3D Metal Printer

PROJECT PLAN

May 2018 - Team 5

Client and Advisor:

Dr. Timothy Bigelow

Team members:

Kevin Oran - Engineering lead, programming and mechanical design

Ben Pieper - Software design and integration

Jett Ptacek - Software design and integration

Rachel Shannon - Sensor integration, wiring/connectors

Caleb Toney - Sensor integration, wiring/connectors

sdmay18-05@iastate.edu

http://sdmay18-05.sd.ece.iastate.edu/

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1 Introduction

1.1 Project statement

This senior design team is tasked with designing and creating a Metal 3D Printer. The scope includes designing the printer mechanically, designing safety systems to prevent harm from the pure nitrogen gas required for printing, designing software to drive the motors, and developing a user interface to make the printer accessible to researchers.

1.2 purpose

The twist with this printer's design is that there is an interferometer to perform non-destructive evaluation on each layer of the part as it is printed. This is a research component to try to correlate print quality with part performance. The cost of this evaluation is speed. The printer will ideally be able to perform this evaluation as it is printing, without require a second scanning step for every printed layer. As will be discussed later, metal 3D printing is becoming the standard in industry for developing hard to manufacture parts, many of which need to be of high quality for system critical applications. This creates a strong need for new and innovative NDE methods in the area of 3D printing.

1.3 Goals

As discussed with our product owner, Dr. Bigelow, the team should focus on trying to achieve one of two goals: a printer with a functioning NDE scan, or a printer that can print. Both of these will require similar deliverables. The main difference being which function gets more effort to be completed. It is our understanding that this senior design project will be continued in future years. As a team, we are currently focusing getting the printer to print objects first. We feel that this is logical, as it will be much easier to test the evaluation component if the printer is able to evaluate which it is printing.

2 Deliverables

Deliverable	Description
Solidworks Model	This is the virtual design of the printer. We will use this to check space conflicts and estimate costs. The design will be reviewed by the chemistry machine shop for manufacturability.
Manufacturing Drawings	Provide mechanical drawings/parts to the manufacturing lab to create the necessary components to assemble the printer.

Software interface	For accessibility, we need an accessible software interface to coordinate the safety and motor subsystems of the printer. The software will incorporate some standard slicing formats to enable commercially available tools to prepare path planning for our printer.
Safety System	The team will research and integrate sensors to guarantee the system is sealed and operating safely. The two primary hazards are a gas leak and radiation leak from the laser. Appropriate sensors and visual alerts will be provided to the user to ensure safety.
Embedded system	Team will develop an embedded safety system to link sensors into the desktop computer. The embedded system will also operate safety alarms regardless of the state of the PC connection.

3 Design

3.1 Previous work/literature

Additive manufacturing (AM) is a process created in 1984 by Charles W. Hull in which a product is built by printing layer by layer, similar to a standard inkjet printer but with other materials (e.g. resin, metal powder). This manufacturing technique enables people to build more intricate objects, such as naturally occurring honeycomb structures or geometrical lattices that would be difficult if not impossible to craft with standard methods.

The growth of AM technology owes its success to non-critical applications popular with the average consumer (Seifi, 2016; Sorrentino, 2012). While the ability of 3D printing is praised, there is a lack of in-situ process monitoring as well as a lack of quality control for each part being made (Waller et al., 2014; Slotwinski, 2017). The lack of real-time monitoring hinders the full potential of AM by making it unusable for mission critical applications especially for flight (Book, et al., 2016; Seifi, 2016). It is necessary for the development of qualification standards and certification to ensure that parts produced by AM are able to survive intense environments. It is thereby essential to know the size of voids or inclusions and the location of the defects if they are present (Ramsey et al., 2016). This is where nondestructive evaluation (NDE) comes into play.

NDE techniques can be used to measure for defects within materials before, during (real-time), and after a part is manufactured (Sorrentino, 2017; Slotwinski, 2017). An example would be measuring powder particulate size, distribution, and chemical composition, or use in-situ techniques to measure the temperature and size of the melt pool in powder bed fusion systems. Integrating lasers into the build chamber allows for immediate defect scanning as each layer is applied (Slotwinski, 2017).

According to NASA, "compared with a traditionally cast part, a printed [part] has superior strength, ductility, and fracture resistance, with a lower variability in materials properties." The Goddard Space Flight Center (GSFC) reported that telescopes made with AM save mass, increase dimensional stability, and reduce required parts. Additionally, some other parts can come in an order of magnitude less expensive and produced on a much shorter time scale (Waller et al., 2017). The ability to print intricate structures that are lightweight and strong seems like a perfect fit for aerospace industry (*Figure 1*).

(a) GE fuel nozzle [1] (b) SpaceX combustion chamber [2] (c) NASA engine baffle [3]

Figure 1: Example applications of AM to fabricate mission-critical aerospace products (Waller et al., 2014; Albakri et al. 2015)

The need for NDE in 3D metal additive manufacturing is an emerging field of interest. The ability for integration of NDE into the additive manufacturing process fulfills the need for real-time evaluation of defects and the ability for quality control that is much needed to take 3D metal printing into commercial manufacturing. As it stands, organizations are continuing to find new ways to leverage AM techniques to enable themselves to achieve more.

3.2 Proposed System Block diagram

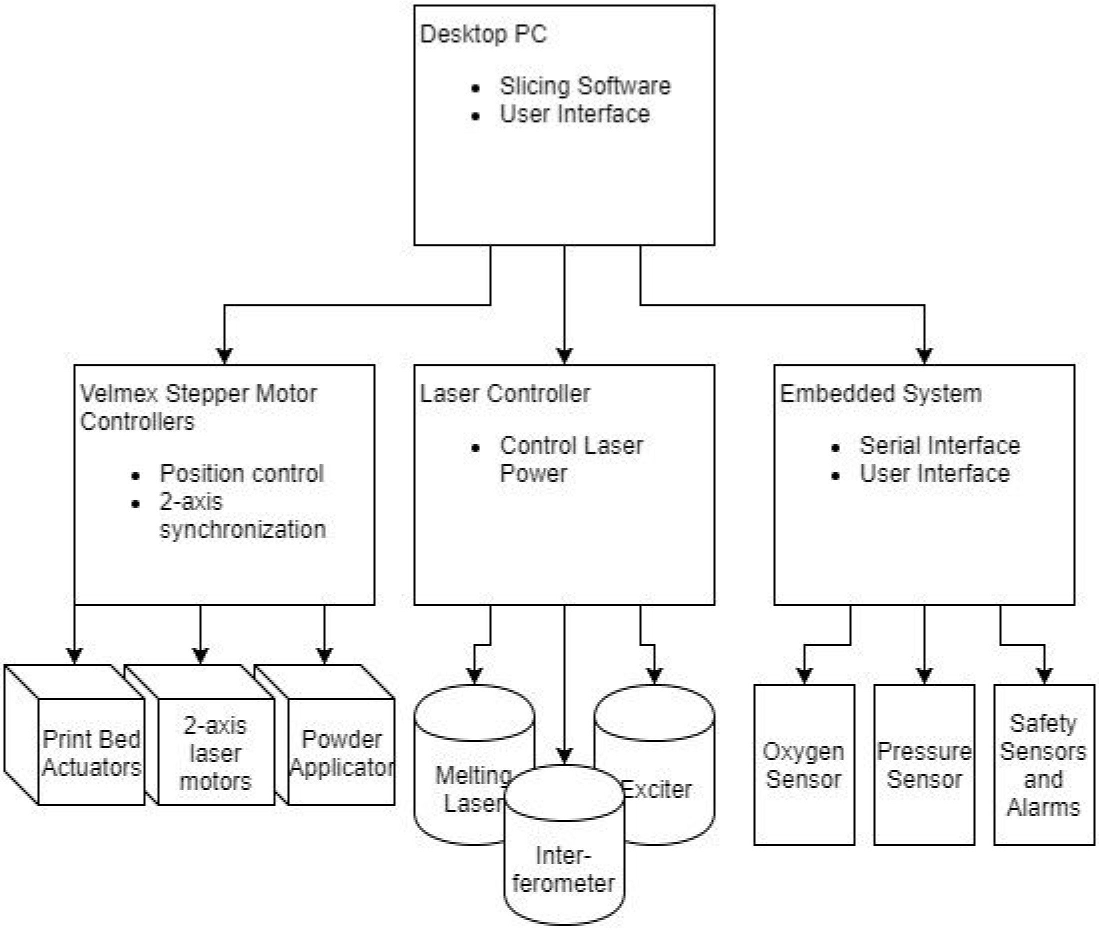

Figure 2: Block diagram of 3d Printer design

3.3 Assessment of Proposed methods

For the overall organization and structure of the project, we considered a few approaches. We thought about splitting into two teams, a powder system team and a laser system team, but decided that there would be far too much overlap between the systems for splitting into two distinct teams. Instead, we decided to stay together as one group and dole out responsibilities as need arises.

As the above diagram illustrates, our system has been planned out and discussed with our advisor at length. Based on the knowledge of Dr. Bigelow and our own engineering work, the fundamental design is sound. We control the printer via a PC. Then we use stepper motors to move the laser heads and powder system. The PC will get data from various sensors and cameras in return. Every part of our design is doable by this team. One of the biggest downsides to this design is that our printer will be very slow. This shouldn't matter for the scope of our project since speed was not a constraint we were given.

3.4 Validation

Due to the expensive nature of a lot of these parts, we really only have one shot. For the most part, we won't be making prototypes. This means that we have to work very carefully to ensure success. To do this we will confirm that Dr. Bigelow is on board with all of the important decisions in the project and carefully check each other's work. If it doesn't work the first time, we will make adjustments via software or swap out some hardware if necessary. The best way to ensure that our solutions will work is taking the time for calculation and analysis prior to action.

That being said, we must have a comprehensive plan on how to test each component of the printer before assembling it, otherwise it will certainly not work the first time. This project has many complicated hardware and software elements, and thus the testing can be dividing into hardware and software testing.

With regards to software testing, there are several approaches we can take. Most of the software we will be writing will be C# code on a Windows PC, so it will be very easy to quickly debug and change. One challenge with the software is that the hardware will not be fully ready and tested for a while. We plan to create a piece of software which essentially emulates the physical hardware of the project. This will be a simple GUI application which listens to the output commands of the software we write, and then draws what 'should' be printed to the screen. This will allow us to validate all of our code before the actual drivers which communicate with the printer hardware.

There will be several elements to the hardware testing of the 3D Metal Printer. One of the first, and most critical, pieces to be tested is the sealed chamber. This chamber or box must be able to handle enough vacuum to be evacuated of air and filled with nitrogen. We plan to test this box well before installing any of the printer assemblies or components, as it will be easier to fix problems with it early on. Another major hardware component which will require extensive testing, particularly because it works closely with the software, is the movement of the laser head. The laser head must move in a precise manner, and it would be preferable to ensure it is operating correctly before actually turning on the high power melt laser. Our current plan is to affix a writing utensil of some sort to the laser head, and having the printer draw paths on a piece of paper. This will allow for a visual verification that the print head is moving in the correct path.

The final test for the 3D Metal Printer will be the printing of a simple CAD model. This will test both the hardware and software of the printer. There could be several problems revealed that were not present in individual component testing.

4 Project Requirements/Specifications

4.1 FUNCTIONAL

- The printer shall have 3 lasers- a 1064 nm 200 W melt laser, a 1064 nm ultrasound generating laser, and a 1550 nm laser interferometer.

- The printer shall have a powder bed which moves up in order to deposit a new layer of powder
- The printer shall have a brush or roller of some sort to deposit powder from the powder bed to the print bed
- The printer shall have a print bed which moves down after each layer is sintered by the laser
- The printer shall have a collection bin which collects excess powder not deposited on the print bed
- Any place with powder must be enclosed in a sealed chamber which can withstand a vacuum and be filled with nitrogen or argon gas
- All lasers shall be able to be pointed at any point within the print bed using some sort of servo control
- There shall be a pressure and oxygen sensor inside the sealed powder chamber
- There shall be an oxygen outside of the printer which will alarm the user if oxygen levels in the room are unsafe
- The system shall use an interlock such that the laser cannot be powered unless it is contained

4.2 Non-functional

- The volume of the sealed chamber should be minimized
- It should be easy for future users to modify system software
- The time for printing and scanning should be a small as possible while keeping the printer design simple

4.3 Standards

Engineering standards helps create constraints when designing a technical product. Constraints allow for greater creativity to achieve an end goal and also allows devices held to these standards to be easily transferable between platforms. The standards we will be adhering to are industry and IEEE standards.

Our code will be written with supporting documentation in Javadocs style comments. This is considered industry standard for software of this nature, and will be necessary to meet the requirement of easily understandable and modifiable software.

As there is a high power laser, several safety standards must be followed. All of our team members will take EHS Laser Safety training, and will work with EHS to ensure the system and its environment is safe before powering on the lasers.

The following are IEEE standards that pertain to our project:

270-2006 - IEEE Standard Definitions for Selected Quantities, Units, and Related Terms, with Special Attention to the International System of Units (SI).

This standard defines physical quantities and units used in applied science and technology, including a systems of measurement. The standards emphasizes the International System of Units. This is relevant to my team's project because half of our project is mechanical design. We need to make sure that the parts we choose will be compatible when we start building the printer. Therefore, our team must be aware if parts are in mm, inches, or any other type of measurement.

1100-2005 - IEEE Recommended Practice for Powering and Grounding Electronic Equipment.

This standard is a collection of best practices for powering and grounding electronic equipment used in commercial and industrial applications. The best practices are designed to enhance equipment performance and maintain safe installation. This is relevant to our project because we will essentially be building a device that needs proper powering and grounding. We will be using several lasers, implementing a sensor system, and powering a printer. We need to be able to properly distribute power and ground these systems for safe handling.

299-2006 - IEEE Standard Method for Measuring Effectiveness of Electromagnetic Shielding Enclosures.

This standard describes uniform measurement procedures and techniques to determine the efficiency of electromagnetic shield enclosures. This includes welded, demountable builds of materials such as steel plate, aluminum, and copper. This is relevant to the project because we will be using several lasers, including a high beam melt laser. We need to be able to have an enclosure that helps prevent any radiation and reflection to the user. This standard will help ensure that our device is safe to handle

754-2008 - IEEE Standard for Floating-Point Arithmetic

This standard specifies interchange and arithmetic formats and methods for binary and decimal floating-point arithmetic in computer programming environments. This standard is geared toward the software part of our project. Our printer will be controlled by a program that will control the movement of our printer by pushing coordinate values via arrays. We want to be able to store precise values as possible to maintain accuracy of the 3D printed product.

5 Challenges

The biggest challenge currently facing the team is finding the best way to integrate an interferometer. Ideally, we would use two mirrors for scanning, but most interferometers have a very specific beam length at which it functions. A mirror solution would mean we had a variable beam length which most likely won't work. This is a challenge we are currently working through. Another challenge will be getting the interlock system set so that we can even turn on the lasers at some point. There are a lot of regulations on lasers and it's hard to get regulatory approval to use them. A third challenge is the precise and extreme accuracy necessary for 3D printing to work. While in theory this accuracy should be achievable, it is highly likely that we will face challenges in practice. While it is likely that we will face many more challenges over the course of the project, these are the biggest and most foreseeable issues right now.

6 Timeline

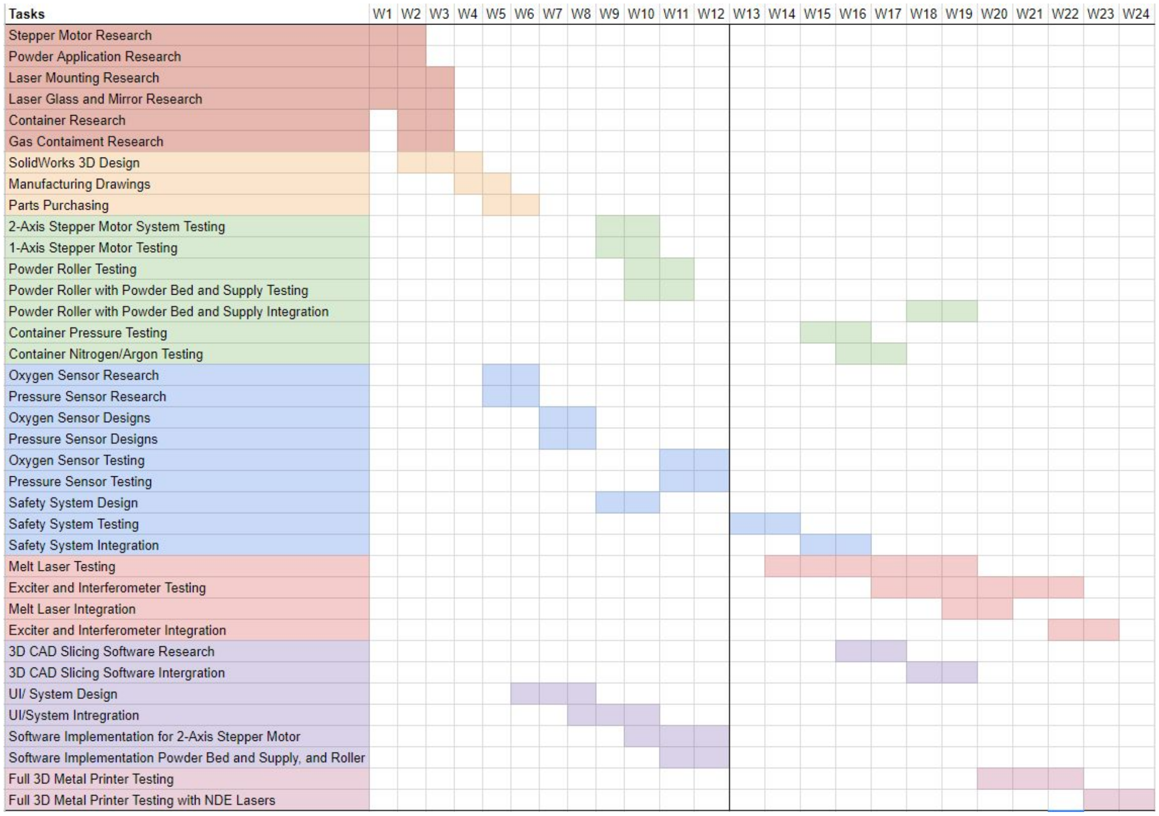

Figure 6.1 : Gantt Chart of Senior Design Fall and Spring Semesters

6.1 First Semester

The first semester will consist of research, design, purchasing of parts, and implementation of mechanical parts and electronic sensors. In the beginning each member is researching different aspects for the design. Around the time parts are being ordered, teams will be formed around sensor creation and software creation. The sensor team will be involved with the research, design, and testing during the first semester. The software team will create a basic application that will integrate with the mechanical parts.

6.2 Second Semester

During the second semester, a safety system based off the sensors will be tested and built in conjunction with container pressure/gas testing. The lasers will be tested in and out of the nitrogen/argon environment, and the software application will be able to splice a CAD file to map points for the 2-axis stepper motor system. A full scale 3D metal printer testing will occur with only the melting laser, and then testing for the NDE lasers will follow. Team collaboration from the previous semester will continue.

7 Conclusions

Our project is to create a 3D Metal for Dr. Bigelow. Our goals for the project is to get as far as possible in the creation of the printer. Ideally, we would at least be able to print parts by the end of the year. We are planning to have much of the parts acquisition done by the end of the semester so that we can focus on implementing functional requirements during second semester. Our plan to achieve this goal includes weekly meetings as a team and with Dr. Bigelow, and constant communication about ideas and problems. Each week we are tackling design and implementation challenges as they arise. The printer will interface with and be controlled by a pc. The pc first takes in a 3d schematic, then slices into layers, then sends instructions to a set of stepper motors for each layer. For each slice, a roller adds a new layer of powder. In return the pc will get data from sensors and cameras. Certain alarms and sensors will run through an Arduino. Some of our biggest challenges include laser safety, dangerous gas volumes, and print accuracy. The implementation of these functions will continue throughout the year as we attempt to overcome the major challenges.

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