor:** To control the heat of the hot end on the extruder.
  NTC 3950.

  It has two pins:

One pin is connected to ground or another reference voltage and the other pin is connected to an analog input (an ADC can be used to determine a precise measure). As the heat increases the resistance decreases.

- **7 LEDs:** To show if the 3D printer is on (LED incorporated in the 3D printer), and 6 more LEDs to indicate the temperature of both the hotend and the heatbed (red for a temperature that is too high, blue for a temperature that is too low and finally green for the right temperature):

  LEDs have 2 pins:
    - Ground or VDD.
    - GPIO or PWM.

I decided to use PWM to reduce power consumption and to reduce the intensity of the light which was too bright using GPIO.

- **Fan:** To cool down the cold end:
  It has 2 pins:
    - Ground or VDD.
    - GPIO or PWM.

- **Trigger switch drive module:** It is used to control the power supply of the cartridge heater, the heated bed and of the fan.

It is supplied with the power required to use the component it controls with the bottom-right pin of figure 10, connecting the current to the pin on the right and ground on the pin on the left. Then the component that will be controlled is connected to the pins on the top-right of figure 10, having the positive side connected to the right pin and the negative side connected to the left pin. Finally, a pin of the controller that can be both a trigger or a PWM, is connected to the right side along with ground.
The way it works is that both positive pins are always short circuited, but when the trigger signal is 0, both negative pins are insulated not allowing the flow of the current and then deactivating the component it controls. When the trigger signal is 1, the flow of current between negative pins is allowed again and thus the component is activated.

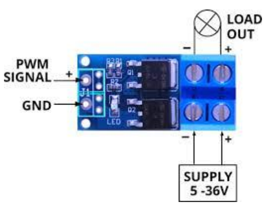

Figure 10: Trigger switch drive module

5.2 Estructure

- **V-rails:**

As explained earlier, to generate a linear motor system to move the components around, there can be used both linear rails or rods.
I chose the linear rods because I only needed a single one for each axis and it acts as the frame itself as well, simplifying the assembling process.

The sizes and amounts used in the project are the following: 20x20 400mm 2u, 20x40 150mm 2u, 20x40 400mm 3u
They are attached as shown in figure 11.

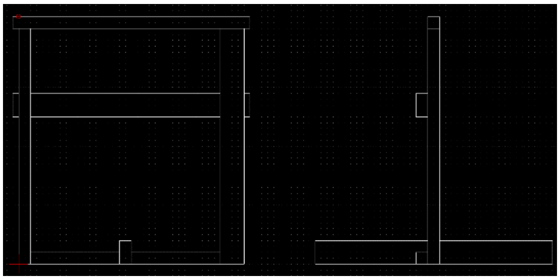

Figure 11: 3D Printer's frame
[4]

- **Transmission:**

As discussed before, there are two main ways of transmitting movement on 3D printers. The belt-driven transmission and the lead screw-driven transmission. I chose to use the screw-driven transmission on the Z-axis to keep the extruder in place when the power is cut off without risking damaging the 3D printer crashing the extruder onto the heatbed. For the X and Y axis, I chose to use the belt driven transmission because it is cheaper and there is no real risk of damaging the 3D printer because the movement is done on the sides so gravity cannot really mess it up when the power goes down.

- **Filament:**

There are many filaments, but I chose PLA because it is biodegradable and non-toxic. It is also cheap, it does not require a particularly resilient nuzzle and does not need a heatbed at all, despite the heatbed improving its performance.

5.3 Software

The software for the 3D printer has been written in MicroPython and is executed on the microcontroller which is a Raspberry Pi Pico H.
The basic operation of the software is expressed in a flow diagram (figure 9).

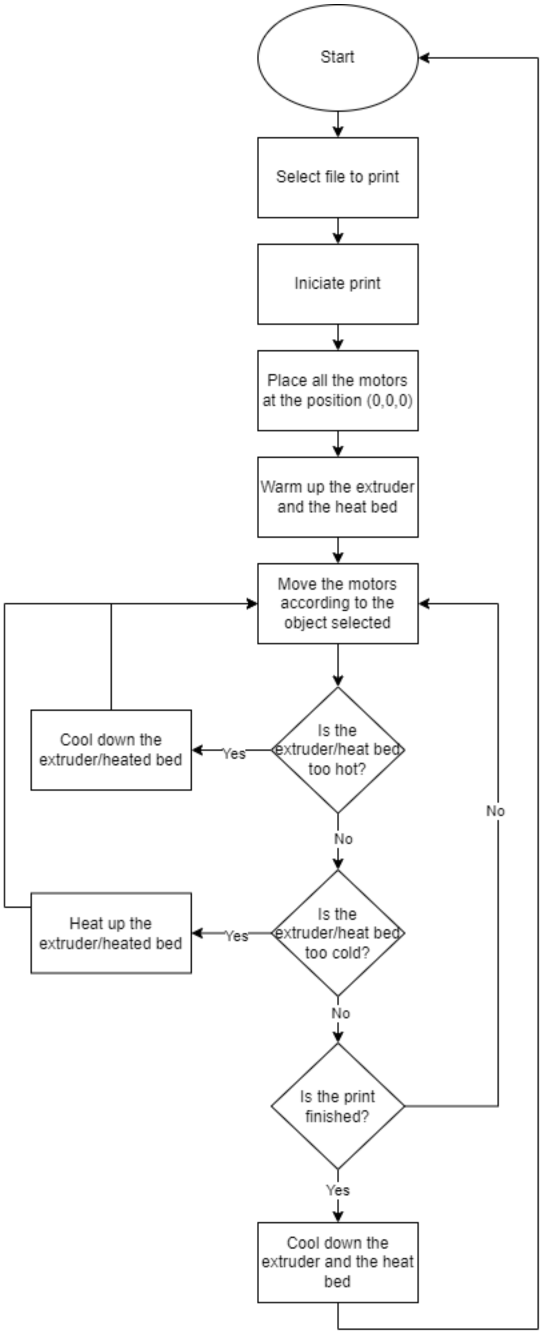

Figure 12: Flow diagram of the software

6 Results

As it can be seen in the figures 13 and 15-17, the 3D printer is capable of drawing straight lines and curves at the moment but needs some adjustments to increase the precision, mainly with actual filament.

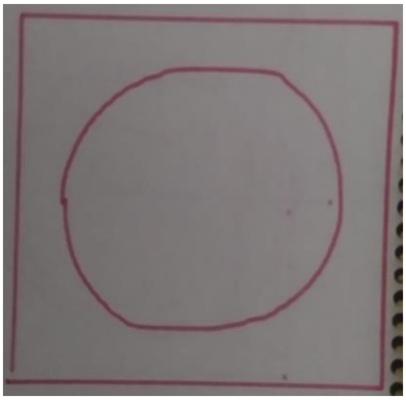

Figure 13: 3D Printer's drawing of a square and a circle

Figure 14: 3D object to print

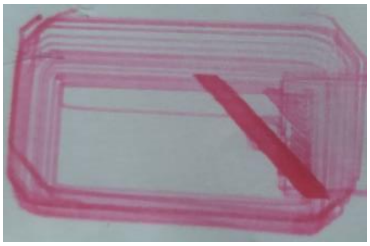

Figure 15: 3D Printer's gcode drawing

Figure 16: 3D Printer's gcode drawing with an infill

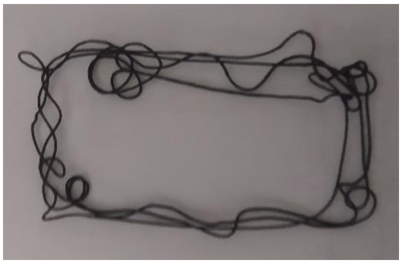

Figure 17: Print with actual filament

7 Conclusions

In this work, a 3D printer has been designed with a microcontroller based on Cortex M0. The microcontroller used in this project, the Raspberry Pi Pico H, is not a common one used in 3D printing which has proved to be a challenge due to a lack of compatibility with the firmwares commonly used in 3D printing like Marlin or RepRap Firmware, but it also proved to have some advantages as it consumes less power and helps to deepen the understanding of how do the components involved work altogether.

8 Future work

Some features could be added to the 3D printer developed during this project like improving the precision and then implementing a configuration for different kinds of filament, a better user interface with an LCD screen as it was originally planned or an additional extruder to print different objects faster or with a different texture or colour depending on the filaments used.

9 References

[1] B. M. Díaz and C. J. Girbau. "Impressió 3D en el món medicinal" Accessed: Jan. 21, 2024. Available: https://drive.google.com/file/d/1SYFbNA0rTlK90leyd1s1s6ki2pZBifc4/view?usp=sharing

[2] Raspberry Pi Foundation, "Raspberry Pi documentation" Accessed: Jan. 21, 2024. Available: https://www.raspberrypi.com/documentation/microcontrollers/raspberry-pi-pico.html

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APPENDIX

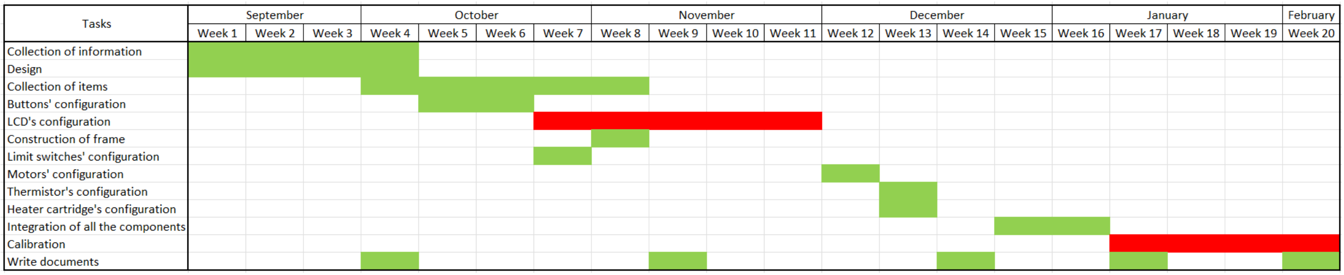

Figure A.1: Planning. Green indicates work done, red indicates work failed to do and grey indicates work planned to do.