3D Printing Laboratory Manual

Introduction to Product Development and Management for Engineers
GNG 2101
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Objective

To utilize 3D printing technology to accurately produce and prototype components for use on a small electro-mechanical system, as well as investigating the strengths and limitations of this manufacturing process.

Background

3D printing, or additive manufacturing (AM) is a manufacturing process involving depositing material onto a build surface in layers, to construct a three-dimensional shape. This technology was initially developed in the 1980's for use in industry, but during the past decade printers targeted toward desktop/personal use have been produced by companies such as Ultimaker and MakerBot Industries.

The concept behind printing a 3D object is fundamentally straightforward. By dividing a component into thin layers, a 3D shape can be represented by multiple 2D images stacked in the correct order. 3D Printers utilize an onboard controller to control the printer head and build plate in order to print each 2D layer in the right order and position. In addition, most 3D printers have downloadable software that allows a user to position a 3D model on a virtual build platform, as well as adjust the printer's settings for the build before sending the data to the printer. Theses 3D models used by the software can be generated using CAD (computer-aided design) methods, laser scanning, or photogrammetry, although the CAD method is usually the most accurate.

Modern printing technology has enabled the accurate printing of nearly any shape in a wide variety of materials, with many different printing methods to choose from. Selecting a print method will depend on the application, material, and budget used. Materials vary from almost any metal alloy, thermoplastics, ceramics, paper, edibles, rubbers, and clay. Printing methods include extrusion (heating material and forcing through a nozzle), powder bed (placing powdered material and using adhesive or melting to attach), and light polymerized (using light to polymerize material on a build plate). Some build settings allow for otherwise difficult geometries to be constructed more easily using supporting structures, although sometimes this compromises surface finish. Rafting or brimming structures are used to help keep large flat builds from detaching from the build surface (usually from heat stress) by placing material under the first layer of the component. Supporting structure can be added to builds to ensure that overhanging areas have a surface to print material on to, and to ensure that the part does not sag or collapse during cooling. All of these supporting structures are detached and discarded once the print is finished.

The type of printer, and the options that are fitted to the printer, determine the capabilities in terms of accuracy, speed, and complexity a printer is capable of. The printer extruder and nozzle combination will dictate what materials the printer is capable of using. Multiple extrusion heads enable for different materials to be used during the same print and are common on more commercially-targeted products but can also be fitted to high-end personal-use models. This can enable a printer to use weaker (or even dissolvable) support material for easy removal, or the ability to add colour schemes to a print for aesthetic purposes. Heated build plates are fairly

common, and are used to improve the quality of prints by reducing the heat stress placed on a component during printing and cooling. In addition, many printers are open source projects, enabling users to edit the printer's software, and even use it to build their own printer.

The printers used in this lab utilize an extrusion printing method, and are designed for printing PLA, ABS, or CPE plastic parts. These printers utilize a single print nozzle, with a material feeder operating near the filament spool to help regulate filament flow, and a regular extruder just before nozzle.

The printers in the lab are also fitted with heated build plates, which keeps the printed portions of the model at a higher temperature during the print, allowing the model to cool more uniformly when the print is finished. Finally, these printers have a 'Tune' option, which enables most of the print settings to be adjusted during the print, useful for tweaking settings to find an acceptable balance between accuracy and speed.

Apparatus and Equipment Overview

For this lab, the following equipment and materials will be used:

- Ultimaker 2+ 3D printer
- Cura 2.6.2 printer software
- Coloured PLA plastic filament
- SD Card and USB adapter
- 3D part models (.STL files)

Before starting a print, students should become familiar with the printer they will be using, and be able to identify and use properly all of the main components.

User Interface

On the front of the Ultimaker 2+ there is an SD card slot, a display screen, and a dial used for navigation, whose center is also a button. On the back of the printer's chassis is a power switch, a USB connection port, and the power cable.

Extruder and Nozzle (CAUTION: HOT!)

The extruder heats and pulls partially melted filament into the nozzle. During a print, the extruder and nozzle will heat up to over 200^{o}C, so exercise caution around it. The location of the printer nozzle and extruder is controlled on an axis system made up of belts and gears. This assembly can be moved while the printer is idle by gently pulling on the extruder/nozzle assembly, being careful as parts of this assembly can be extremely hot even after a print has finished. If the printer is printing, or has recently been printing the motors will still be engaged. Set the printer to idle and wait a few minutes, or power off the machine to disengage the motor lock.

Build Plate (CAUTION: HOT!)

The build surface is where the printed part is placed on. On the lab printers, this is heated to 110^{o}C during printing, so exercise caution around it. The plate can be raise or lowered while the printer is idle by going to Maintenance>Advanced>Raise/Lower Build Plate. If the printer is not printing properly, this may need to be adjusted, by using the three knobs on the underside of the plate. This can be leveled through the printer's onboard software by going to Maintenance > Build Plate, and following the onscreen instructions.

Filament Spool

The filament spool can be found attached to the back of the printer. If the printer is out of filament, it can be replaced by going to Material > Change in the printer's user interface and following the onscreen instructions. It can also be replaced midway through printing by selecting Pause > Change Material and following the onscreen instructions.

Pre-Lab Preparation

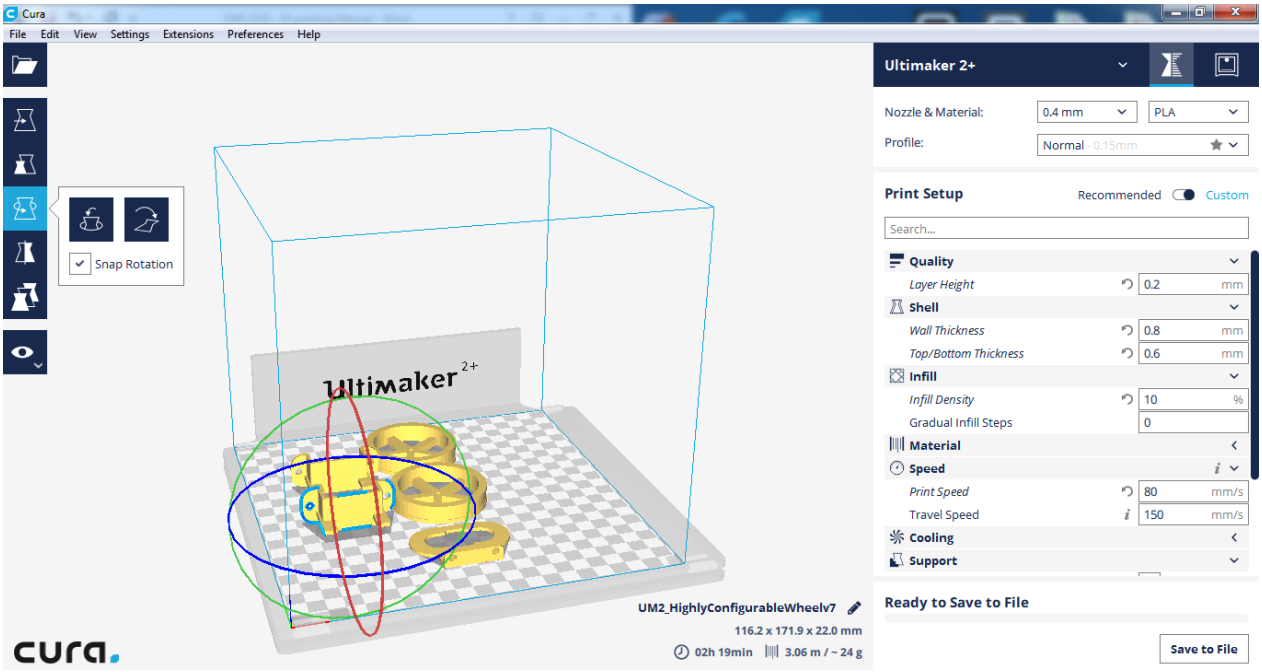
Before coming to the lab, students should review the lab manual, to ensure familiarity with the equipment and procedures used during the lab. Students must also download the .STL files they will be using off BrightSpace to a USB flash drive or an SD card, which will be brought to the lab. Lastly, if a student wishes to utilize their own computer instead of the lab computers they may do so, provided that Cura 2.6.2 be downloaded and installed beforehand.

Setting Up Cura 2.6.2

To install the most recent version of the Cura software used by the Ultimaker 2+ go to https://ultimaker.com/en/products/cura-software and download the software (default is for 64-bit versions of windows). Settings may have to be adjusted to fit the recommended settings used in this lab.

Procedure

1. Open Cura 2.6.2 and make sure the nessessary .STL files have been downloaded from BrightSpace or MakerRepo (http://makerepo.com/jboud030/gng2101-chariot-3d-printing).
2. In Cura's main window, select 'Load' and select a .STL file to open. The part will load in the middle of the virtual build plate.
3. Select the part by clicking on it, then select the rotate icon in the top left hand corner. Rotation axis lines should appear around the component, click and drag along a line to rotate the component until it lies flat. This is done so that it lies flat on the build plate, eliminating the need for any support material to be printed.



4. Ensure that the print settings have been properly configured by referencing the table below. Verify the estimated print time matches the print time in the table for the part being printed. This will ensure that the parts will print quickly while still maintaining accuracy.

Part File (.STL)	Estimated Print Time (min)
Wheel	38
Motor casing	25
Sensor mount	17

Basic Settings	
Layer Height (mm)	0.2
Wall Thickness (mm)	0.8
Top/Bottom Thickness (mm)	0.6
Infill Density (%)	10
Enable retraction	Yes
Print Speed (mm/s)	80
Travel Speed (mm/s)	150
Generate Support	Yes
Support Placement	Touching Buildplate
Build Plate Adhesion Type	None

5. Insert an SD card into the computer or connected card reader and go to File>Print. This saves a .gcode file to an external storage device. If there is more than one device

connected (for example, an SD card and USB flash drive), Cura will ask which one to use.

6. Safely eject the SD card with the .gcode file on it from the computer and insert it into the Ultimaker 2+ printer.
7. Before starting the print, ensure the printer:
    - Has enough filament for the print (found on the spool on the back of the printer).
    - Nozzle and build plate are clear of debris.

    Replace filament spool and clean debris away if necessary. Heating the build plate or nozzle may help in removing plastic (CAUTION: use a towel or pliers to avoid risk of burns from the nozzle or build plate).

8. Select Print>yourfilename.gcode in the printer's user interface. The printer will take a few minutes to heat up, then begin to print.
9. Monitor the print job for major errors in extrusion or adhesion of the plastic. If errors do occur in the print, it can be paused or aborted (Tune>Abort) using the printers interface. See the troubleshooting section for advice on how to correct print errors.

*NOTE: The printer gives a readout estimating the remaining print time, and during the first few layers this estimate is usually a gross overestimate.

10. After the print has completed, allow the build plate to cool for a few minutes before removing the print. Trim any excess plastic from the component (including support structures), and ensure the printer is clear of debris and ready for the next print. Show the TA the completed part. Repeat this process for a total of:
    - 1 Sensor mount
    - 2 Motor casings
    - 2 Wheels

Questions

What kind of filament is used in this lab? What other materials are useable by the Ultimaker 2+?

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What is the advantage of using a heated build surface?

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How can you create/obtain your own .STL files to print?

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What are some advantages and disadvantages of 3D printing?

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Troubleshooting

Part Edges Lifting

- Clean build plate

Residue from old prints, dust, dirt, or other debris can hinder the adhesion of a print to the build surface. Remove any material by hand (ensure the plate is cool before touching it), and wipe the plate down with a damp cloth if needed.

- Level build plate

If certain areas of the print are not adhering or being pressed onto the build plate, the plate may need to be leveled. In the user interface go to Maintenance>Build Plate and follow the onscreen instructions.

- Increase/decrease material flow

If printing leaves unintended spacing in the print, the extruder may not be extruding enough material for the current printer speed setting. On the other end of the spectrum, if the printer head is collecting a large excess of material, the printer may be extruding too much material. During a print go to Tune>Material Flow and adjust the percentage accordingly.

- Raise/lower print speed

Print speed can affect the adhesion of the print to the build plate, as well as the time required and accuracy of the print. If the first few layers of a print are not adhering properly or experience other print errors, reducing the print speed can usually fix. After the first few layers, the speed can usually be increased again. To adjust print speed during a print, go to Tune>Speed and adjust the percentage accordingly.

- Mid-print adjustments or part trimming

Occasionally in the interest of time it is not practical to repeatedly adjust and restart printing jobs. If printing errors are minor, sometimes pausing the build and trimming away portions of a print that are elevated, can produce desirable quality parts. The build pate can also be adjusted using the three screws underneath the plate during a print (however the software assistant cannot be run). These adjustments can help correct small errors occurring early in the print job as the errors will affect future deposited layers to a lesser extent if the proper adjustments are made.

Leaning/Sagging Prints

- Use the ‘Lay Flat’ option in Cura

Leaning parts usually indicate that the component was not properly orientated on the virtual build plate within the Cura software before printing. Use the angle indicator while rotating a part, and the ‘Lay Flat’ option can be selected once the part is in the proper orientation to ensure proper contact with the build plate.

- Rotate component or enable supports in Cura

Sagging or collapsed parts occur when a printer tries to lay material for overhangs without enough support below it, causing the still malleable plastic to flow out of its intended position. Minimizing overhanging sections of the part by properly orientating it within Cura should be done before resorting to supporting structures (one part in this lab needs supports). If it is not possible to eliminate all overhanging sections, use the support option within Cura (‘Touching Buildplate’ or ‘Everywhere’) that best suits the build.