3D Metal Printer

DESIGN DOCUMENT

May 2018 - Team 5

Client and Advisor:

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1 Introduction

1.1 Acknowledgement

We would like to thank Dr. Timothy Bigelow, Associate Professor of Electrical and computer Engineering at Iowa State. Dr. Bigelow serves as the faculty advisor for this project. He provides guidance, technical advice, and design constraints in each of our weekly meetings. Additionally, the majority of the funding for the project comes from a research grant obtained by Dr. Bigelow. His support is expected to continue through the duration of the project.

1.2 Problem and Project Statement

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

Additive manufacturing is often used to create parts which have hidden, non exposed surfaces, which prevents them from being analyzed with typical nondestructive evaluation techniques. [1] This printer will have the capability to do nondestructive evaluation while the part is being created, which is a key focus area for Dr. Bigelow's research.

Our solution consists of a mechanical design comprised of several stepper motors to deposit layers of powder onto a print bed and move the melt and evaluation laser heads around. This system is totally enclosed in a sealed chamber which can be evacuated of oxygen gas. Our solution also contains software which provides the ability to process and print CAD files, monitor print status and sensor readings, and provide critical safety checks and monitoring to the system.

We hope to complete all that is outlined above, which would mean by the end of our project we will have a printer which will allow researchers to print simple objects safely and easily. Also, we will have the system build in a way that allows the addition of the nondestructive evaluation components. It is not expected that our team get all of this added because of time constraints, rather that we build a base for future project teams to finish the nondestructive evaluation portion.

1.3 operational Environment

The operating environment for the Metal 3D Printer will be a laboratory setting. There should not be any dust or temperature issues with this environment. However, one concern is the safety of using our printer in this environment. The sealed chamber of the printer must be filled with nitrogen or argon gas to evacuate all oxygen within. Thus, if this chamber leaks, there may be risk of suffocating people in the room the printer is. We will be communicating with EHS at Iowa State to ensure that all proper safety measures are taken when using the printer in a confined room. [2]

1.4 Intended Users and uses

The intended end users of our printer are researchers in the area of nondestructive evaluation and materials. They will use this printer to produce and evaluate several simple shapes.

As this printer will be used for research use, it must be able to be adapted and easy to understand. In other words, the technical portions of it must be very well documented and easy to work with, as they will likely be modified by others in the future. Hence, it is not supposed to be a sealed, non modifiable, end consumer product. This also means that we should keep the end users in mind when selecting the hardware and programming languages used. As likely none of the researchers using the printer will not be software engineers, simple and well documented Java or Python code would be preferable to efficient, yet complicated and lower level C code.

1.5 Assumptions and Limitations

Assumptions

The project is to develop a laser based nondestructive evaluation system for inline monitoring of additive manufactured parts. Thus, the build speed and complexity of the printed part is not of concern. The end product will not be for commercial use but for research purposes.

Limitations

The budget for this project is approximated at $60,000. The end product will fiber-couple 3 lasers to focus on the same spot. The three lasers (client requirement) in use will be a 200 watt fiber laser (spilasers), Nd:YAG laser at 1064 nm wavelength, 50 mJ (Quantel), at 20 Hz; and the last will be a laser interferometer (OPTECH) at 1550 nm wavelength, 50 mW. The fiber-coupled laser will be housed in an optical head and would need to be able to be in a vacuum chamber of 10^{-3} to 10^{-6} torr. Dust protection from the powder bed will be needed.

1.6 Expected End Product and Deliverables

The end product will provide researchers the ability to analyze parts in real-time produced by additive manufacturing. The mechanical design in our solution simplifies the complexity needed for a galvanometer mirror based system by removing the need to adjust the intensity of the laser as it is redirected by the mirror. The mechanical design shall include stepper motors for the powder bed and roller blade, as well as the optical head containing the 3 lasers. The expected delivery date of the mechanical design (as in an overall mechanically functioning system) shall be the end of the first semester of Senior Design. The optical head will be integrated into the whole system during the second semester of Senior Design. An infrared camera and/or basic camera for monitoring shall also be introduced in the second semester of Senior Design.

In addition, a sensor system will be set in place as part of the overall safety requirements. The sensor system will be comprised of an external oxygen sensor, an internal oxygen sensor, and a barometer. The external oxygen sensor will be a standalone device that will warn the user if the oxygen levels within the room are not sufficient for the user to be in. The internal oxygen sensor and barometer will be an Arduino based system that will allow the users to monitor the oxygen and pressure within the chamber of the 3D metal printer. This system shall be expected to be finished at the end of the first semester of Senior Design.

2 Specifications and Analysis

In its most basic form, the goal of our project is to design a full sintering 3D metal printer which can perform non-destructive evaluation on parts while they are being printed. This leaves a lot of room for freedom in our design, and also leaves a lot of mechanical, electrical, and software design to be done. We started our designs based off of some ideas Dr. Bigelow had, but grew them over the course of the semester into a single manufacturable design.

2.1 Design Specifications

Functional Requirements

- 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 power bed which moves up in order to deposit a new layer of power
- 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

Non-functional Requirements

- 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

2.2 Proposed Design

Although the project was initially presented with a very broad scope, the team has narrowed our plan to a few big goals. First, the physical design of the printer must be finished and implemented. Second, the electronics of the printer must be chosen and integrated to provide a physically capable system which can print objects. Finally, the team will create a software interface to control the printer and print standard model files.

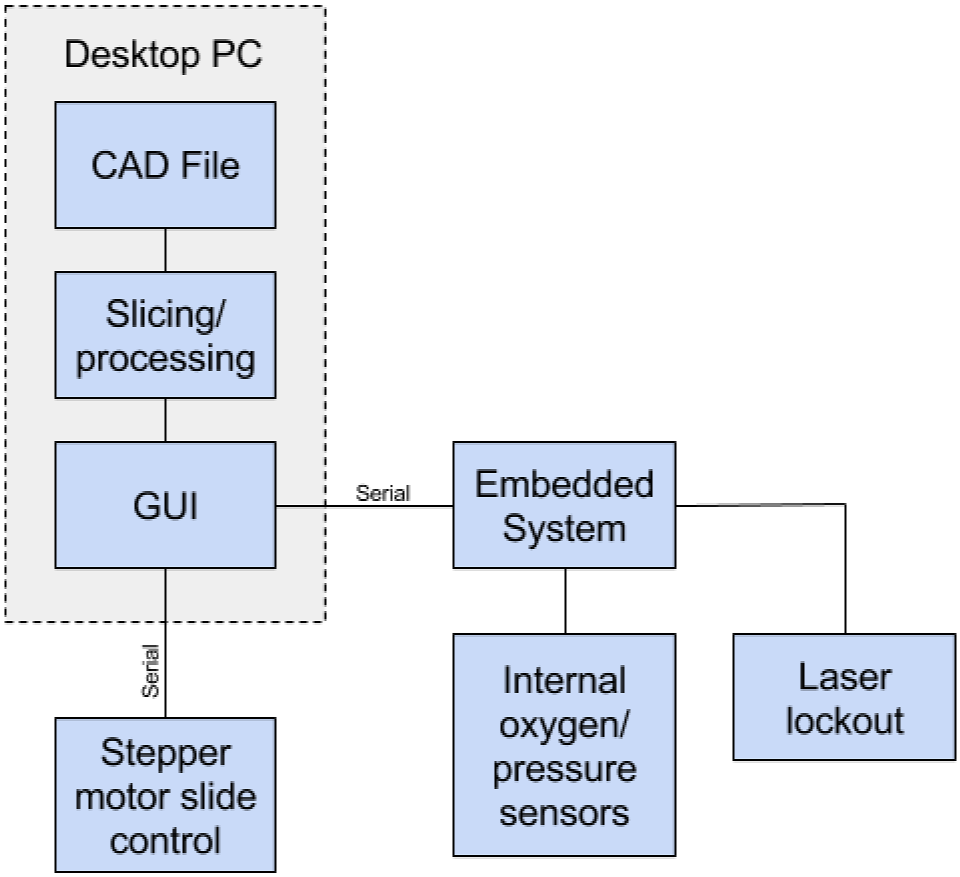


Figure 1, Software high level block diagram

The above diagram describes the layout of the software elements of the project. The GUI software on the PC is the main central application which will coordinate all of the other pieces.

2.3 Design Analysis

Current mechanical analysis includes loading analysis for the print beds and actuators. We also spent a fair amount of time analyzing different configurations for the printer. The two main safety concerns for the printer are containing radiation and containing the gas inside. In order to prevent oxidation on the pieces, the printer must be evacuated of oxygen and refilled with pure nitrogen or argon. A leak in the printer's seal could mean pushing oxygen out of a room containing the printer.

To approach these challenges several different configurations were considered for the printer. The first configuration assumed we could have mirror so that the laser traveled through a window into the pressure sealed chamber and bounced off a mirror onto the print surface. This method would have significantly reduced the volume that needed to have the oxygen removed. An alternative solution to these methods still used a window, but had the laser pointing directly onto the surface. Figure 2 and Figure 3 show these two methods compared side by side. In both diagrams, the blue rectangle represents the cross area of volume affected by the configuration.

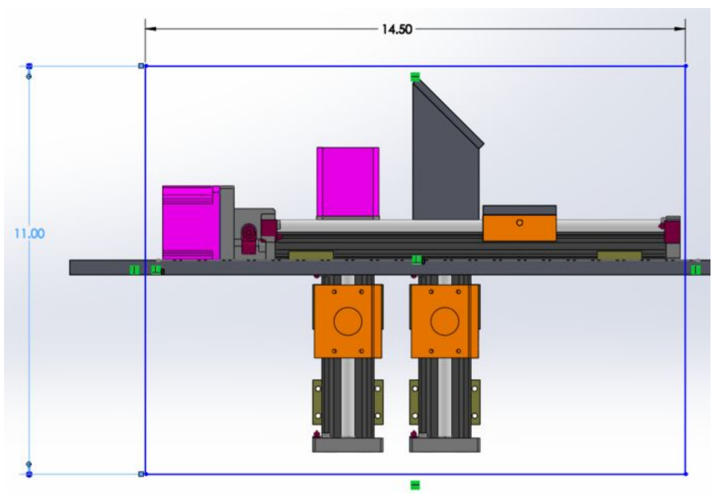


Figure 2, The mirror method

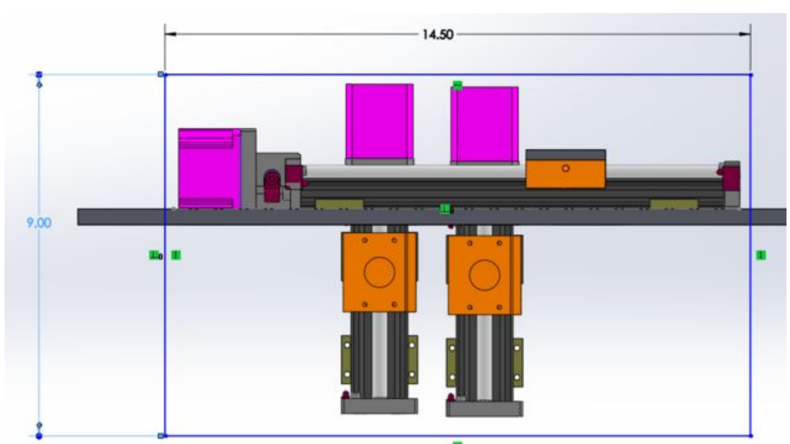


Figure 3, The window method

In addition to these configurations, the team also went through several iterations of the print beds themselves. The print beds are challenging geometrically, as they have to provide a floor which can sink and remain flush with the walls. The current iteration of the print beds has one of the wall attached to the the bed and doubles as a bracket and print wall. This iteration of the beds can be seen below in Figure 4.

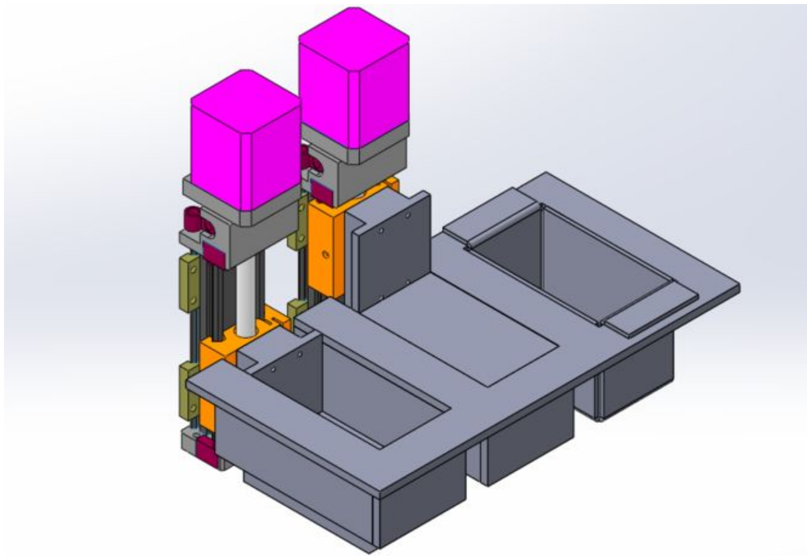


Figure 4, The current print bed configuration.

During our research, we discovered that an affordable window to support the multiple wavelengths of the lasers was not going to be available for this project. We then moved to another configuration which included all moving hardware for the printer inside the vacuum chamber. The new configuration is pictured below in Figure 5.

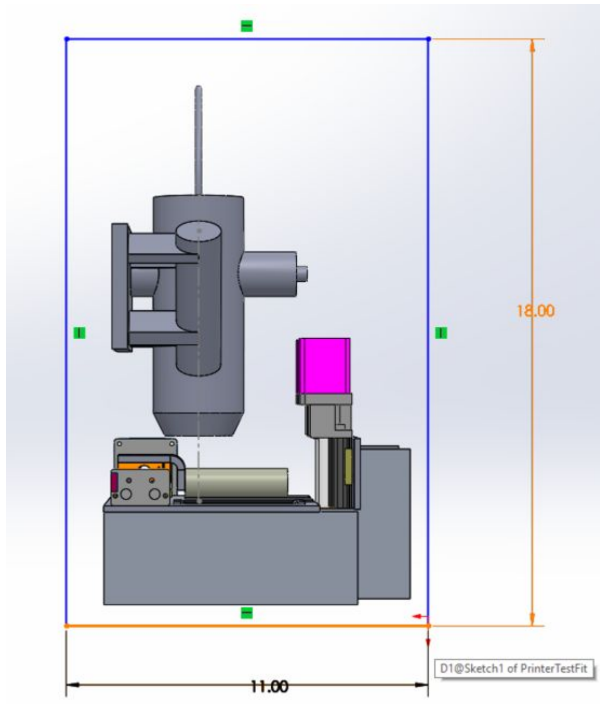


Figure 5, A side view estimating the size of the printer

This design will be modified further. The laser housing changed drastically during the design phase and puts the stepper motors (pink) in conflict with the laser head so appropriate adjustments need to be made.

3 Testing and Implementation

This project will need significant testing before it can be approved. Before we get to testing the system as a whole, each individual piece must be thoroughly tested. Both functional and nonfunctional items require testing. Functional items to be tested include the laser-guiding stepper motor system, oxygen sensor, powder system motors, lasers, software interfaces, oxygen alarm, and thermal camera. Nonfunctional items to be tested include print speed, vacuum level, print accuracy, powder efficiency, temperature, and oxygen level. One of the first nonfunctional systems to be tested will likely be how much powder is thrown into the air as we move the roller across the powder.

3.1 Interface Specifications

Our test interfacing will largely be done via a PC connection. We will use this interface to enable testing functional requirements by sending commands and such. We will also use it to receive data from sensors and cameras. We can use this data to confirm functionality of the sensors themselves and the processes they measure.

3.2 Hardware and software

As of this writing, we do not have any hardware or software used explicitly for testing. It is likely that as we get nearer to testing, we will develop both hardware and software. Functional portions can be tested by either observation or data collection. For example, we can test the oxygen sensor against another sensor's readings to confirm validity. We will test stepper motors by measuring out exactly how far a motor is supposed to move on a command and then compare it to actual distance moved. Some of the nonfunctional requirements can also be tested by observation or simple instruments. For example, we can find print speed by simply observing and timing a print. We can find print accuracy by observing a part and comparing it to expected results. We can test temperature and oxygen levels by using sensors already within the scope of the project.

3.3 Functional Testing

Much of the testing done for the project will be testing of individual units. These units are both hardware units and software units.

With regards to software, some of the unit testing for the project has already begun. For example, the slicing software is currently under development, but the piece of software which loads a CAD file and converts it to 2D slices is complete and being tested. If this unit produces correct 2D slices, then those can be input into a path planning unit which will generate the actual machine paths for the printer. It is key that we are sure that both pieces of software work on their own before attempting to combine them and go from a CAD file to machine paths. There is more less formal testing going on in the software at the function level. The code is broken into small, logical functions as much as possible, and each of them is tested to some degree.

With regards to hardware, no testing had been done yet, as we are not far enough along to do so yet. However, there are several key tests which must be performed as the hardware is completed. The first major hardware test will be of the physical vacuum sealed box- we will need to see how well it holds a vacuum with all of the connectors and components installed. We have designed for a pressure sensor to be installed in the box, and it is likely that there will be some sort of vacuum level indication in the vacuum pump we will be using. Some other physical functional tests will include drawing basic shapes on paper with a pen or pencil replacing the melt laser, spreading a single layer of powder, and finally printing basic shapes. The printing of basic shapes will be a full system test, as it will require the proper interaction of all software and hardware components.

3.4 Non-Functional Testing

There are several non-functional parameters which can be evaluated for the printer. One obvious parameter to be tested is the printing speed, however it was made clear to us that this is not the top priority for our client. An important parameter for us to test is the ease of use of the printer, as well as the ease of modifying print settings. As the printer will be used primarily for research, people without a computer background will often be needing to use it and change parameters for various tests. We can evaluate the printer's ease of use by bringing in an outsider, perhaps one of Dr. Bigelow's grad students, to perform various tasks. Feedback from this test will allow us to create an easier to use interface, and improve the documentation we will have on using the printer.

3.5 Modeling and Simulation

Almost all of our current design work is being modeled in CAD software. This is key as it allows us to visualize how the printer will look before doing any manufacture. Furthermore, it allows us to identify potential interferences or complications with the way the parts are put together. Since the printer components need to be machined and manufactured by professionals, we do not have a lot of room for building a second revision without dramatically increasing cost, thus it is very important that our design is sound.

3.6 Implementation Issues and Challenges

Our greatest implementation issues and challenges lie in the mechanical nature of the project. In order to implement our printer design, we must manufacture the physical hardware of the printer. We have been in collaboration with the Chemistry Machine Shop on campus to do the machining and assembly of the printer components. The greatest challenge here is that our design must be manufacturable. For example, certain materials cannot be welded to other materials, and certain shapes are very hard to machine. Furthermore, small variations in our design can drastically impact the cost of manufacture. All of this leads to a considerable amount of time between a finished design and a finished project.

3.7 Testing Process

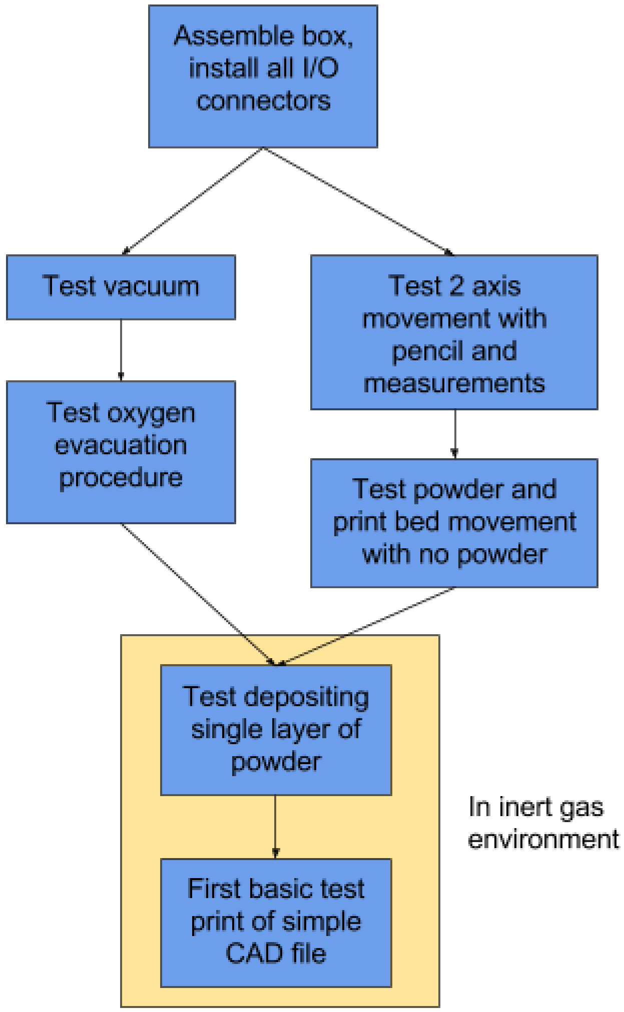


Figure 6, The basic steps in our system level testing process

The above flow diagram illustrates the major steps of testing which must occur in order to finish the project. The order of these large scale tests is important, as the depend on each other, and changes made to pass earlier tests could affect later tests. The timeline for this testing depends greatly on when the first manufactured components come in, which should be over winter break or early next semester. Then, depending on the results of initial tests, the rest of the testing could be quick.

3.8 Current Results

We have not reached the testing phase at this point. As we continue progressing, we will have results, lessons, and data to include here. As mentioned earlier, we should be able to begin the large scale testing phases once manufactured components arrive. We are very close to sending final drawings to a machinist, and will do so before the end of the semester. This should leave us with manufacture parts during winter break or early next semester, at which point we can start the above testing process.

We have started some of the unit/component level testing of software, which is going well. The rapid nature of software development allows us to quickly change components when they do not perform as expected. Currently, our software is able to parse STL format CAD files, and by the end of the semester will be able to generate 2D slices for an input CAD file.

4 Closing Material

4.1 Conclusion

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 a lot of the parts acquisition done by the end of the semester so that we can focus on making it work during the second semester. Our plan to achieve this goal includes sticking as one team for the entire project, weekly meetings as a team and with Dr. Bigelow, and constant communication about ideas and problems. The printer will interface and be controlled by a pc. The pc sends instructions to a set of stepper motors and the powder system. In return it will get data from sensors and cameras. Some of our biggest challenges include laser safety, interferometer limitations, and necessary preciseness in the laser.

4.2 References

[1] Albakri, Mohammed, et al. NON-DESTRUCTIVE EVALUATION OF ADDITIVELY MANUFACTURED PARTS VIA IMPEDANCE-BASED MONITORING . Virginia Tech, sffsymposium.engr.utexas.edu/sites/default/files/2015/2015-118-Abraki.pdf. Accessed 14 Sept. 2017.

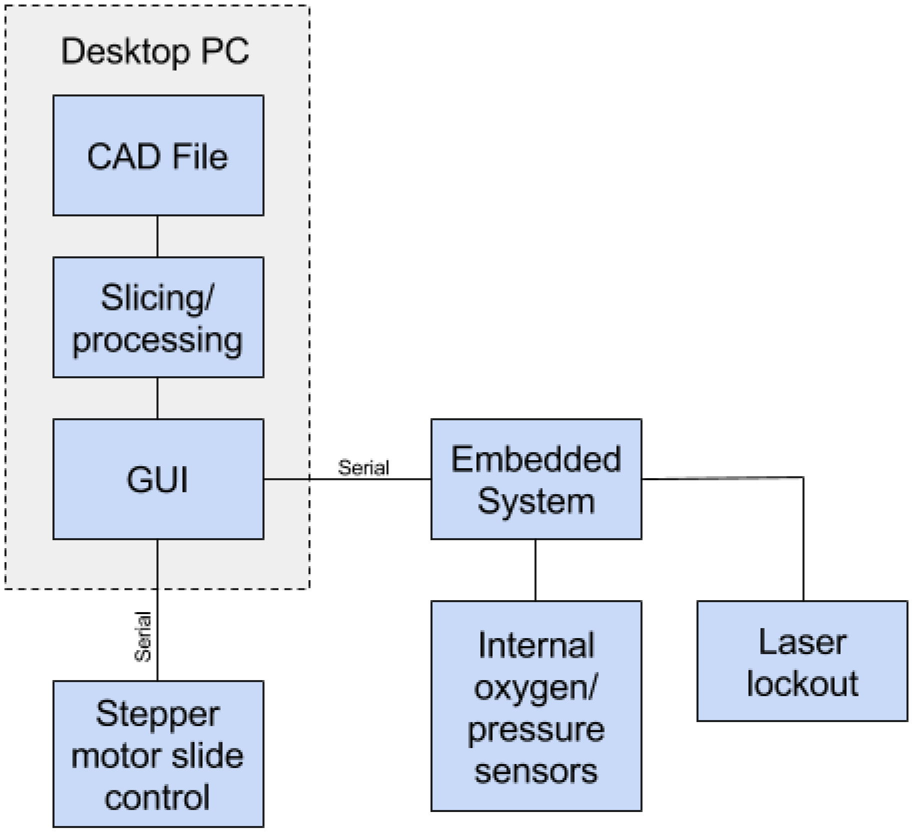
[2] "Laser | Environmental Health and Safety." Environmental Health and Safety, Iowa State University, www.ehs.iastate.edu/radiation/laser. Accessed 25 Sept. 2017.

[3] Slotwinski, J.A. Additive Manufacturing: Overview and NDE Challenges. National Institute of Standards and Technology, Engineering Laboratory, ws680.nist.gov/publication/get_pdf.cfm?pub_id=914545. Accessed 16 Sept. 2017.

[4] Sorrentino, Joseph. "Have technology advances made nondestructive testing more complex: the manufacturing industry is using additive manufacturing to create large metal parts for aircraft and other complicated shapes." Quality, Aug. 2014, p. 11+. Academic OneFile, go.galegroup.com/ps/i.do?p=AONE&sw=w&u=iastu_main&v=2.1&id=GALE%7CA390471659&it=r&asid=a33db15c0c41b06dd4b6882879c48472. Accessed 24 Sept. 2017.

[5] Waller, Jess, et al. "Nondestructive Evaluation of Additive Manufacturing." NASA, NASA, Dec. 2014, Nondestructive Evaluation of Additive Manufacturing. Accessed 12 Sept. 2017.

4.3 Appendices



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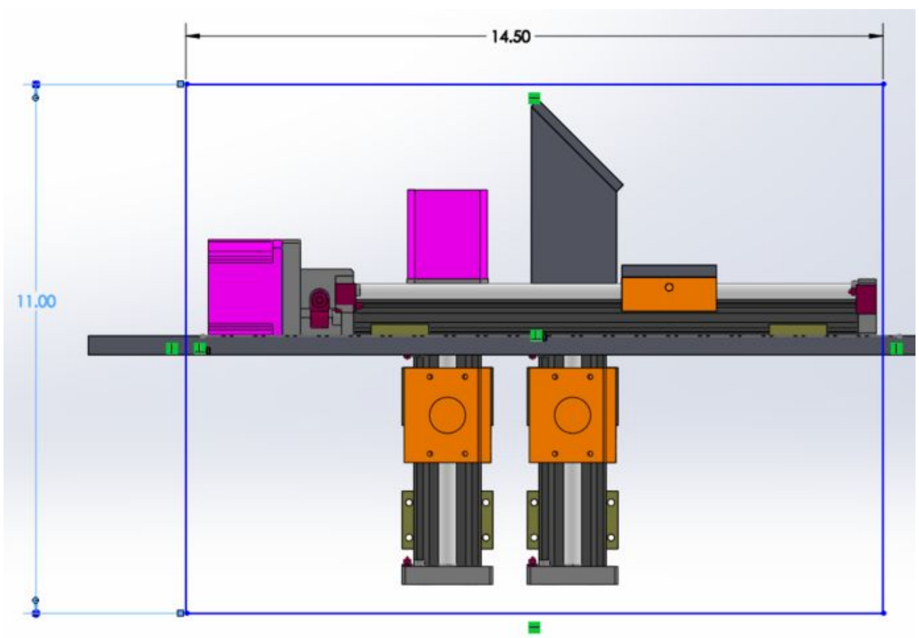

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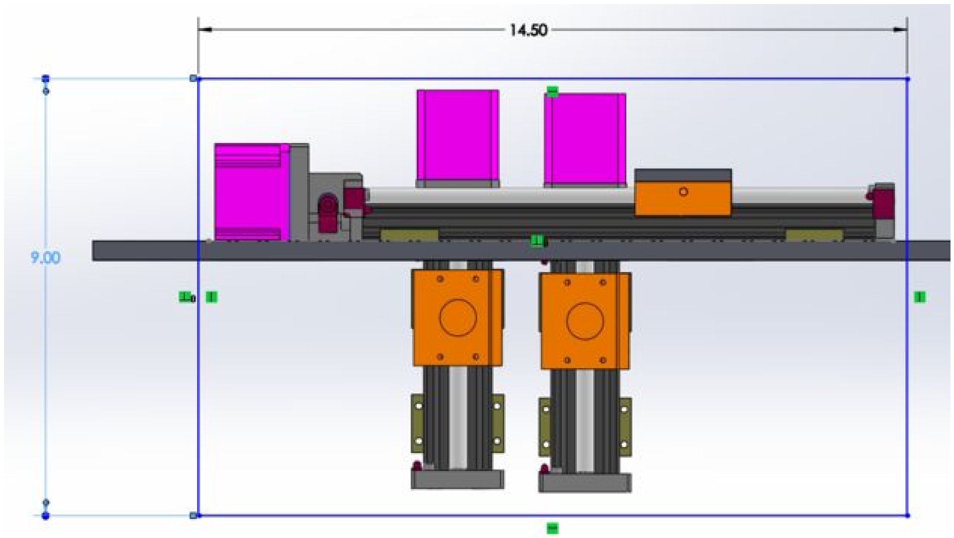

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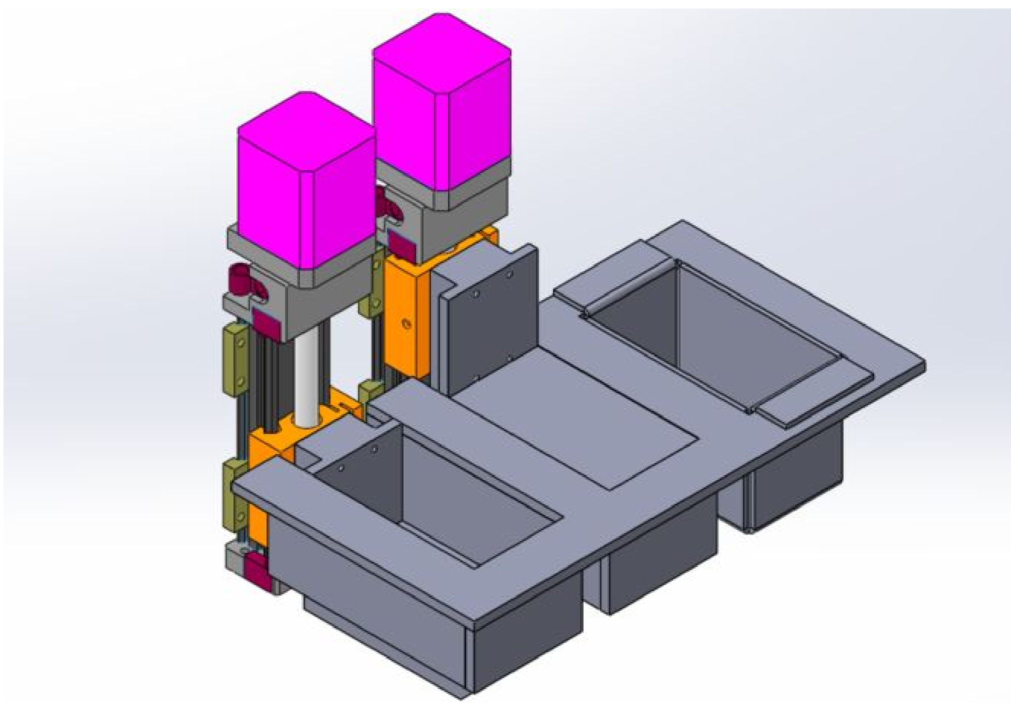

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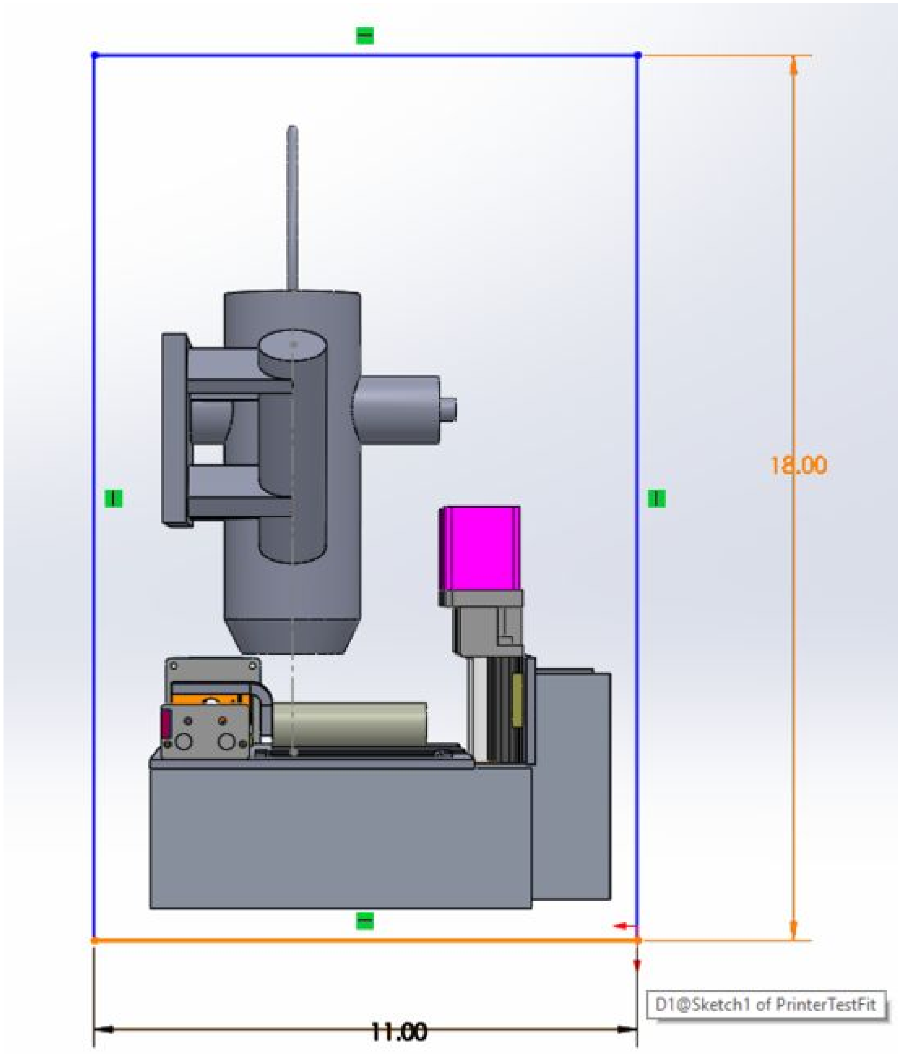

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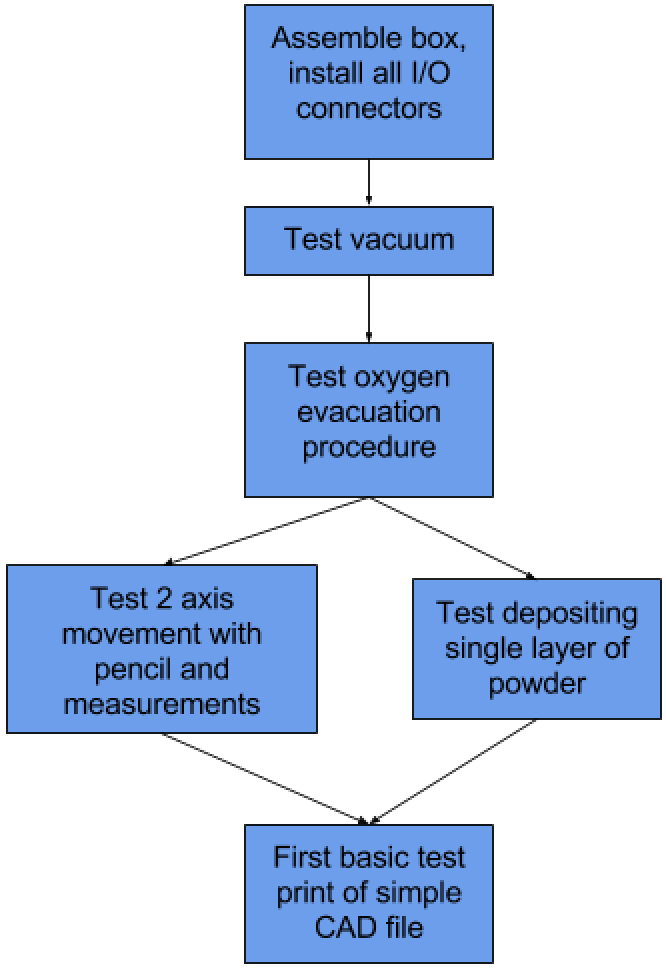

Figure 6, The basic steps in our system level testing process