3D PrintEarth: A Delta Robot as a 3D Printer with Scrap Plastic as its Printing Material

By: Team RAL

I. Abstract

This project is a feasibility study of 1) a cost-efficient delta 3D printer made from scratch, and 2) the use of plastic smelting to recycle scrap plastic into 3D printing filament. The objective is to hopefully develop a way to make 3D printer technology more affordable, while also reducing plastic waste generation in the process.

II. Problem Statement

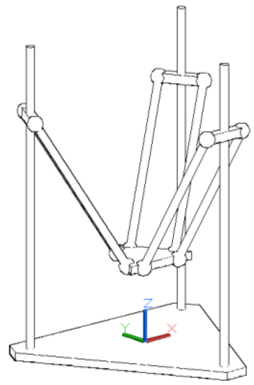
3D Printing is the future of manufacturing. It allows users to create virtually anything. What's holding it back though is that it's not accessible to the average person --- it's too expensive. In addition to the cost of thousands of dollars for the 3D printer unit itself, the plastic filament is quite costly, reaching prices up to $70/kg (roughly P5600/kg). While 3D printing has so much potential to change how people live, it's unlikely to happen if the prices don't drop soon.

Another problem addressed by this project is the alarming rate of waste generation in the Philippines. Even as early in 2011, our country produced a total of 35,000 tons per day, 16% of which were all plastic. Considering that plastic is non-biodegradable, 5,600 tons of plastic per day is frightening, to say the least. The worst part is, our waste management programs currently are not that well implemented, and so majority of these wastes end up in our sewers and rivers.

III. Conceptual Framework

- Delta robot

  Invented by Reymond Clavel in the early 1980's, the delta robot is a type of parallel robot with three arms. Because of its unique topology, it is said that it is the fastest robotic manipulator structure today. Because of this, it has been used in many applications, such as factory assembling, robotic surgery, and most recently 3D printers.



(The linear delta robot topology)

- 3D printing (fused deposition modeling method)

(A delta 3D printer printing a bust model)

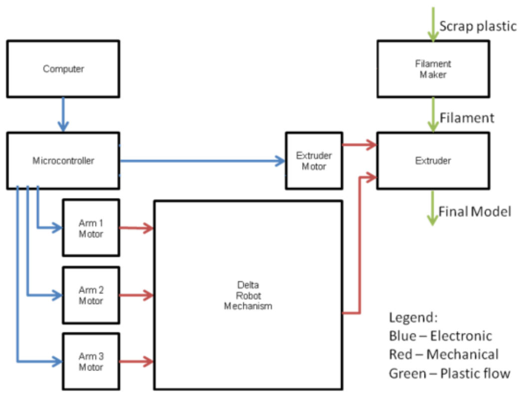
3D printing is not a new technology. In fact it has been around since the 1980's. The reason it only became popular now is because of the fused deposition method (FDM). In FDM, a robotic manipulator is used to actuate an extruding element. While this extruding element ejects the printing material (usually hot plastic), the manipulator moves around to trace the model's shape. The printer does this one layer over another, hence the term deposition, until the physical model is finished.

- Plastic smelting

There are numerous ways to manipulate plastic, including machining, vacuum forming, molding, and the previously mentioned 3D printing. One simple way yet underestimated method however, is by means of smelting. Similar to iron smelting, it's the process of heating up plastic into pseudo-liquid form, and working it into the desired shape. The melting temperature varies as different kinds of plastics are used, so heat regulation is important. It must be noted though that the plastic shouldn't be exposed to direct fire, as that would result in releasing chemical gases and fumes.

IV. Prototype Description

1. Block diagram



- Electronics

1. Computer

   The printing process starts with the computer, where the design is sketched or downloaded. The models can then be prepared for use with most 3D CAD programs such as AutoCAD and OpenSCAD. After importing the designs into the .STL format, a Python program then processes the design for the actual 3D printing. Finally, it sends the required information via USB/RS232 to the microcontroller.

2. Microcontroller

   At the heart of the electronic circuits is an ATMega328P microcontroller. Stored in its 32KB of flash memory is the firmware coded in C code. With 20 GPIO pins, the microcontroller can interface with the other parts of the printer, such as motor drivers, an LCD display, sensors, switches, and the computer. Running at 16MHz, it's guaranteed to run smoothly and with precise timing.

3. Motor drivers

   To fully drive the 12V stepper motors, a L298N dual H-bridge was used to energize the motor coils. A 74LS194 bi-directional shift register is then connected to the H-bridge to allow smooth motor rotation in both directions. To regulate the torque output and heat generation of the driver, a PWM signal is used to control the duty cycle of operation.

4. Extruder driver

In addition to the stepper motor driving the filament, a UA-SH-105D 5V relay is used to turn the heating element on and off. This is done to regulate the extruding temperature to the desired level, which is around 200°C for PLA plastic. The heating element to be used to melt the plastic is a hacked 220V 40W hot glue gun. The chosen filament diameter was based on the glue gun's feed diameter.

- Mechanisms

1. Linear actuators

   To simulate the motion of linear actuators, the stepper motors drives the 608ZZ ball bearing pulley with the GT-2 timing belts, to which is the carriage mounted to. Using LM8UU linear bearings, the carriages are mounted on parallel aluminum cylinders, thus allowing the carriage to move up and down the beams with high precision.

2. Universal joints

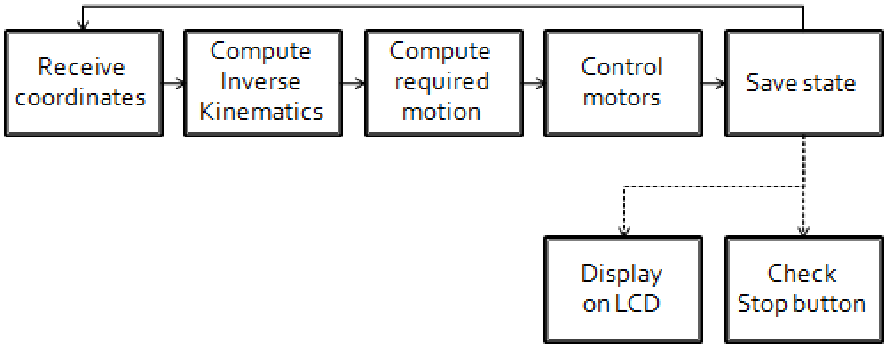
   An essential part of Clavel's delta robot design is the use of universal joints. These are joints that constrain the motion to 2 degrees of freedom (DOF), to be specific, two intersecting axes of rotation. By having 3 parallel arms made of dowel wood, the whole manipulator is constrained to translational motion (3DOF). All of these joints are implemented with 3D-printed Hooke's joints, held together by nuts and bolts.

3. Printer body

   Majority of the printer is made with ¾" plywood, including the base, the frame, and the platform. Everything is held together by steel angle girders and wood screws. As for the printing bed, 1/8" tempered glass was used.

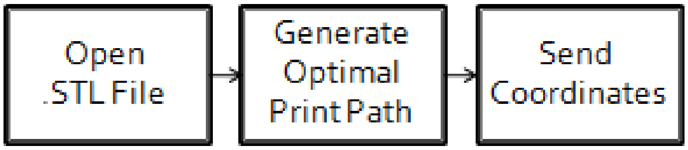
2. Flowchart

- Microcontroller C code algorithm



As the heart of the printer, the microcontroller is expected to perform everything. It takes in the desired manipulator coordinates and drives the motors to reach the new position. Further tasks are displaying text on the LCD display, waiting for button presses, reading limit sensors and controlling temperature.

- PC Python code algorithm



The PC's job is more straightforward. It opens the prepared .STL file and computes for the path to be traced by the printer, to be sent to the microcontroller via USB/RS232.

3. Illustration

(The plastic to be used)

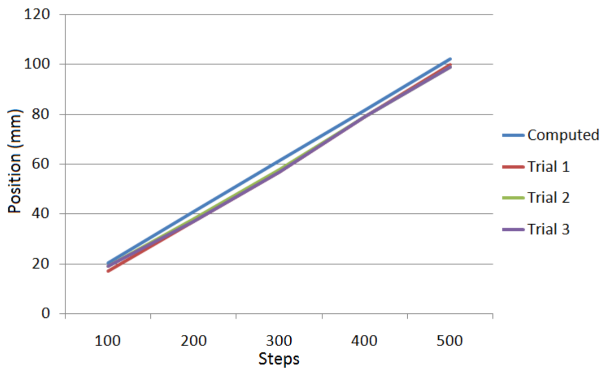
(The smelting process)

(The heating element with the plastic filament)

(The hot end mounted to the delta robot end effector)

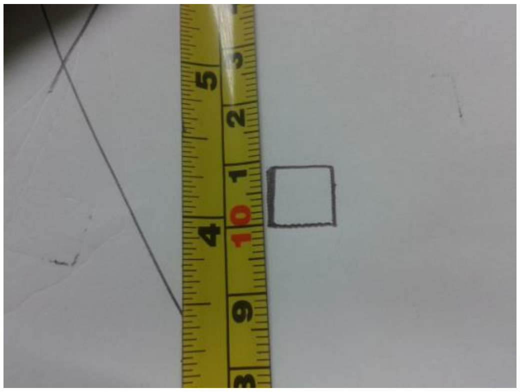
V. Test Results and Discussion

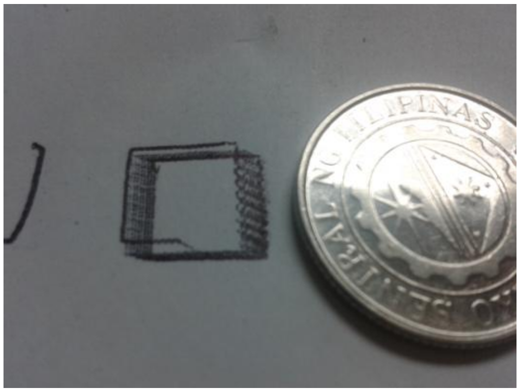
- Changes in design
  1. The initial design included a way of producing the plastic filament automatically using a machine. However, upon looking at the different consistencies of scrap plastics, this stage was scrapped and filament production is now done manually to ensure consistent filament.
  2. Furthermore, the previous design also had an extruder motor to eject the molten plastic. While this contributes to the liquid plastic flow, it is optional for most kinds of plastics, as molten plastic tends to ooze out on its own.
- Performance
  1. Accuracy



Aside from an offset in the carriage position and input (which was later resolved using a tighter timing belt), the final precision reached up to 0.2mm. This resolution is only for the linear actuator. Since the delta robot is a parallel manipulator, the resultant precision would be much better, as errors would be reduced drastically.

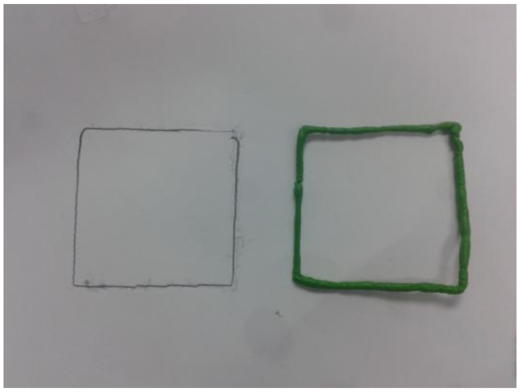
The following picture shows a square of length 1cm repeatedly printed on paper. As seen in the picture, it indeed measures 1cm. Take note, this square is repeatedly printed on itself, meaning that the repeatability of the manipulator is quite impressive.





Another test, as shown in the figure above, tests the precision of the manipulator by printing squares that are slightly apart. As comparable with the 1 peso coin, the offset between the squares prove the high precision of the printer, with a visible offset of about 0.1mm.

2. Print quality



As seen in the photo above, the accuracy with printing is still high, as the printed plastic is almost the same as the printed paper. It’s not as accurate as printing in small squares because this is printed in a very slow motion.

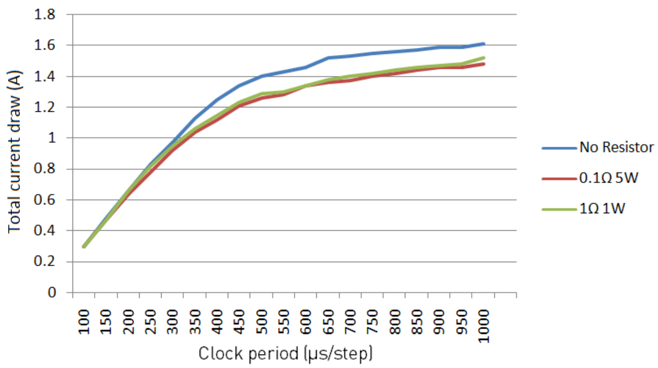
Unfortunately, the extruding of the filament did not work as expected. The resulting filament was too wide, causing the plastic inside to not heat up as the outer plastic did. The result is that the plastic came out too slow and too cold, ending up in blobby and messy prints. This can be fixed in future tests by using a hot end with a smaller feed diameter and/or a higher power rating.

In addition to the blobby extruding, the printed pieces seem to have warped as it cooled, especially along the bottom. This is because the printing bed is at room temperature, and that the pieces have cooled down too fast. To solve this in the future, a heated bed can be used to print plastic, in order to control the cooling time of the plastic.

(warped 3D printed 4-level rectangle)

(3D printed 2-level letter P)

3. Power consumption



Upon running the motors at rated voltage (12V), the current draw reached up to 1.6A. With a total of 3 motors, it would reach 57.6W consumption. Upon further testing, the final operating voltage was set to 5V, with a resulting current draw of 0.8A. This lowers down the power consumption for the delta robot alone to 12W.

The hot-end used was a hacked hot glue gun with a power rating of 220V 40W, although for future tests, it may be better to use heating elements up to 100W.

4. Cost

With cost of 3D printers and 3D printing filament being an objective in this project, it is important to analyze the costs involved.

- Printer

  The whole 3D printer cost P15,000 to P30,000 (cost to be finalized). Comparing to a few commercially available products:

Ultimaker 2	$2,600 or P130,000
Replicator 2X	$2,399 or P119,950
Ditto +	$1,249 or P62,540
CD-R King	P100,000
3D PrintEarth	P15,000 to P30,000

  Judging by the sample of prices above, it would be safe to say that our printer is a lot more cost-efficient compared to the ones in the market today.

- Filament

  Just to mention the current price of 3D printing filament:

ABS or PLA plastic	$40 to $70
3D PrintEarth filament	free

VI. Summary and Conclusion

Using a delta robot for the 3D printer turned out to be satisfactory. Based on the precision tests, it has a resolution of 0.1mm or better. As for printing with the recycled filament, much can still be improved. More research and planning should be done on what kind of plastic should be used for filaments, and the conditions and setup to be used in printing.

Generally, this printer has been very cost-efficient. Aside from saving a lot from building from scratch and with locally available parts, the filament really saves a lot. If this filament were to be used to recycle waste plastic in bulk, it would probably affect our economy and environment significantly.