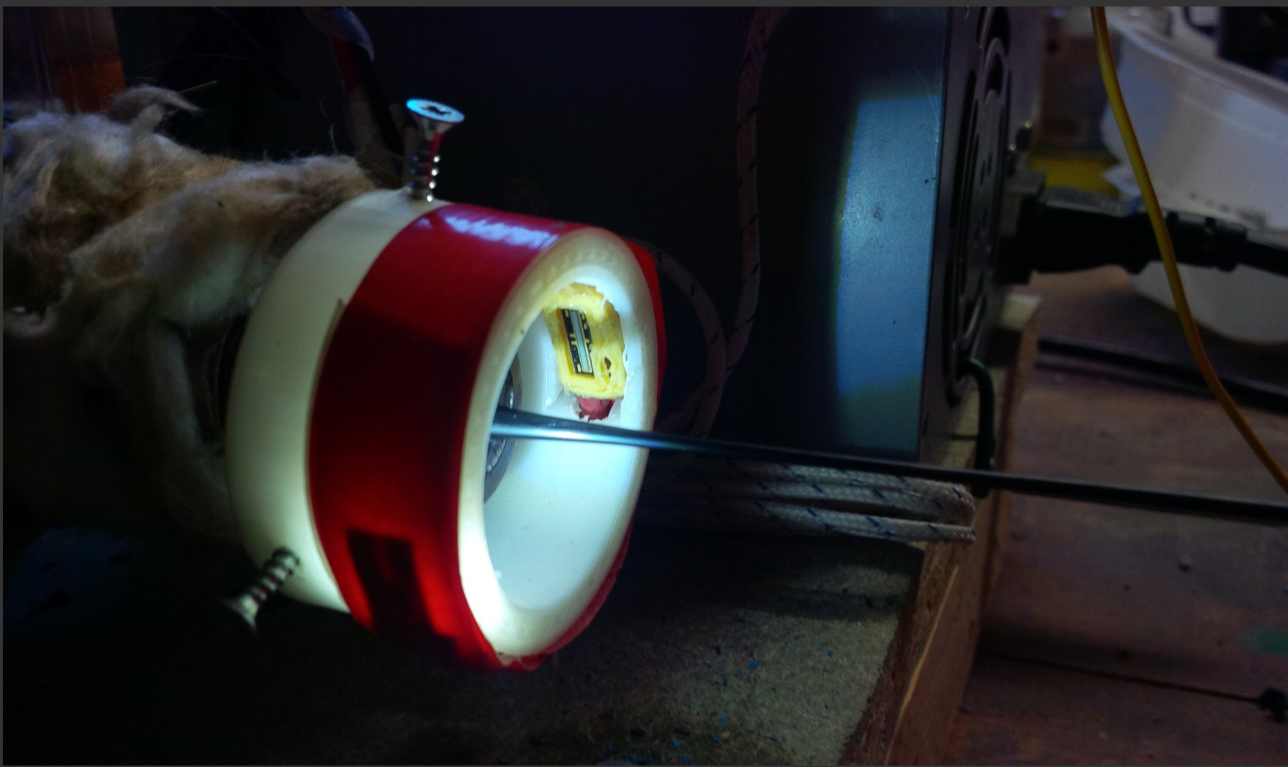
Cheap and dirty process to recycle plastic into 3D printer filament at home.



Long story short *: Get inspired about making your own 3D printer filament at home. Taking material from old household appliances : plastic to recycle and some of the components to build the extrusion line. Let's see how to grind plastic with an electric hand planer and coffee grinder, build and feed a cheap DIY Arduino controlled extrusion line, and print stuffs with that filament.*

Current status :
Plastic used : Mostly polypropylene (PP) and a bit of ABS.
Output : Not very accurate but usable 3D printer filament.
Source Code and 3D models provided.

Contact : littleplasticfactory(a)mailo.com

Table of contents

Intro......3
Part I : From plastic waste to raw material......4
1. Prepare the plastic to be ground......4
   Sort your plastic by type......4
   Clean it !......5
2. Grind plastic pieces to some processable granules......5
   How to grind plastic : various community attempts......5
   My way : electric hand plane + coffee grinder......7
3. Drying......9
4. Fine grinding......9
Part II : Arduino controlled cheap DIY extrusion line......11
1. Understand the challenges of home recycled plastic filament production......12
   Industrial extrusion line workflow : What we try to imitate......12
   The main challenge : Manage a constant extrusion flow rate......13
   A PID loop to stabilize the output flow rate......13
2. Overview of the extrusion line's components......14
   Power supply......15
   Extruder powertrain (pusher module)......15
   Extruder module......17
   Things to help for more homogeneous output......18
   Filament diameter sensor......19
   Puller module......20
   Electronics and interface......21
   Wiring details......23
3. Start the extrusion line and tweak......24
   Starting and interface overview......24
   Pre-heating......24
   Manual extrusion to set rough parameters......25
   Setting up PID loop to get more accurate filament......25
   Save and load preset......26
   Using tips......27
   Cleaning the extruder module......28
Part. III : Print some stuff with your recycled filament......29
1. Check and post process your just extruded recycled 3D printer filament......29
   Thin filament :......29
   Thick filament :......30
2. Print it !......31
Ways for improvement......33
1. Improve the diameter consistency......33
   Diameter sensor accuracy......33
   Speed controlled motors......33
2. Minimize plastic leftovers......34
3. Improve PP printing......34

Intro

3D printing is a very exciting technology as it reaches the home scale but using brand new filament was not acceptable to me as it would just increase the plastic waste amount on the planet. I started to look for a way to turn plastic scrap around me into usable 3D printer filament... On the web I could find many plastic extruders and recyclers but they exceeded my budget so I decided to build my own process. My current system costs less than 100€ with half of the parts taken from scrap.

The process consists in sorting and cleaning plastic pieces taken from defective household appliances, grinding them to small granules, and feed those granules to a home made small extrusion line. After a quick post-processing step, the output filament can be used by a 3D printer to print new objects.

All my work is widely inspired by others projects on the web : Filastruder, Lyman filament extruder, Precious Plastic project and various YouTube or instructable.com contributions. You will find links to those projects further when evoked. Thanks to all the people behind for sharing their research. Sharing what I've learned so far on this topic is my attempt to give back to the community.

At this stage I can produce some 3D printer filament and I am able to print some things with. RC drone frames, chair plastic feet, gears and parts of the extrusion line, battery holder for e-bike and others stuffs have been successfully printed with that recycled filament. That said, I'm not fully satisfied with the process as the filament output is no yet very accurate and also because the grinding system I use is not able to grind some medium and small pieces, that are left over for now.

Early prints with recycled yellow PP filament : RC drone frame and scissors fix.

I started working on this project 3 years ago (Jan. 2019), and what I expected to be a 2 months project ended being a never ending story of try-fail-think-improve-try-again-break-rethink-and retry... almost a half-time job, but with many holidays ;) . I'm glad to share what I've learned so far and hope you'll find some useful things here.

In this guide, I will try to cover all the steps I pass through while converting plastic waste into new things. The first part will explain how to get some raw plastic material ready to be extruded into 3D printer filament. The second part is about building and using a cheap and small DIY Arduino controlled extrusion line. The third part focuses on post-processing and printing that recycled 3D printer filament.

Hope my English is understandable. Now let's jump into the topic ! Nezo.

Part I : From plastic waste to raw material

1. Prepare the plastic to be ground

Vacuum cleaner, coffee machine, food container, or car part can be a good source of plastic.

Looking for recycling plastic obviously means you'll need some plastic to recycle... I find mine from old household appliances given by people around me. I take also some out of shops waste bins where the waste are not going to be recycled.

Sort your plastic by type

Once you've got the material, be sure to sort your plastic by type as they don't react the same to heat and don't always mix in a good way. I used mostly PP as it was the easiest to find for me, and it's also not so harmful as ABS which release styrene while heated. You can check for the logo to know what kind of plastic it is.

Clean it !

The dirt can clog your extrusion line or pollute your filament, it can also clog your 3D printer nozzle. I wash the part with water or using a cloth.

2. Grind plastic pieces to some processable granules

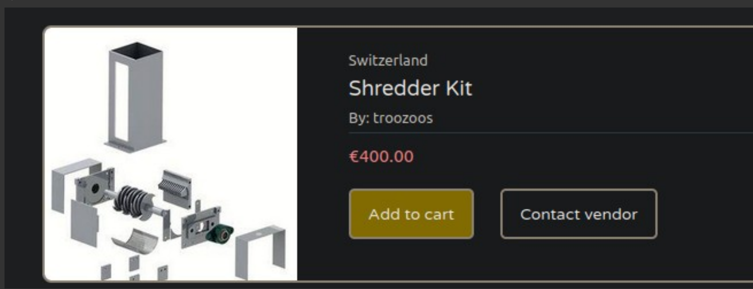
When you got some plastic clean and sorted, you need to grind it down to granules in order to feed the extrusion line.
This step is maybe the more challenging one when trying to keep the process cheap and at a small scale. Before I present my way to grind my own plastic, let's see what how other people do.

How to grind plastic : various community attempts

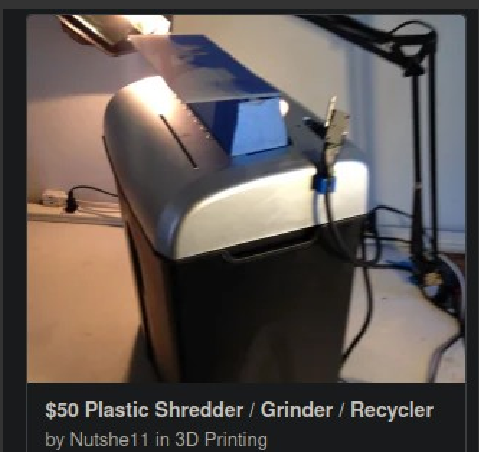
Over the internet there are many different attempts at converting big plastic pieces to small granules. Here is a quick review of the ones I've seen :

Plastic shredder : Precious Plastic project released an open-source kit to build a small scale industrial plastic shredder which seems to work very well but is quite expensive comparing to the price of a small desktop 3D printer.

https://preciousplastic.com/



Hacked paper shredder : seems to work with small 3D printed parts or plastic package sheets. Not tested myself.

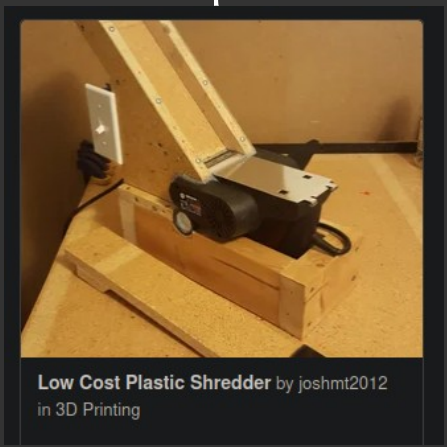


https://www.instructables.com/50-Plastic-Shredder-Grinder-Recycler/

Food blender : Homo Faciens uses a blender to convert PLA parts into small granules for his direct pellets extruder (very interesting project by the way!). Seems to work in his case. I broke my blender trying to break down PP parts to smaller granules : the gearing between motor and blades melted and the bowl got cracked due to the repeated impacts. But there are some weird YouTube videos showing blenders blending everything.

https://homofaciens.de/technics-machines-3D-printer-Granule-Extruder-V2_en.htm
https://youtu.be/Nycx9_I9eec

Electric wood planer : This is the way I chose. Brought to me by joshmt2012 over instructables.



https://www.instructables.com/Low-Cost-Plastic-Shredder/

Not as popular as other ways over internet but I did a quick test with a borrowed tool that convinced me it should work. Not very safe process by itself. But I used it for a while now and I still got all my fingers. See below how I use it.

My way : electric hand plane + coffee grinder

Here is my set up for the first grinding : an electric hand plane fixed on an heavy wrench. The coffee grinder is for the fine grinding (we'll see that later). The cardboard box around is here to keep plastic projections from flying everywhere. I use a small tube to hold the planer switch ON.
The vacuum cleaner bag is meant to catch the ground output which consists in some plastic shavings and granules. The main output should go to the bag, but around 25 % ends around the plane. Sometime, plastic get stuck inside the outlet pipe, maybe due to too much heat aggregating the shavings inside the pipe... You can check from time to time by removing the bag.

Basic grinding tools : electric hand plane, vacuum cleaner bag, pliers.

The "grinding box"

CAUTION 1 : THE PLANER CAN BE HARMFUL, KEEP YOUR HANDS FAR AWAY FROM THE BLADE, USE PLIERS TO HOLD SMALL PIECES.
Sometime the plastic part flies away from my hand/pliers or just break. At that moment the hand or pliers continue to push so if you were pushing to the blade, the tool -- or your hand ! -- will end on the running blade !!! I use pliers when the distance between the blade and my hand is under 20 cm. I stop grinding a part when it is less than 3 or 4 cm long in one direction. Some leftovers, but safer.

CAUTION 2 : WEAR SAFETY GLASSES AND ORGANIC VAPOR FILTER MASK.
Plastic is heated by the blade and releases toxic fumes (more or less according to the type of plastic) and some shards can fly to your face. I use also ear protections.

Finger bites, flying shards and toxic smell are the main dangers here !

At this step we got some mixed plastic shavings and granules that is good to regrind one more time in order to obtain a more dense and homogeneous material. But before the fine grinding I dry the plastic at this stage if needed.

What we got after grinding : plastic shavings + leftovers.

Side note about the electric hand plane lifetime : It happened several time to me to find some plastic parts and even screws from the electric plane inside the freshly made plastic shavings. The plastic inner side of my electric plane housing got slowly eaten by the plane itself! So I'm not sure how long it can last.

3. Drying

Some plastics like ABS needs to be dried before extruded. Over time, moisture get inside the structure of the material and stay trapped in here. When the material is heated again, vapor will expand the plastic like a bread dough, causing bubbles inside the filament. I had success letting the plastic shavings inside an oven for 60 min at around 90℃, checking the temperature with an infrared thermometer. During the drying, I left the oven's door opened. I like to do the drying step when the plastic is still airy. I mean, I think the moisture is more prone to get out of airy plastic shavings than compact small granules or powder. Also shavings will less likely stick together than granules or powder.

PP is not hygroscopic (doesn't absorb moisture), so no need to dry it.

Plastic shavings entering the oven for drying. Blue and gray spots are some shavings from previous ABS grinding attempts.

4. Fine grinding

Why grind again the already ground material going out of the electric hand plane and not just sieve it ?
When extruding without fine grinding, it happened from time to time that the screw stopped to push the plastic out of the pipe. I think that plastic shavings where just turning around the screw inside the barrel. This was solved by feeding more compact material to the hopper, like the one processed through the coffee grinder.


Coffee grinder before and after grinding for 30s to 1min. : Volume get divided by 2.

My old coffee grinder have a max continuous working time of one minute... I do only small amount and let rest the motor for a while. Also I take care to not put too big pieces into the grinder as the grinder blade's end already broke once.

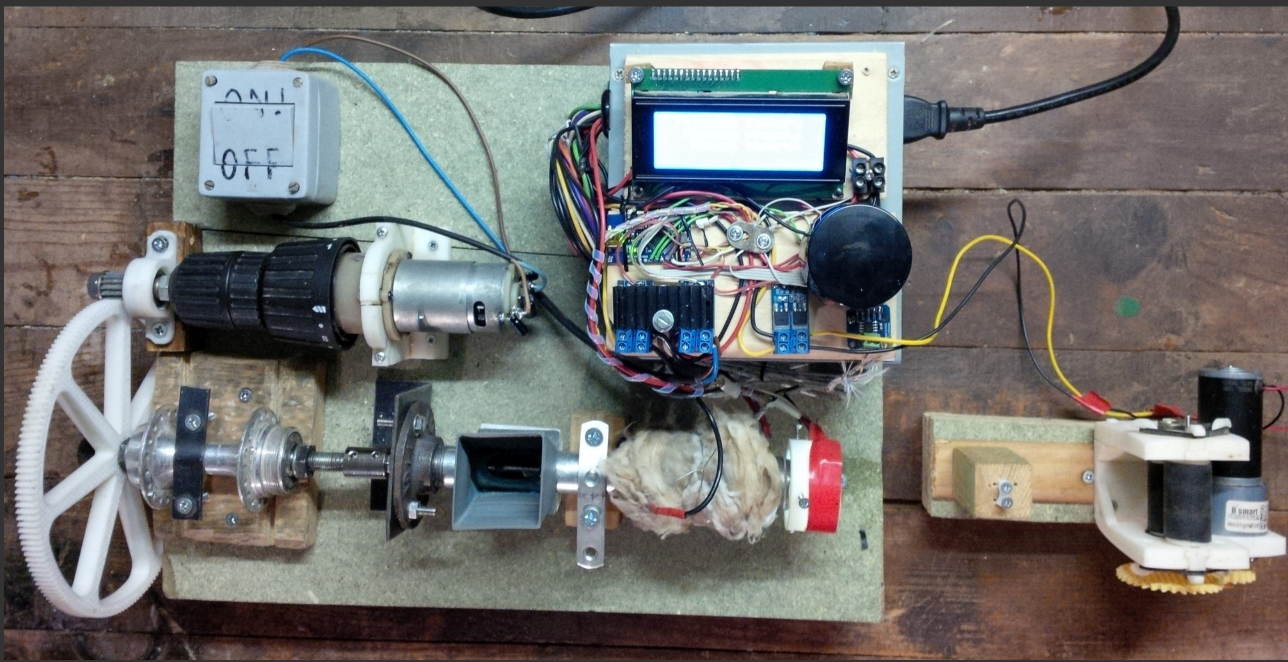
After fine grinding, the last step is to sieve the material to remove some big parts if any. When fed to the extrusion line, too big parts could stop the extrusion screw at the barrel entrance. They also melt slower than smaller granules, causing unwanted flow rate variations and diameter inconsistency to the produced filament.

As a sieve, I use a plastic tray with 5 mm drilled holes.

And finally ! Some ready-to-feed material. The big parts on the left are leftovers.

Ready to extrude ? Or maybe we need to build an extrusion line first ! Let's see below how I did.

Part II : Arduino controlled cheap DIY extrusion line



My actual Arduino controlled cheap and small extrusion line.

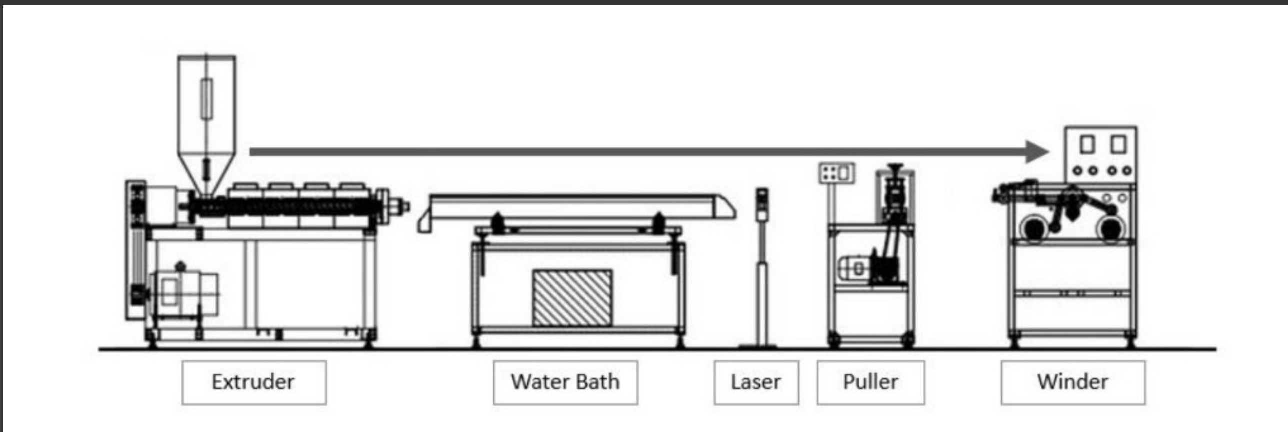
Here is my attempt at making a cheap home scaled extrusion line. Made with low budget and plastic recycling in mind. The initial idea was to end with a kind of cheap desktop filament factory, fully enclosed with air filtering… but as time goes on I share it as it is : a smelly garage recycling device !
Over that part, I’ll try to make you understand how 3D printer filament extrusion works inside of the industrial world and how we could do it on a similar way but at a smaller scale and with recycled material. I’ll try to explain my choices in the building process, in order to help you making something similar if not better. I will finally explain how to use and tweak that prototype assuming yours would work in a same way. Arduino’s source code and source files for 3D printed parts are also provided with that guide.

You can have a look at the projects linked below. Those are the main projects that inspired my build process :

- 3D filament factory by instructables user ianmcmill : https://www.instructables.com/Build-your-own-3d-printing-filament-factory-Filame/
- Lyman/Mulier filament extruder : https://www.thingiverse.com/thing:380987
- Filastruder : https://www.filastruder.com/
- Diameter sensor by thingiverse user ilornate : https://www.thingiverse.com/thing:636420

1. Understand the challenges of home recycled plastic filament production.

Industrial extrusion line workflow : What we try to imitate



Schematic of an industrial extrusion line.

Source : https://github.com/IC3DPrinters/filament-extrusion/blob/master/Open%20Source%20Filament/IC3D%20Open%20Source%203D%20Printing%20Filament%20Documentation%20Rev1.pdf

Here is how 3D printer filament industrial production works, from left to right.

1 Raw material (pellet usually) is feed to the barrel through a hopper.
2 An extrusion screw (special shape) pumps and compresses the raw material towards the end of the barrel.
3 The raw material gradually mixes and melts as the barrel is heated to a regulated temperature.
4 Melted plastic flows by a hole at the end of the barrel getting cooled down (by air/water) and pulled to the right diameter. A control mechanism ensures a constant filament diameter.
5 The filament is winded through a winding system.

Our cheap extrusion line works on the same principle, but because of recycling and in order to make it cheaper and smaller, there are some few things that differ. The less significant ones are that there is no winder and no active cooling system :

- No winder : filament just lay on the ground. I implemented an easy winder but as the filament still needs to be post-processed, it’s just useless for now.
- No active cooling system : I didn't want a water bath as it adds a bit more complexity to the build, and many others DIY projects use only air cooling path. I tried several air blowers but I had no success with them : filament’s shape was going oval instead of circular with a fan, or the nozzle got cooled to much and got clogged by cold plastic. Natural cooling is enough in my case if there is no quick temperature change or something that would blow on the hot filament by accident.

On another side, the most significant differences with the industrial process are :

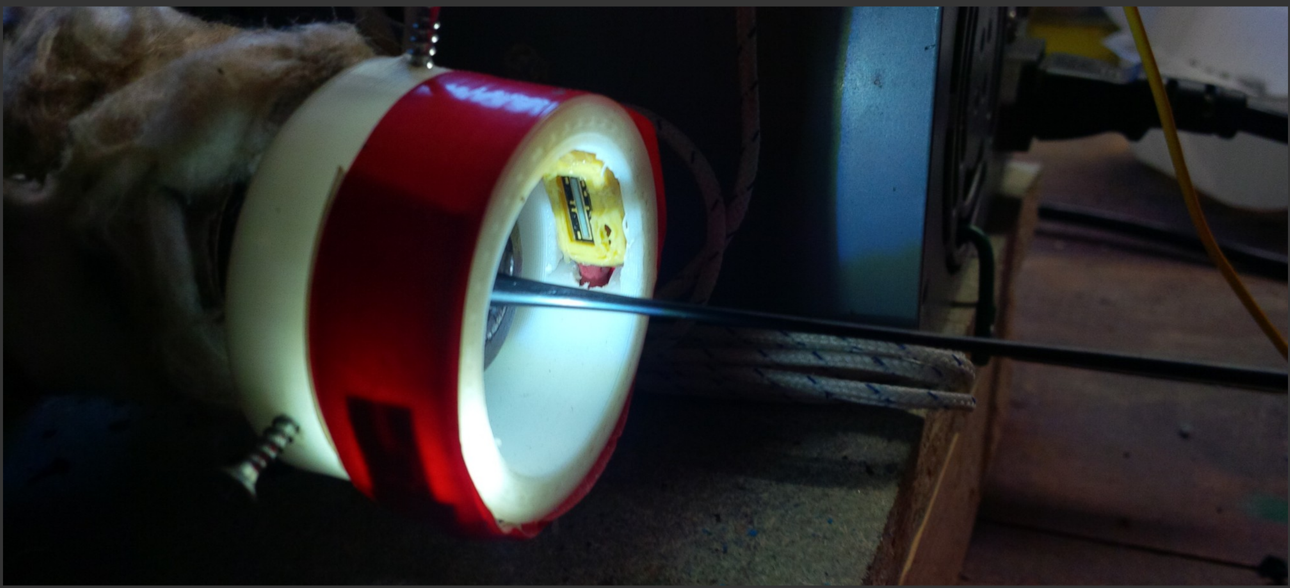
- We use rough plastic granules as feeding material instead of pellets which are much more homogeneous.
- We don’t have a proper extrusion screw but a wood drill bit instead.

This bring us to the main challenge of making 3D printer filament at home : **get a constant extrusion flow rate**. Let's dig a bit deeper into it.

The main challenge : Manage a constant extrusion flow rate.

A part of what makes 3D filament printing accuracy is tolerance of the filament diameter variations. The more accurate is your filament, the more predictable is the printer. Filament diameter changes will lead to under and over-extrusion while printing whit its related print failures (layer delamination, dimensional inaccuracy...).
So what affects the filament diameter? When hot plastic flows out of the nozzle, it gets pulled by a puller module. For a given nozzle output rate, a faster puller speed means thinner filament production.
The ground plastic is not as homogeneous as industrial pellets so it can go through the barrel more or less quickly. I mean, for one single rotation of the extrusion screw, the amount of extruded material will differ from another single rotation. While the puller module is pulling at a constant speed, the amount of extruded material varies over time, causing filament diameter to vary accordingly.
Moreover, industrial extrusion screws have a particular thread shape which gets thinner and thinner as we reach the screw's head. I don't know exactly why but this shape helps to get a more consistent flow rate.
So, in order to get a consistent filament diameter, we need to control the output flow rate. Let's see how.

A PID loop to stabilize the output flow rate.



Output flow rate measured by a related shadow on a pixel array sensor.

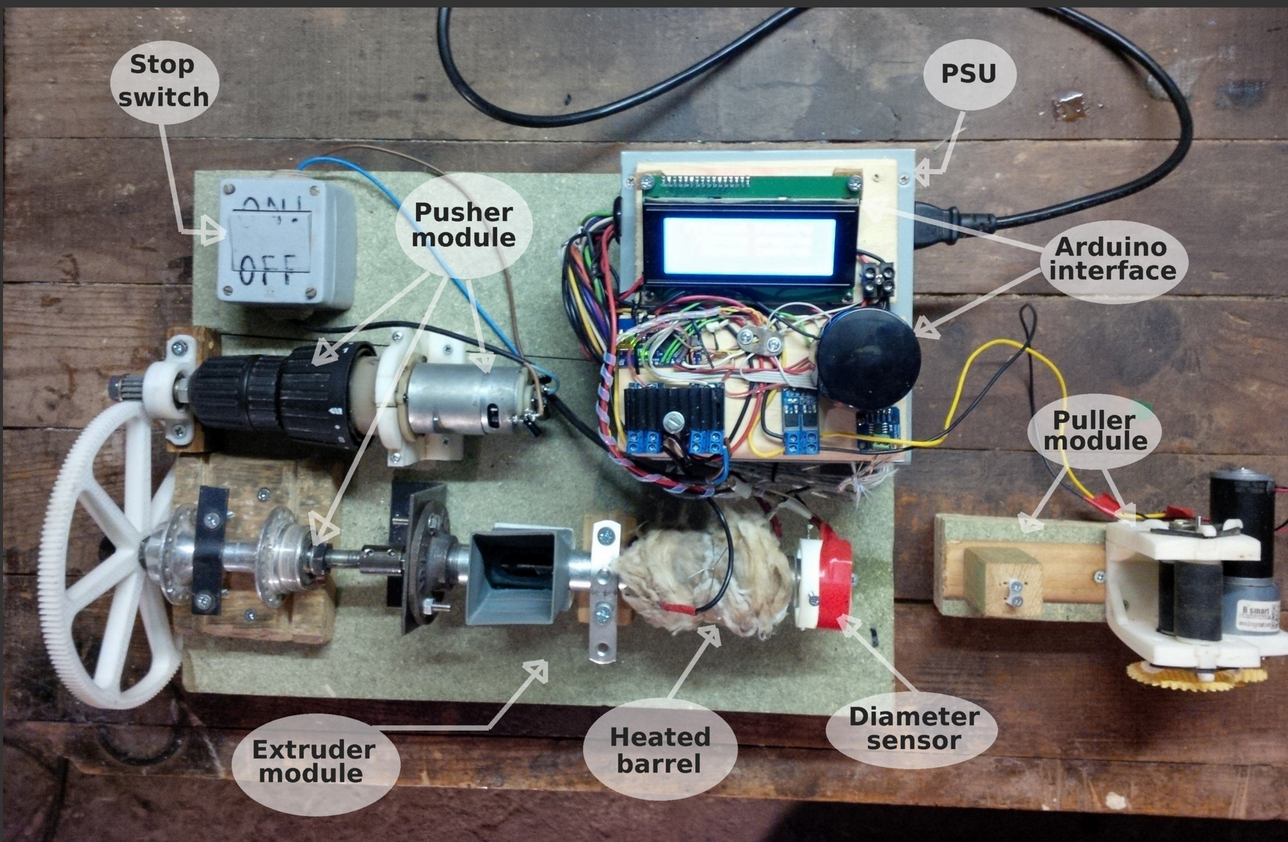
We saw that the plastic output flow rate of our extrusion line is varying because of inhomogeneous input material and not optimal extruder screw's shape, but there is an easy way to influence the output flow rate while extruding : changing the extrusion screw's speed !
The extrusion screw is driven by a geared motor (pusher module) : **By changing the pusher module's speed according to the measured diameter of the plastic output we can try to keep the flow rate as constant as possible.**

The extrusion line is controlled by an Arduino micro that can control the power given to the pusher motor. This is done using a small Pulse Width Modulation module (PWM). While extruding, the Arduino reads the measured output diameter. In fact, it counts the number of pixels of a sensor array that are in the plastic output shadow. Then it compares that value to the diameter target set by the user, applies some math according to P, I, and D values (set by user too) and increases/decreases the PWM output command of the pusher motor. For example, if the measured output diameter is lower than the targeted diameter, meaning the current flow rate is too low, the controller increases the pusher motor PWM command, and vice-versa.

I hope that you understand now why and how to keep a constant flow rate while extruding recycled plastic granules at home with a cheap equipment. Let's see below in details how mine looks like.

2. Overview of the extrusion line's components.

Here I want to give you some details about how the extrusion line is built. I will go through each part of the extrusion line, and explain why I came to that specific choice.
Except for the cordless drill motor and bicycle wheel hub, all parts needed to build the line should be easily available from internet (Aliexpress). You will also need some random pieces of wood, small metal plates and a bunch of screws. The whole system is driven by an Arduino Pro Micro. As I have almost no coding skills, I used only Arduino compatible electronic modules that were documented enough for me to integrate them into the project. Now let's have an overview and focus on each component.

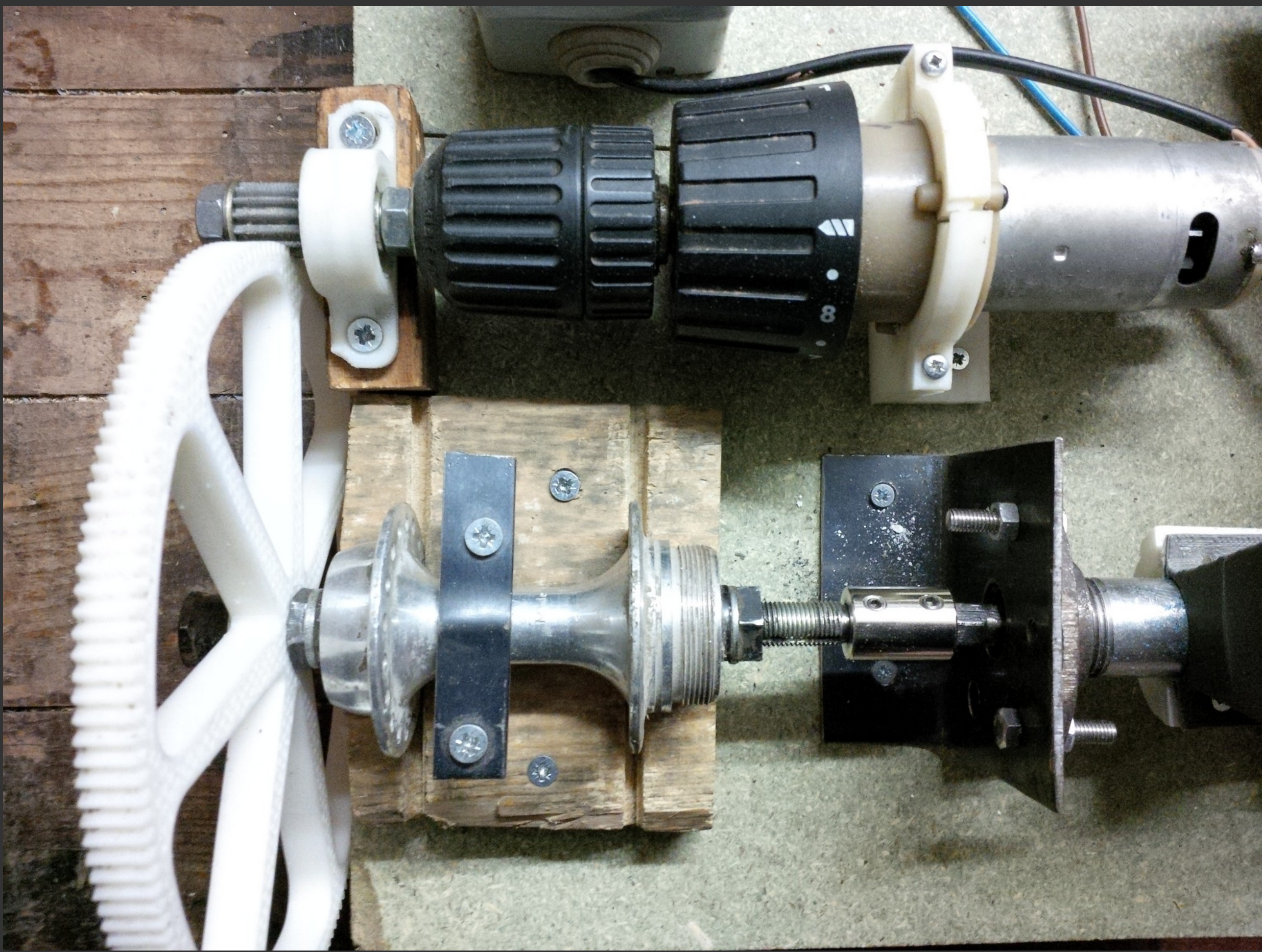


Cheap Arduino controlled extrusion line overview.

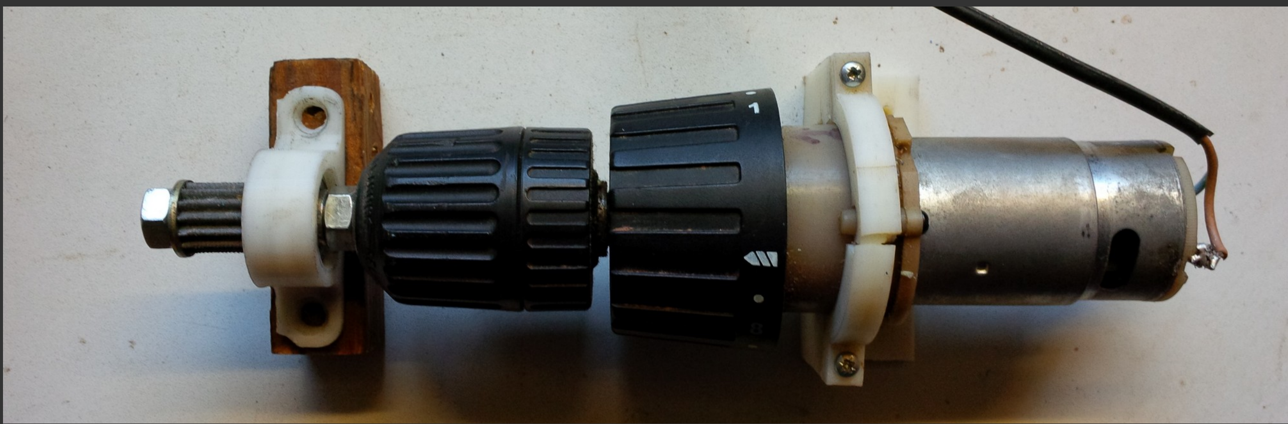
Power supply

The whole line is powered by an old ATX power supply unit (PSU). Easy to source from old computers, or brand new on the web. You got 5V to power the Arduino and sensors (also motor in my case) and 12V for other accessories. Also, the built-in over-current and short-cut protection are always welcome. To turn on that kind of PSU you need to connect a power signal cable to the ground. In my case it's the green one. Sometime my old PSU cut off : it can be because of overload but also because of not enough current draw on 5V output.

Extruder powertrain (pusher module)



This was the hardest part to achieve. As I wanted the extrusion line to be easy to make I firstly bought some geared motors from Aliexpress (JGB37-3157 for example). But it happened several time to brake a small gear inside the gearbox because of too much torque at the extruder's module. As I had this hand drill motor, I decided to give it a try and was very satisfied with the included overload clutch that could protect the whole mechanism.



Cordless drill motor, gear box, overload clutch and chuck.

Actual pusher module is made up of :

– Gearbox and motor from an old cordless drill. Powered by 5V from PSU, 12V was to fast and caused the PSU to shutdown (to much current draw).


Motor's filtering.

– Overload clutch (came with hand drill system). Set to minimal torque to prevent damaging the plastic gears and motor.

– 3 electrolytic capacitors to filter the motor's voltage rejection : the diameter sensor is very sensitive to voltage variations. The measured diameter was unusable when the motor was running without filtering. The 2 small caps are 47 µF 16V, soldered between the power cable and the motor housing (negative side), the big one is 470 µF 26V, soldered between the 2 power cables (negative side to negative power cable).

– 3D printed gear reduction. The big wheel is made from commercial ABS and the small one from recycled PP. Max speed of the screw : 12-15 rpm

– Security switch : allows to start/stop the motor whatever the Arduino's command is.

– Used bicycle wheel hub. Resists against the kickback force that occurs when the extruder screw is pushing the material. I tried also thrust bearings but that hub is strong, free and let remove the screw easily.

– Metal coupler. From now it is a metal one, the previous 3D printed PP exemplary did the job for a while but tend to soften at the contact with the hot extruder screw extremity.

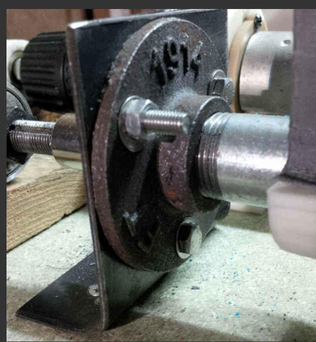
Everything is hold on a wood plate using 3D printed parts, pieces of wood or small metal plate and screws. A roller bearing fits the white support for the small plastic gear.

Extruder module

Extruder module with hopper, glass-wool isolated barrel, lead removed.

The extruder module is where plastic granules get mixed, melted, and finally extruded through the drilled barrel lead (nozzle). You can purchase all the parts on Aliexpress but maybe the pipes would be cheaper at your local store.

– 16 mm diameter wood drill bit, 230 mm long. The end of the bit was cut with a dremel and the entire screw was polished using sandpaper (but it worked also for a while without polishing it).



– Steel threaded pipe 1/2 inch (DN15, male, 20 mm thread), 200 mm long, 16 mm inner diameter.

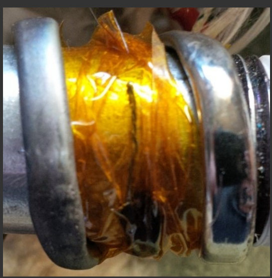
– Sharp pipe opening to eventually cut an unexpected big granule/shaving.

– Cast iron flange fixed on a drilled and bent metal plate.

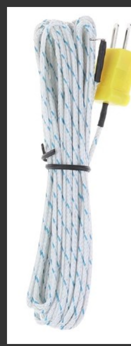
– 3D printed hopper (recycled PP). Small angle to prevent the material from getting stuck inside the hopper.

– Isolated heating barrel with glass-wool to help with melting the granules.


– Hacked 12V water boiler as heating element.



Isolated T° sensor.



– K-type thermocouple with MAX31855 ADC (Analog to Digital Converter). That sensor allows the Arduino to know the barrel's temperature and keep it around a value set by the user. The thermocouple had to be isolated from the barrel with kapton tape to work properly.

– Removable pipe lead drilled to 3.5 mm (DN15, female, 19mm thread).

– 3 loops of Teflon tape to avoid melted plastic to escape through the thread.

Things to help for more homogeneous output

– 5 to 8 mm free space between the end of the screw and the lead.

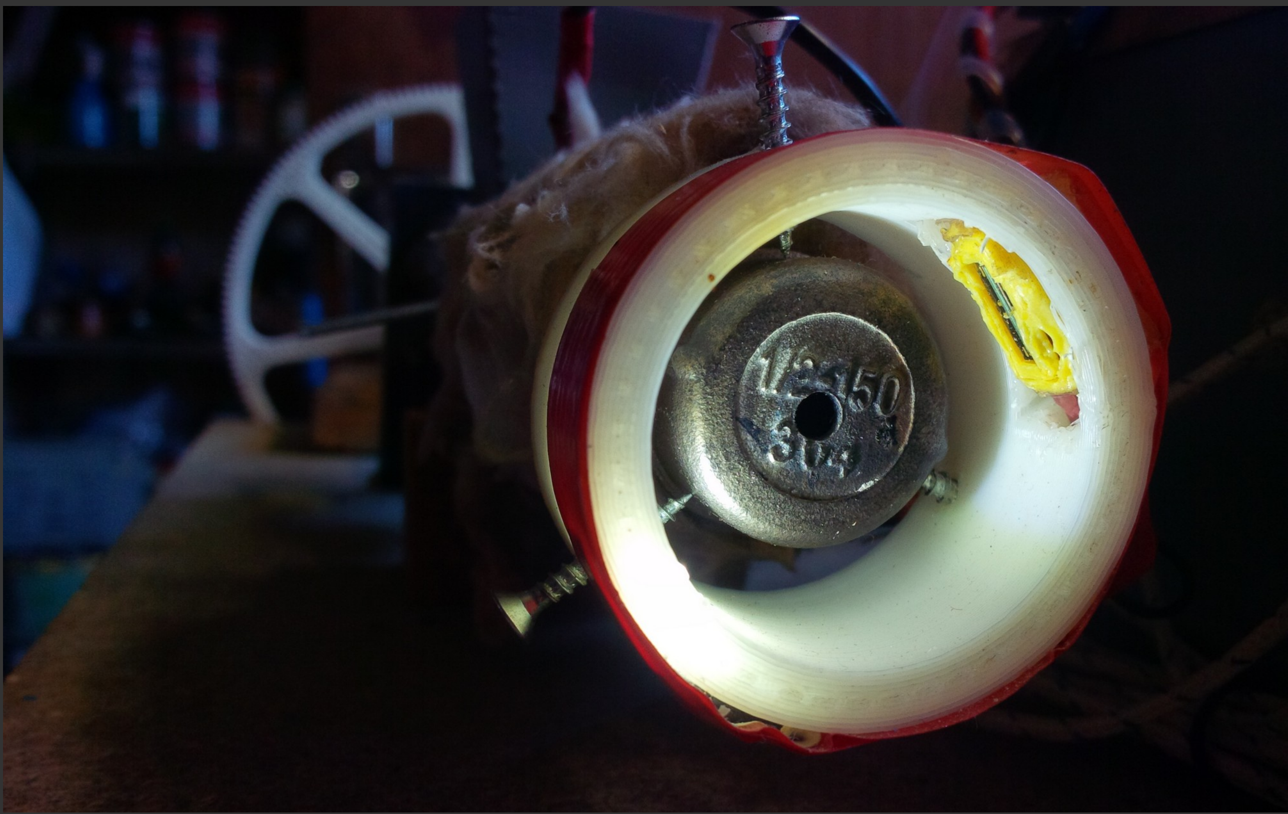
– DIY melt filter with some mesh (80 mesh size) wrapped around copper wire.

– Washer to keep some space between the filter and the outer hole.




Theses little things should help with mixing and evenly melting the plastic granules, more than just catching the dirt, the filter can break some bigger pieces of plastic that are no yet fully melted.

Filament diameter sensor



The optical sensor will be impacted by changes of the ambient light.

The diameter sensor allows the Arduino controller to “know” about the extruded plastic flow rate according to the size of a shadow projected on the sensor by the extruded filament. It features :

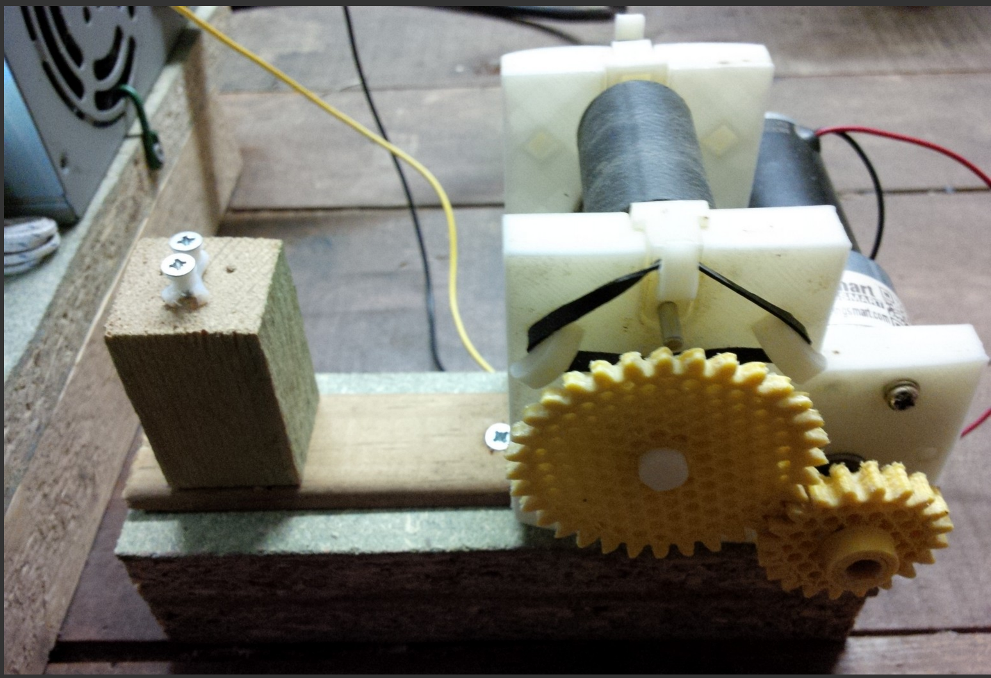
– 3 screws for a minimal heat transfer fixation and easy to remove sensor module.

– 3D printed housing.

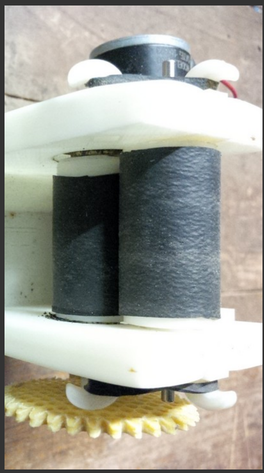
– 5v led from led strip.

– TSL1401CL line array sensor counting the amount of pixel under the shade of the plastic output. This sensor is a bit hard to solder because of its small size. I soldered very thin wires to the pads then gluing everything inside a 3D printed case.

Puller module



The puller module on wooden blocks to adapt its height.



The puller module is here to pull the extruded filament at a certain speed set by the user. The faster it pulls, the thinner will be the produced filament. What's inside ?

– 3D printed pulling cylinders, gearing and housing.

– Bicycle tire hub grip on both cylinders and elastic rings to press the upper cylinder against the lower one (the upper cylinder can slide up and down).

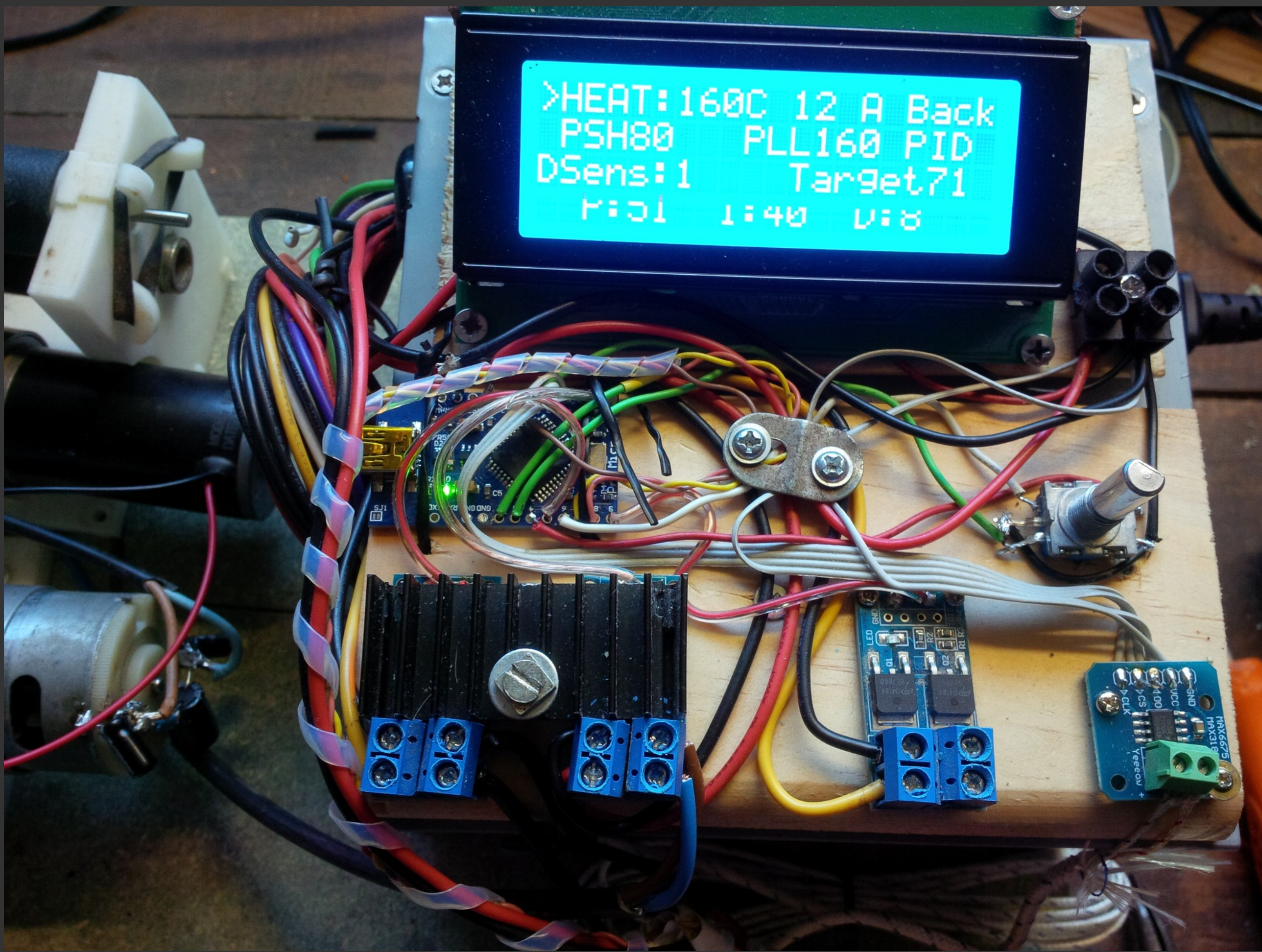
– JGB37-3157 gear-motor (smaller would be ok too).

– Small guide to keep the filament on a straight line (PTFE tube and screws).

– 2 roller bearings for the lower cylinder.

I like to be able to move the module closer or further to the extruder nozzle as there is an optimal distance according to the extrusion flow rate and temperature. To me it is optimal when the extruded filament turns solid just before reaching the small PTFE guide. Filament will be distorted if it reaches the guide while too soft, but on the opposite, placing the guide too far away from the extruder nozzle will tend to twist the extruded filament. A bit of tricky fiddling at this step.

Electronics and interface



A huge part of the electronics driving the extrusion line is fixed on that board.

Here is the brain of the extrusion line. What we have around is :

– An LCD 2004 with i2C interface (at the top). Cheap and well documented.

– An Arduino Pro Micro as main board (under the LCD's left corner). Small and cheap, with enough pins to connect everything. Uses Arduino Leonardo's target with Arduino IDE.

– A rotary encoder with build in push button (under LCD's right corner). Needed to navigate trough the user interface and change settings.

– A MAX31855 ADC (bottom right corner). Needed to interface the Arduino to the K-type thermocouple.

– 3 PWM MOSFET modules to power the heating element and motors (rest of the bottom area). The 2 ones on the left side are covered with a heat-sink. They drive the pusher motor and heating element and turn quite hot while the line is working. I've fried some MOSFETs before adding the heat-sink.

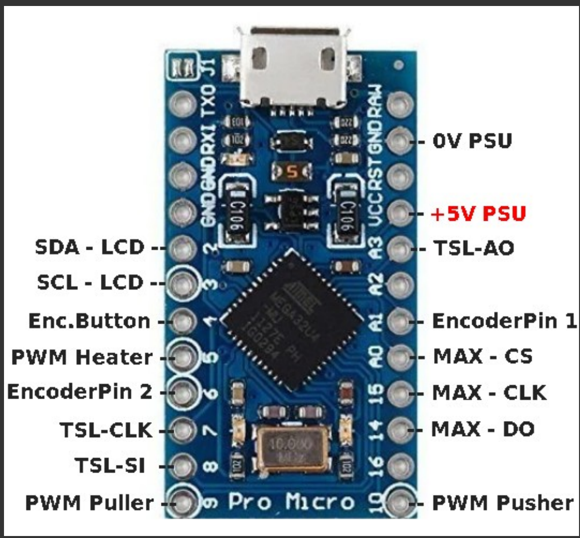
– And last, inside the Arduino's memory, a fully open-source copy-pasted code from many Arduino tutos, libraries and examples found over the internet, sticking together with some magical invocations...

…Well, to build the code, I started with a small step like how to show something on the LCD, then how to measure a temperature with the K-type thermocouple, and adding it to the previous code. Then, following with how to use a rotary encoder, then how to drive a motor with PWM… each time incorporating the new feature into a global code. The hardest part for me was the menu and controlling an arrow pointing to items while keeping everything running in the background like measuring temperature, reading sensor's value, changing PWM value… Hopefully you don't have to go through all those steps as the code is already there !

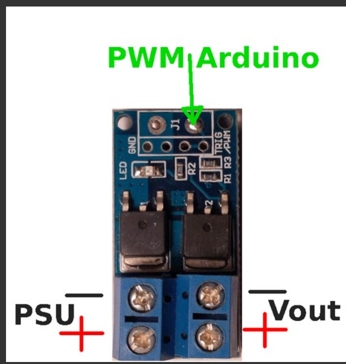
Flashing instructions :
Arduino IDE is well documented on the web. But to flash the code to the Arduino Pro Micro you basically need to install Arduino IDE on your computer, open one of the .ino file of the code's folder (it will open all the code's tabs into Arduino IDE), compile and finally flash. Search the web for tutorials to install and flash some example code on the Arduino. You'll need also to install some libraries so have a look at how to do it too. When you're ok with that, open the extrusion line arduino's code, check for needed dependencies (they are listed at the top of the main tab) and install them. Then compile and flash the code ! You just need to know that the Pro Micro target board for Arduino IDE is Arduino Leonardo.

Wiring details

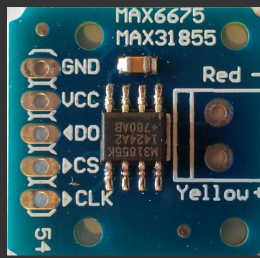
Here are some details about how to wire things together :



Pro Micro wiring.



PWM MOSFET Module wiring.

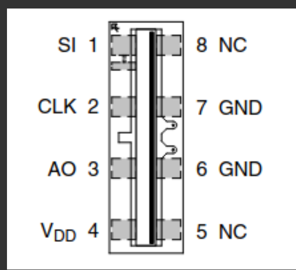


MAX's Pins.

PWM modules wiring : For each PWM module, you only need to connect Vin, Vout and the PWM pad (green arrow). Ground is already shared between the Arduino and the PWM module by the PSU 0V. Invert Vout wires if the corresponding motor is not rotating in the desired direction.

MAX31855 wiring : just follow the pins label. The module needs to be powered by 5V from PSU. Red- and Yellow+ are for connecting the thermocouple. You may try to reverse the sensor's wires if the temperature regulation is not working (+ and – were not labeled on my cheap sensor).

TSL1401CL wiring : Here is a **top view** of the sensor (transparency). But looking from **bottom** you can see those little pads. SI pad is kind of double to help with orientation. Just connect each pad to the corresponding Arduino's Pin (SI to TSL-SI and so one). Don't forget to power the sensor by 5V to VDD and 0V to GND. Other pads are not used. Good luck with tiny soldering !



Rotary encoder wiring : Easy. Connect the 2 GND pads together then to 0V PSU.

LCD wiring : Power it with 5V, and connect the I2C SDA and SCL pins to Arduino's SDA and SCL pins.

3. Start the extrusion line and tweak.

Here is a guide about how to use my cheap Arduino controlled plastic extrusion line. I assume you built a similar system using the code provided with this guide.

Starting and interface overview.

Check the puller motor switch is OFF, and power the PSU. The LCD should turn on and you'll see the main screen. Use the rotary encoder to move the small arrow and push the rotary encoder button to select an item. On the main screen you can manage presets or go to the control panel (Manual mode). On the first time you'd rather go to the control panel to set various parameters. You can go back to the main screen by selecting "back" on the control panel.

Main screen. (4th row is dying...)

To change the value of an item, place the arrow in front of it and click on the rotary's button. Then turn the encoder clockwise or counter-clockwise to increase/decrease the item value. One more click allows you to move the arrow again and select an other item. When you are happy with the parameters on the control panel, you can go back to the main screen and select "Manage presets" to save the current state of the parameters you set on a preset. Next start you'll be able to load it through the "Manage presets" panel. The interface allows you to load and save until 3 different presets.

Pre-heating.

Control panel. Last row : "P:0 I:0 D:0"

Before starting the pusher motor you need to preheat the barrel in order to avoid locking the screw with cold plastic. For that, set the "HEAT" item to the desired temperature, in my case 170℃ to 200℃ for PP, and 230℃ to 240℃ for ABS. Wait until you can melt some plastic you're going to extrude by pressing it against the hot end of the extrusion line. It can take up to 30 minutes. When beginning with a new material, set the temperature rather too hot until you can extrude some filament, and then slowly lower the temperature. Don't forget to have an organic vapor filter mask around to wear in case of odor. Breathing a small nasty vapor once is maybe OK but for sure on a long term it will affect your health.

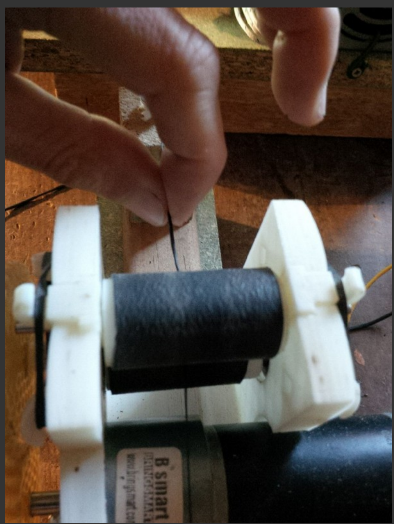
Manual extrusion to set rough parameters.

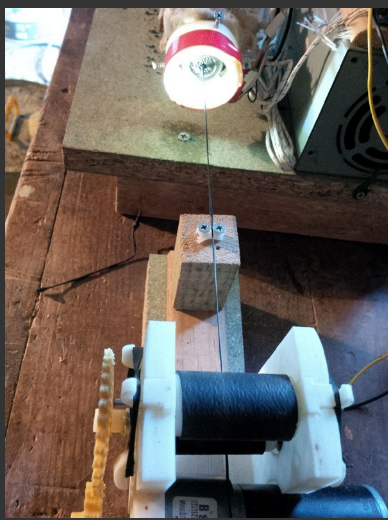
Melt some plastic on the nozzle to check temperature.

When the temperature is high enough to melt some plastic on the extruder's nozzle, select the "PSH" item to increase the pusher's motor speed to max (255) and turn ON the pusher module switch. The screw should start rotating. On the first start your should check that the overload clutch is set to the lower value to avoid destroying the gearing in case of too much torque on the extrusion screw.

Now you can feed some granules to the hopper and check that they get pushed through the barrel. It takes a while until the granules get compressed and reach the end of the barrel. Be patient and look at the overload clutch. It could activate for example if the internal temperature is still to low.

When some melted plastic starts to flow from the output nozzle, switch OFF the pusher motor and increase PLL speed from the control panel. I first set PLL to a rather too high speed and go down slowly when the line is started. Slow down PSH speed to around 180 and switch the pusher motor ON again. With your fingers or pliers (Caution it's hot !) take the outgoing plastic and pull it to create a thin line. Cut the big end of this line and feed the filament between the two rolls of the puller module. This must be done fast enough. If everything goes well your extrusion line is started ‼





In a perfect world this should be enough to produce some 3D printer filament. Pusher motor's speed affecting the filament production rate and puller motor's speed setting up the filament's diameter .... But no ! We need to control the flow rate in order to get more accurate filament diameter. And this is the next step.

Setting up PID loop to get more accurate filament.

As you may try yourself, running both pusher and puller motors at constant speed leads to high variations in the filament diameter. Let's set the PID loop in order to reach a more constant extrusion flow.

When the line is started and working in manual mode, look at the “Dsens” value on the Manual control panel of the LCD and estimate it’s average value. Set the “Target” value to this average. When activated, the PID loop will try to keep Dsens value as close as possible to the Target value by increasing/decreasing the pusher motor’s speed. You need to rise above 0 at least the P value on the control panel for the PID loop to be able to change PSH value. Then, to activate the PID loop point the arrow on the control panel to “Man” and Click the encoder. “Man” should be now turned into “PID” and PSH value should be moving between 80 and 255.

Now you can start playing with PIDs gains. Have a look over internet to understand how PIDs work. That’s what I understood until now :

P is for Proportional : it plays on the output according to the error. The bigger the error between Dsens and Target values is, the higher/lower will be set the pusher’s speed. Increase P for higher change.

I is for Integral : it plays on the output over time. As time is going and the error maintains or increases itself, the I will increase the output (pusher’s speed). Increase I for quicker change.

D is for derivative : it tries to avoid overshooting the target with some magical future prediction (something about how fast the error changes). I add some like adding salt to a cake (don’t know if it’s enough or useful yet). Way for improvement here...

What is important to understand is : when your pusher motor is going to max then to min, max and again, that means you have too much of P, I, and/or D !

I’ve noticed also that sometimes while extruding, I was slowly increasing P, I or D getting better accuracy over time and suddenly there is a huge flow rate change and the PID loop gets lost shouting at pusher module to max and min. So I keep it now with a weaker flow rate adjustment but less prone to break in case of a flow rate drop.

Save and load preset.

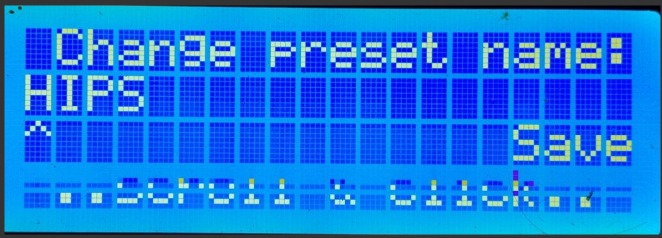
Manage preset Panel.

When you are happy with a configuration you can save it to Arduino’s internal memory. Go back to the main screen and select “Manage presets”.

Load a preset.

You can now load/save on one of the three preset slots. When loaded, a preset will apply the stored values to each item of the control panel (Heat temp, PLL value, Man or PID mode...). The

PID values are loaded too but they need to be selected, changed (1 unit) and validated once again to be taken into account by the loop.



Save a preset.

While saving a preset, you can change its name : select a letter or empty block and scroll with the encoder to the desired character, validate and go to another block in order to change its value. Move the arrow to “save” and click to save the preset under that name.

Using tips

Here are some tips to help with the use of our small extrusion line.

Empty the extrusion line before stopping the system. Why ? to avoid some plastic to slowly melt and cool down inside the screw in an area not reached by the heat when the screw is constantly bringing new and cooler material.

The diameter sensor must be as close as possible to the output hole, as it will “read” faster a change in the flow rate leading to a better PID loop accuracy.

Check for proper alignment/distance between nozzle hole and puller guide/cylinders. The right distance between puller module and nozzle is the closest possible with cold filament on the puller guide.

Activation of the overload clutch could mean :

- Melt filter clogged by dirt.
- Too cold extrusion temperature.
- Big plastic granule at the entrance of the barrel.
- Screw/barrel/bicycle wheel hub misalignment.

Bubbles inside the produced filament usually means moisture inside the extruded material (need to dry more). It can also be caused by a too hot extrusion temperature and that plastic is starting to disintegrate.

Produced filament with oval shape could mean :

- Too hot extrusion temperature.
- Uneven cooling of the filament. (Fan on PP filament output for example).

Cleaning the extruder module.

You'll certainly have to open your extruder module to clean the screw or melt filter. When experimenting with temperature, it can happen that hot plastic comes to a cold zone of the screw (closer to the hopper) and get solid here, stopping the not-yet melted granules to go further. In that case you would need to open the module and clean the screw. But you would also do it when changing your type of plastic extruded.

If possible, you may extrude all the plastic inside of the extruder module before to open it. But if the extruder module needs to be opened and the hopper is still filled with plastic granules, you can empty it by rotating it around the barrel.

Rotate the hopper to empty it.

While mounting, you may tighten the nozzle when the barrel is cold. Heat up the barrel to loosen it.

To remove the screw from the barrel, remove the nozzle and loosen the coupler. Then you can push the screw through the barrel. Plastic needs to be still hot to not stick everything together.

It's also easier to clean the screw while the machine is still hot (but take care : it's hot ‼). You can scrap the screw with a screwdriver.

Removing sticky plastic with a screwdriver.

Using the screw to clean the barrel.

Once done you can heat the barrel again and use the screw to remove most of plastic remaining inside the barrel.

I clean the nozzle lead and melt filter by placing them into the fire for a while.

Part. III : Print some stuff with your recycled filament

Ok so you got fresh recycled filament, let's print stuffs with it ! But before we need to prepare it as the extrusion line is not yet very accurate.

1. Check and post process your just extruded recycled 3D printer filament.

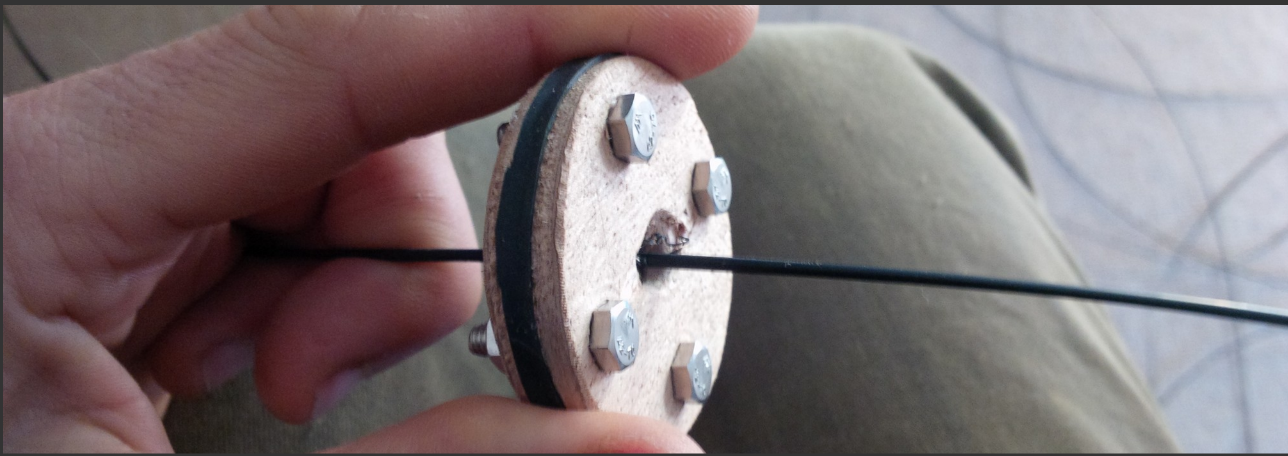
Filament post-processing.

Because of not being accurate enough, our small extrusion line produces a filament which is sometimes too thin, sometimes too thick comparing to what accurate commercial grade filament is. That's OK if you don't print pieces with too much details, but sometimes the produced filament is even not accurate enough to be used by the 3D printer. It could be so thin that the extruder gear couldn't grab it or so thick that it would just get stuck somewhere in the bowden tube or cold zone of the print head.

Thin filament :

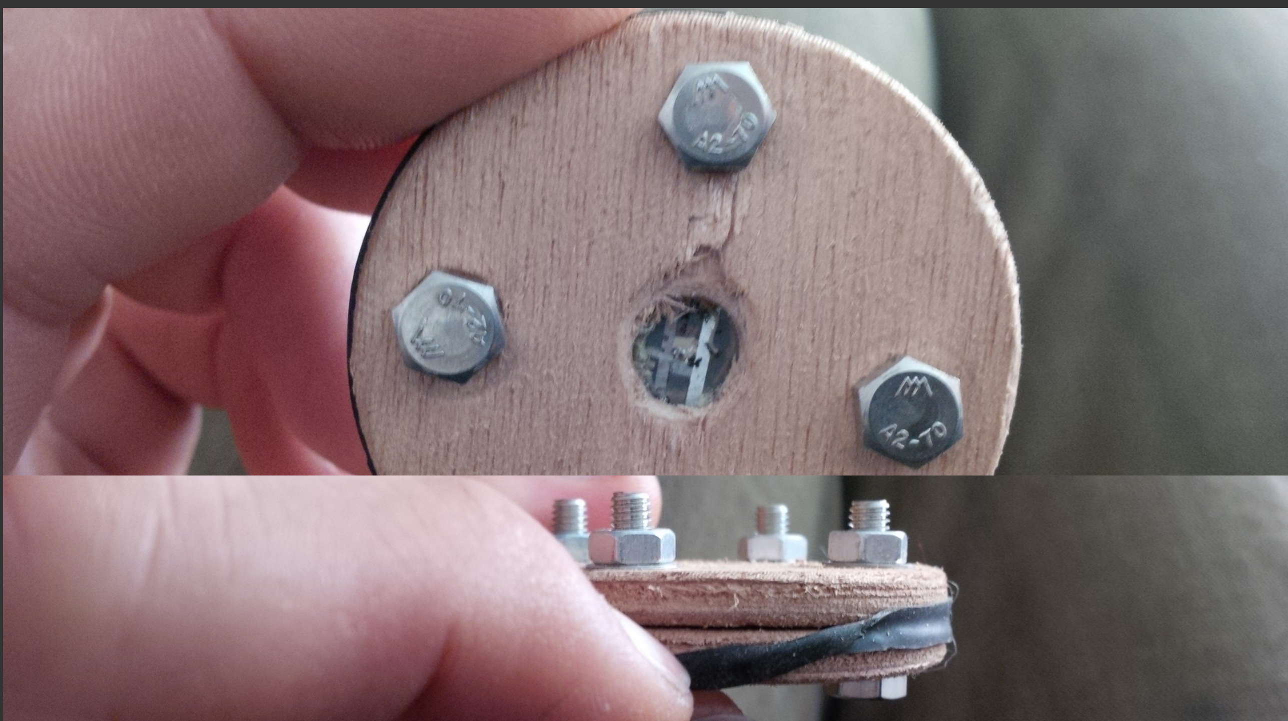
On my side, I try to remove all filament that's less than 1.5 mm diameter. As I don't print large objects often, I just cut the portion of line that's too thin keeping the good part for printing small objects. If I need longer piece of filament I use a candle to melt and connect by hand two pieces together (removing the "soldering blob" with a knife).

Thick filament :



Filament post-processing tool.

I use that home-made tool in order to shave the filament when it gets too thick. The tool is made off two pieces of wood with a hole at the center of both of them. These two pieces are connected together with bolts. Between the two pieces of wood, 4 cutter blades are carefully placed facing each other. I used a commercial filament sample to place them and then tight the bolts. That tool will remove the excessive amount of plastic on the filament going through the hole. When it stops because of too much plastic to remove I use a cutter blade directly by hand to shave the filament a bit more. When it’s done you can double check by pushing the filament through a bowden tube and see if there is any hard spot.



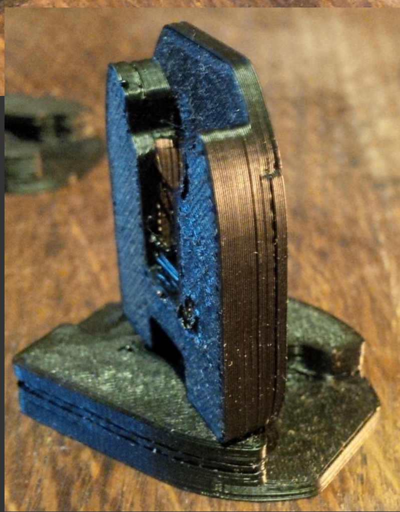
Cutter blades facing each other at the center hole, cutter blade slot.

2. Print it !

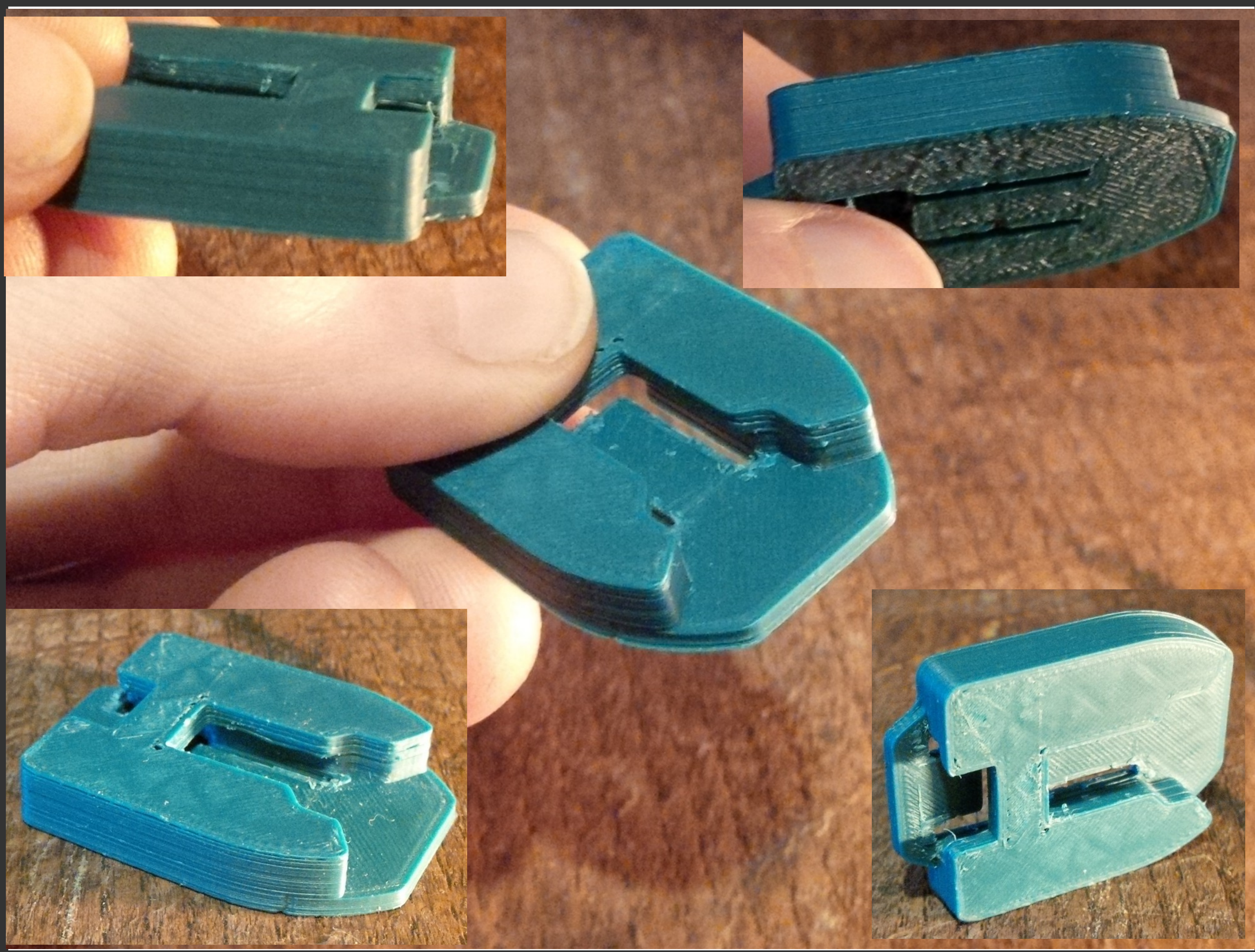
Nice post-processed filament. Ready to print !

Once you've got your ready-to-print filament it's time to experiment with some print jobs. I used all my filament sample made for documenting the project on tuning print parameters to achieve an almost acceptable printed part. This was my first attempt at printing recycled ABS.

Many samples to achieve bearable print quality with a new material.



The last black part have still some under-extrusion or layer bonding imperfections. As I had no more black filament left, I made another test print with another ABS recycled sample produced by myself too. Setting up a thinner filament diameter in the slicer was the key to obtain a nice layer bonding.



First quality print with recycled ABS filament. Looks promising.

Here are the main print parameters used to print the blue part :

Printer : Geeetech A10 enclosed.
Bed temp : 80℃.
Hot end temp :235℃ (245℃ on first layer).
Fan OFF (even for bridging).
Filament diameter : 1.55 mm.
Layer height : 0.2 mm (first layer 0.3 mm.)
Support : yes.
Print speed : 40 mm/s.

The two last parameters I changed to achieve a satisfying result were turning the fan completely OFF and reducing the input filament diameter to 1.55 mm. Fan ON was producing poor layer adhesion on the layer with a bridge. And even if my average filament diameter was around 1.7 mm, I still had to set it down to 1.55 mm in the slicer to avoid under-extrusion.

Ways for improvement

Still reading around ? Wow ! Congratulations ! Then you might be interested in my thoughts about improving that process… Here we go.
The main challenges that I can see with that plastic-recycling-into-3D-filament home scaled process are the followings :

1. To improve the output diameter consistency : no more post-processing, better print quality.
2. To minimize leftovers from shredding : no wasted material anymore, better recycling time efficiency.
3. To adapt 3D printing to recycled filament (recycled PP for instance).

Let see how it could be done.

1. Improve the diameter consistency.

The diameter consistency is one of the keys for accurate 3D printing. We've seen that my process is currently not able to produce a filament with the similar diameter tolerance of an industrial new filament. I think that increasing the accuracy of the control loop would help. This could be done either on the sensor or on the motor side.

Diameter sensor accuracy.

The diameter sensor used for now has a 128 pixels resolution. During extrusion, an increase or decrease of 1 or 2 pixels of measured output diameter causes an increase/decrease of the filament diameter that's visible just looking at it. I mean, the PID loop using that value as an input have a very small range : 1 or 2 pixels under or over the set point is already too much on the result (quite visible diameter inaccuracy), but certainly not enough to get a smooth response of the PID loop.
Using a wider sensor array further away from the filament would create a bigger shadow variation (kind of zoom effect) on the sensor. So, a real diameter variation that caused an increase of 2 pixels on the small sensor would produce now bigger increase (20 pixels would be perfect but not sure it's possible).
Another way to improve the sensor accuracy may be to use a different way of counting : for now the program counts each pixel that's under a certain amount of light. The variable "shadstep" allows the user to set that amount of light. If 85 pixels of 128 are under "shadstep" value, the measured diameter will be 85. Using a second variable with smaller value and counting as "pixel decimal" could improve a bit the measured value precision… needs to be tried to get an idea.

Speed controlled motors.

On the other side of the PID loop is the pusher module's speed. For now the PID loop increases or decreases the PWM command of the pusher motor's MOSFET driver's. But the PWM output is not directly coupled to the screw's speed. I mean, for a fixed PWM value, when the force going against the screw's rotation is changing, its speed is also changing, leading to a modification of the plastic flow rate. A possible improvement would be to use a speed sensor somewhere on the pusher's module and another PID loop to properly control screw's speed, and setting the screw's speed as an output for the PID loop controlling the diameter.

2. Minimize plastic leftovers.

As you may have seen by reading the grinding section, my current process produces quite a lot of plastic leftovers that can't be fed to the extrusion line. Those plastic parts are still too big to be fed into the extrusion line and too small to be processed with the electric hand plane. One could try to regrind those leftovers using some strong food grinders. Here are two YouTube examples :
Corn grinder DIY version : https://www.youtube.com/watch?v=rYSs3_nIcQQ
Dry bean, seed grinder : https://www.youtube.com/watch?v=-PwebNiBWdg

3. Improve PP printing.

Finally, all this guide was made while doing my first try with recycling ABS. But during the last years I was only playing with PP. I lately wanted to try ABS as PP was hard to print, especially with big pieces. The main difficulty I'm facing with PP is warping. I did try to heat the bed up to a point where PP was too soft on it and still warped by colder upper layers. I tried also to heat the printer's enclosure to 60-70℃, until the filament at the extruder's gear was so soft that it couldn't get pushed through the bowden pipe and would escape between the gear and pipe. I'm thinking of enclosing and heating only the print area with some sort of flexible/articulated walls… but that's another story… Thanks for reading.