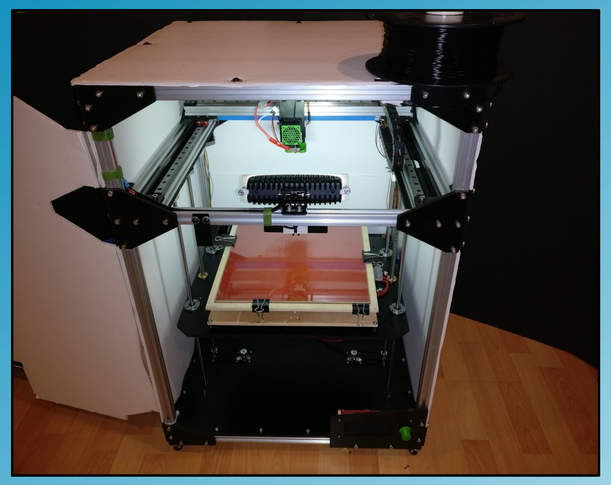
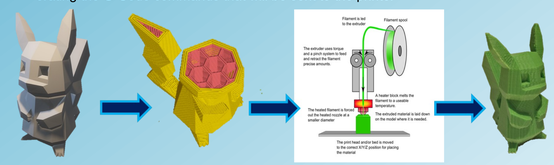
Real-Time 3D Printing Error Detection and Correction

William Makinen



Background

- Fused Filament Fabrication (FFF) is an Additive Manufacturing (AM) process that creates objects by laying down successive layers of molten material according to a CAD drawing
- FFF is capable of replicating much more complex designs more efficiently than traditional subtractive manufacturing techniques, such as milling
- FFF or 3D printing machines are easily accessible and have become popular in hobbyist/ prototyping environments
- Once exported to the appropriate format, the CAD file is sent through slicing software, generating the G-Code commands that will be sent to the printer



Component is designed using CAD Software | A slicing program generates G-Code | The printer melts and extrudes material | A finished component is produced

Purpose

- Current 3D printers are primarily open-loop systems; sensors to introduce feedback into the printing process are nonexistent
- Consistent, high-quality prints currently only achievable on costly, professional FFF machines. Even these rarely utilize process monitoring
- Adding sensors to monitor the print process in real time can ensure consistently acceptable parts even on low-end machines

Common 3D Printing Errors

Adhesion Failure:

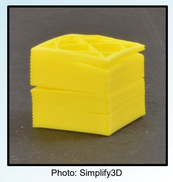


Photo: Simplify3D

Layer Shifting:

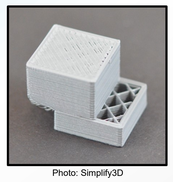


Photo: Simplify3D

Feeding Failure:

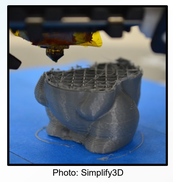


Photo: Simplify3D

Others:

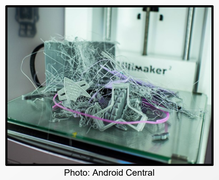


Photo: Android Central

Improper Melt Pool Temperature:

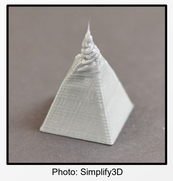


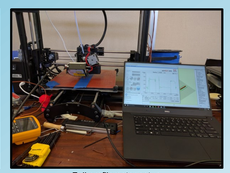
Photo: Simplify3D

Characterization Setup

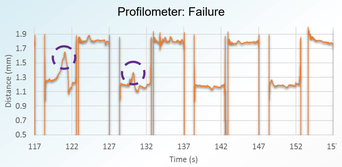
- Four sensor sets were initially tested to determine which ones would be the most viable options for a real time sensing system
- The camera and the load cell proved to be the most reliable and robust options, allowing for the detection of a variety of errors while remaining inexpensive and simple to implement

Profilometer:

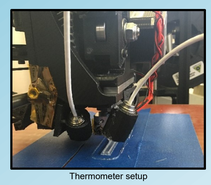
The profilometer's laser dot measuring extruded material



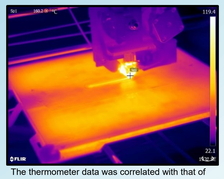
Full profilometer setup



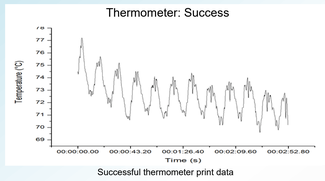
IR Thermometer:



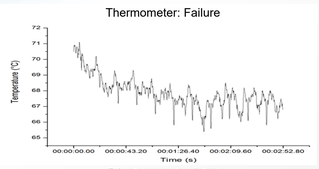
Thermometer setup



The thermometer data was correlated with that of a thermal camera

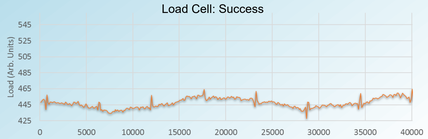


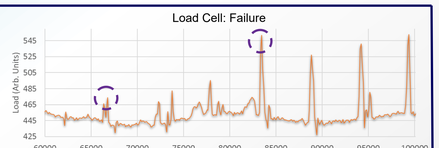
Successful thermometer print data



Failed thermometer print data

Load Cell:





Camera:

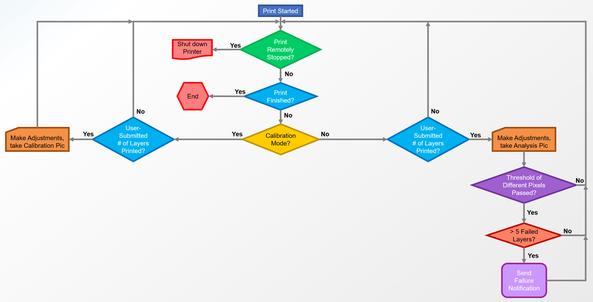
Successful Print | Failed Print | Result after comparing Images

Test Object:

The test object used with each sensor setup

Slips of paper inserted in between two layers to emulate a failure

Camera Flow Diagram

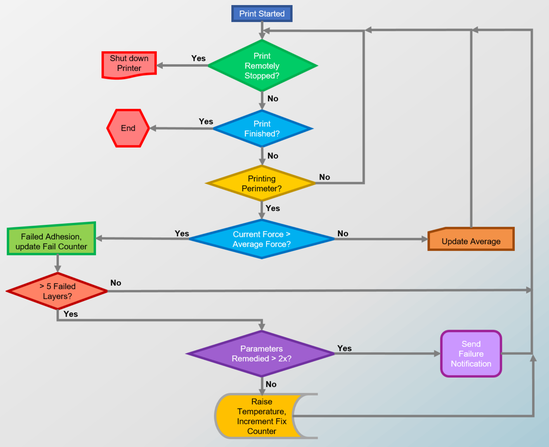


Camera Filter

$$Pixel\ Brightness(loc\ Z) = \frac{\{|Cal(R) - Anlys(R)| + |Cal(G) - Anlys(G)| + |Cal(B) - Anlys(B)|\}}{3}$$

$$if\ (Pixel\ Brightness(loc\ Z) > Threshold)\ \{$$
$$\quad PixelBrightness(loc\ Z) = 255;$$
$$\}$$
$$else\ \{$$
$$Pixel\ Brightness(loc\ Z) = 0;$$
$$\}$$

Load Cell Flow Diagram

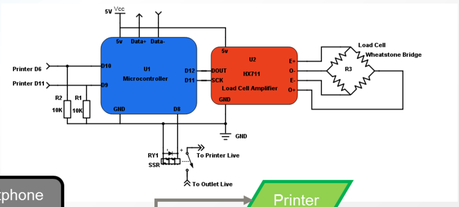


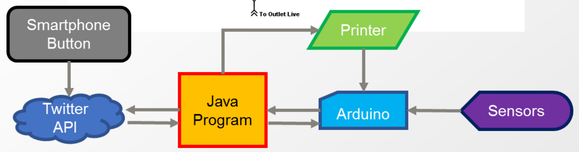
Materials

- Wheatstone bridge load cell
- Load cell amplifier
- Webcam
- Solid-state-relay
- Microcontroller
- USB connectors
- Miscellaneous electrical components (wire, pull-up resistors, transistor, etc.)

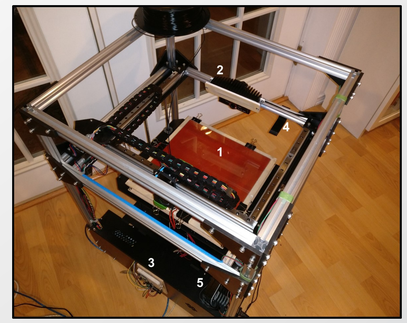
Total Cost Before Printer: ~$70

Schematic

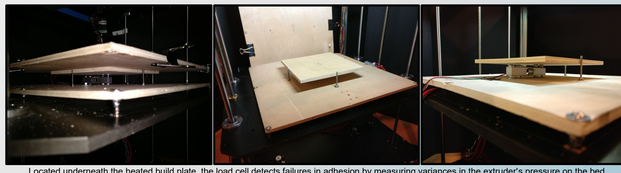




Diagram

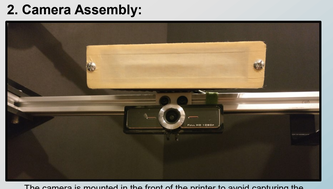


1. Load Cell:



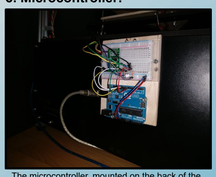
Located underneath the heated build plate, the load cell detects failures in adhesion by measuring variances in the extruder's pressure on the bed

2. Camera Assembly:



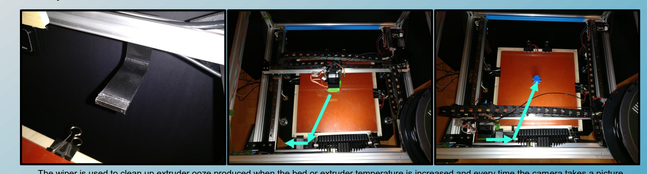
The camera is mounted in the front of the printer to avoid capturing the unintentional movement of the print head assembly. The light (switched off here), illuminates the target to ensure consistent lighting from shot to shot.

3. Microcontroller:



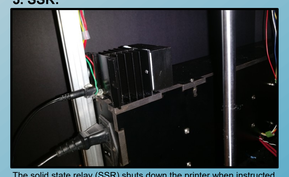
The microcontroller, mounted on the back of the printer, is responsible for communicating the printer's actions to the Java program.

4. Wiper:



The wiper is used to clean up extruder ooze produced when the bed or extruder temperature is increased and every time the camera takes a picture. Located at the front of the printer, a wipe is performed before (middle) and after (right) each action.

5. SSR:



The solid state relay (SSR) shuts down the printer when instructed by the user

Future Directions

- Improve load cell vibration isolation
- More advanced computer vision techniques, additional camera angles
- Integrate multiple sensor arrays into a single system
- Additional sensor types
- In-situ G-Code generation

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