Selective Laser Sintering (SLS) 3D Printer

Group 12

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2. Project Description

2.1 Motivations

Transforming data from one medium to another has been a process known to humans for thousands of years. Printing in the form of woodblock on textiles or paper was known and widely used throughout East Asia since 220 AD. The printing press, a revolutionary device which could print thousands of pages per day, was created in 1440. The art of lithography, which is pattern transfer and replication from one material medium to another, has been around since 1796. Of course, digital printing, where computer data is converted to paper, has manifested as laser printing, inkjet printing, and other types, since the early 1900s.

The nearly 2000 year history of printing has one common theme: all printing materials were two dimensional in nature. With the advent of computers, and thus computer aided design, there was a need to develop printing methods based in three dimensions that didn't involve extensive manufacturing, such as metal machining or forging. First discussed in the 1940s and 1950s, 3D printing came to fruition as additive manufacturing in the 1980s.

As is expected with any new technology, the 3D printers in the mid 1980s cost hundreds of thousands of dollars. Nearly 40 years later, 3D printing is an affordable table-top hobby enjoyed by millions of people worldwide.

Today, 3D printing takes on many forms. Enthusiasts can purchase printers which extrude heated thermoplastic into arbitrary shapes for less than $1000. These are the prototypical 3D printers, but they have limitations. Some of these limitations include necessitating support structures for the builds, as well as constraining users to only printing models with thermoplastic materials, such as acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA).

3D printing with different materials can be done with other types of printers. A subset of laser additive manufacturing, selective laser sintering (SLS) is a 3D printing method which uses a laser to selectively fuse together, or sinter, a powder into arbitrary shapes. One of the biggest advantages of this method is its ability to sinter any powdered material; the limitations arise only from thermal properties of the powder itself. Unfortunately, the cheapest SLS printers can cost upwards of over $18,000, still significantly out of the common enthusiast's price range. Further, these systems are usually only intended for single-material type use. Multi-material SLS printers can exceed $100,000.

2.2 Goal and Objectives

Prior designs of SLS printers, as mentioned before, are prohibitively expensive. These systems have lasers exceeding 50 watts which are a significant contribution to the cost. Further, these systems use heated beds to ease the sintering process and include automated material retrieval. The available SLS printers also use high-speed galvanometers to scan at speeds in excess of 500mm/s. Our system will be designed to maintain high resolution but with decreased throughput.

To build a low-cost implementation of SLS, we will use a low-power laser assembly. One company, Sintratrec, has developed one of the cheapest SLS systems at $24,000 using a 5W blue laser diode as the laser source. Our optical system will also use a blue laser diode of similar power. Using blue light as the thermal sintering source is beneficial over CO2 or Nd-YAG as the blue light has higher absorption in a wider range of materials and is much cheaper than CO2 or Nd-YAG layouts. However, the previously mentioned Sintratec system is only designed for one type of material. We will design our optical system to be robust in its material-sintering capabilities by designing a laser driver to operate the laser at predefined material-specific parameters.

Laser scanning systems vary widely in their performance, whether by resolution, speed, or scanning area. Initially, our system was going to feature an x-y scanning system inspired by galvanometers, as shown in Figure 2. However, galvanometers are difficult to use, are expensive, and have very high maximum scan speeds. They also use two mirrors, which, for high-power applications, can also raise the cost due to the protective coatings. Because of this, we will develop an x-y scanning system based on track-and-rail movements that will scan the laser across the powder bed, as shown in Figure 3. This removes the need for high-resolution motors, high-power capacity mirrors, and a scanning lens to correct for field curvature of the scan area, all of which contribute to excessive costs. While much cheaper, this comes at a reduction of scan speed and product throughput.

Systems on the market can achieve layer heights within 70-100 microns. These layer heights work well with our selection of blue laser diodes as its penetration depth exceeds this. Our powder delivery system will ensure this same level of micron height by using high resolution stepper motors. Micro-stepping is achieved by both the stepper motor, the motor’s driver, and the amount of threads on a supporting rod, and is not a considerable addition to the total cost.

The printer's processing will be done using a microcontroller. The microcontroller is responsible for reading the g-code and controlling the sub-systems accordingly. SPI, a communication protocol designed by Motorola, will be used to transmit data to the user interface screen.

2.3 Functionality

The SLS printer shall be capable of sintering materials, such as sugar and thermoplastic powder, into 3-dimensional objects. The enclosure will have 3 reservoirs: the material reservoir, the build reservoir, and the excess reservoir. The material will be loaded by the operator into the material reservoir. The laser sintering shall occur in the build reservoir. The material in both reservoirs sit on a plate that is capable of vertical motion. Material is transferred by raising the material reservoir plate, lowering the build reservoir plate, and using a sweeper mechanism that pushes the material from the material reservoir to the build reservoir. Any excess material will be captured in the 3rd reservoir.

Once the material successfully transfers, the laser sinters a 2-dimensional shape generated by the g-code, a language that consists of cartesian coordinates, onto the layer of material. Once the layer is complete, material is transferred to the build reservoir and the laser sinters another layer fusing the previous layer to the newest layer. The process continues until all layers are sintered. Once the print is complete, all mechanisms shut down and it is safe to access the 3-D print. Figure 2 illustrates the printer's core functionalities.

The printer will have a user interface which includes a screen and controls to select and start the 3D print. An open source slicer, such as Cura, can take a .stl file and generate the necessary g-code for the 3-D object. The g-code is stored into a USH-1 Micro SD which is inserted into the printer.

3. Requirements Specifications

Table 1: Specifications

Specifications	
Print Bed Area	10 cm x 10 cm
X-Y Build Area	9 cm x 9cm
Print Height	9 cm
Power Source	Wall Power
Display	LCD
Motor Torque	40 - 45 N*cm
Laser Diode Output Power	Varies, 2W - 5W
Laser Diode Wavelength	447 ± 15 nm
Beam Focal Length	125 ± 50 mm
X-Y Scanning Speed	> 30 mm/s
Material Type	Sugar, Polyamides, other TPE/TPU
Material Size	50 µm - 100 µm

Table 2: Standards

Standards	
Wiring Devices - Dimensional Specifications	ANSI/NEMA WD 6-2016
Safe Use of Lasers	ANSI Z136.1
C++ Programming Language	ISO/IEC 14882:2020
Python	ISO/IEC WD TR 24772-4

4. Block Diagram

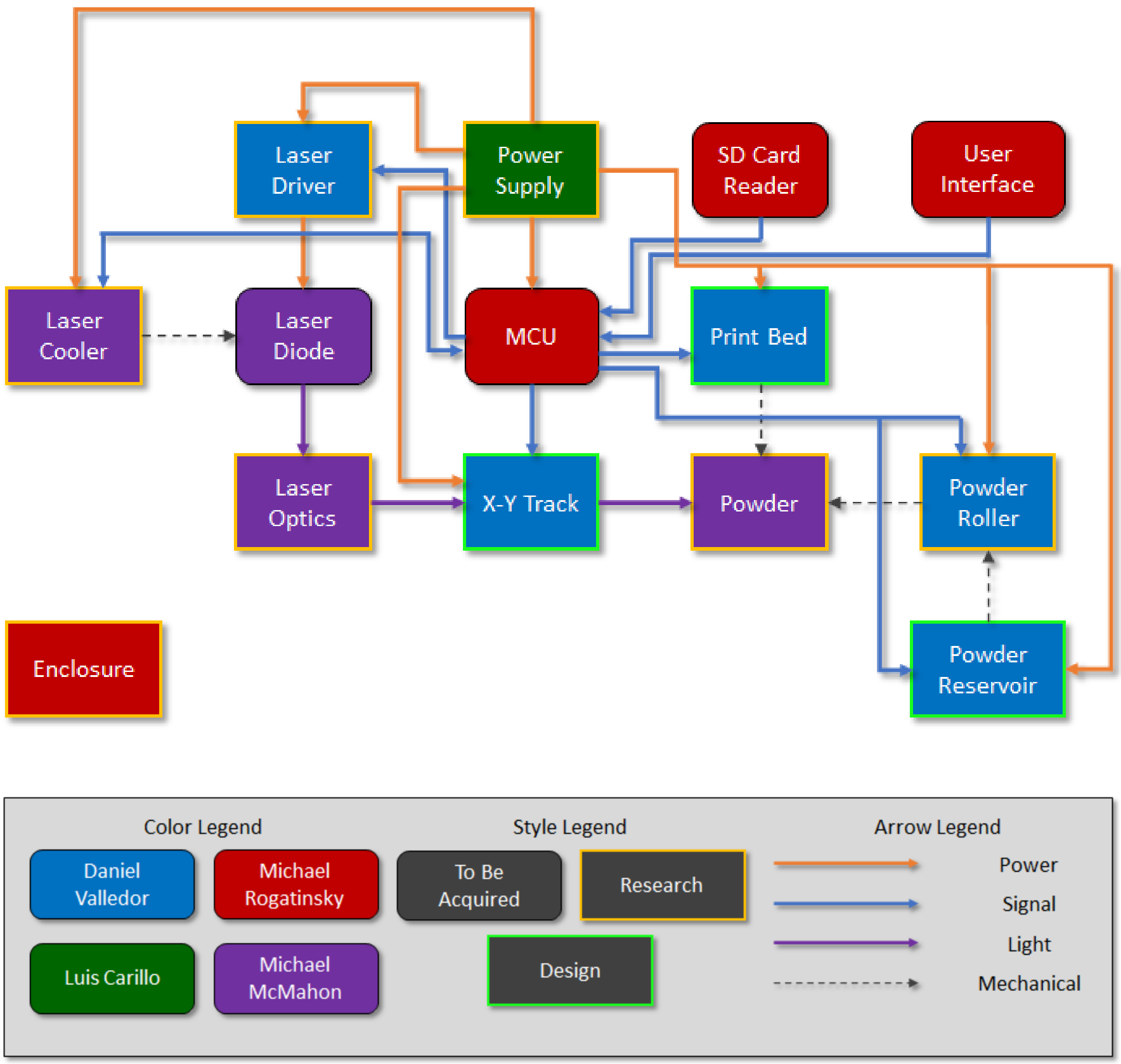

Figure 1: SLS Printer Block Diagram

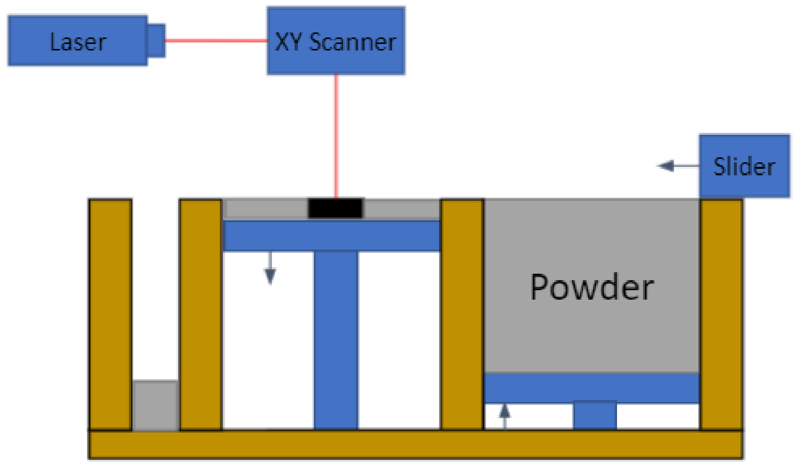

Figure 2: SLS Printer Cross-Section with XY Scanner

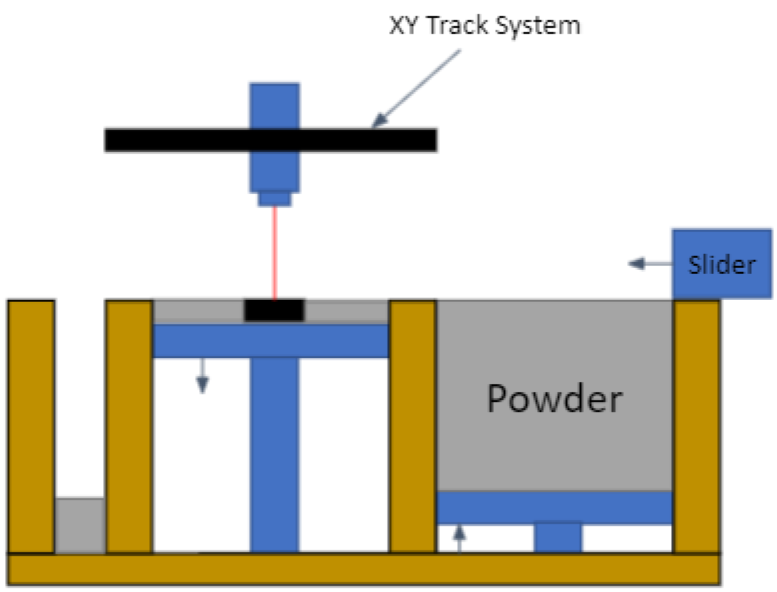

Figure 3: SLS Printer Cross-Section with XY Track System

5. House of Quality

							+				
								++			
					+						
				+		+		++		+	
			--		+		++		+		
	Limitations	Scanning Speed		Part Warping		Laser Power		Price		Materials	Dimensions
Goals		↑		↓		↑		↓		↑	↑
Print Time	-	--		-		++		-		--	--
Build Area	+			--		+					++
Reliability	+	+				+		-		-	
Ease of Use	+							-		-	
Compatibility	+							-		++	
Resolution	+	-						-		--	-
Accuracy	+	+						-			

++	Strong Positive Correlation
+	Positive Correlation
	No Correlation
-	Negative Correlation
--	Strong Negative Correlation

Figure 4: House of Quality

6. Projected Budget and Financing

The SLS 3D printer will be fully funded by the team. The team member who wishes to keep the project after completion will contribute the most. As stated in Table 3, our estimated budget for the SLS printer is around $450. After discussing as a team, we are all willing to contribute $600 to the project. This leaves us with $150 to use for miscellaneous costs, prototyping, and repurchasing parts in the event that a part breaks.

Table 3: Budget Breakdown

Subsystem	Estimated Cost
Laser Diode	$60
Laser Diode Collimating Lens	$30
Laser Driver	$20
Focusing Lens	$30
Build Plate Assembly	$70
XY Track Assembly	$80
Enclosure	$50
User Interface	$20
Power Supply	$50
PCB	$30
Grand TOTAL	$440

7. Project Milestones

Senior Design 1 Schedule

Milestone Description	Type	Start Date	Due Date
Project Idea	Action	8/27/2021	9/10/2021
Divide and Conquer Initial Documentation	Deliverable		9/17/2021
Research	Action	9/17/2021	10/1/2021
Divide and Conquer V2	Deliverable		10/1/2021
Design / Part Selection	Action	10/1/2021	11/5/2021
Senior Design I Documentation - 60 Page Draft	Deliverable		11/5/2021
Senior Design I Documentation - 100 Page Draft	Deliverable		11/19/2021
Design / Prototype	Action	11/19/2021	12/7/2021
Senior Design I Documentation - Final Documentation	Deliverable		12/7/2021

Senior Design 2 Schedule

Milestone Description	Type	Start Date	Due Date
Prototype	Action	TBD	TBD
Test and Redesign	Action	TBD	TBD
Final Prototype	Action	TBD	TBD
Peer Presentation	Deliverable		TBD
Final Report	Deliverable		TBD
Final Presentation	Deliverable		TBD