3D Metal Printer

Design Document

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1 Introduction

1.1 Acknowledgement

Dr. Timothy Bigelow, Associate Professor of Electrical and computer Engineering at Iowa State, 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. 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.

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 $10,000. 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

At this point of the project, our team has done comprehensive research on finding the right stepper motors to order. Our first design assumed that we wanted to use a galvanometer mirror system to direct the laser beams. Unfortunately, this method introduced complexities into the programming of the control system, and also proved to be expensive. Abandoning this method, and going for the mechanically controlled laser head allowed us to simplify our design. However, upon receiving the exact specifications of the optical head housing the 3 lasers, our design needed to be adjusted for larger dimensions.

2.1 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 with the appropriate electronics in place to run the machine. Finally, the team will create a software interface to control the printer and print standard model files.

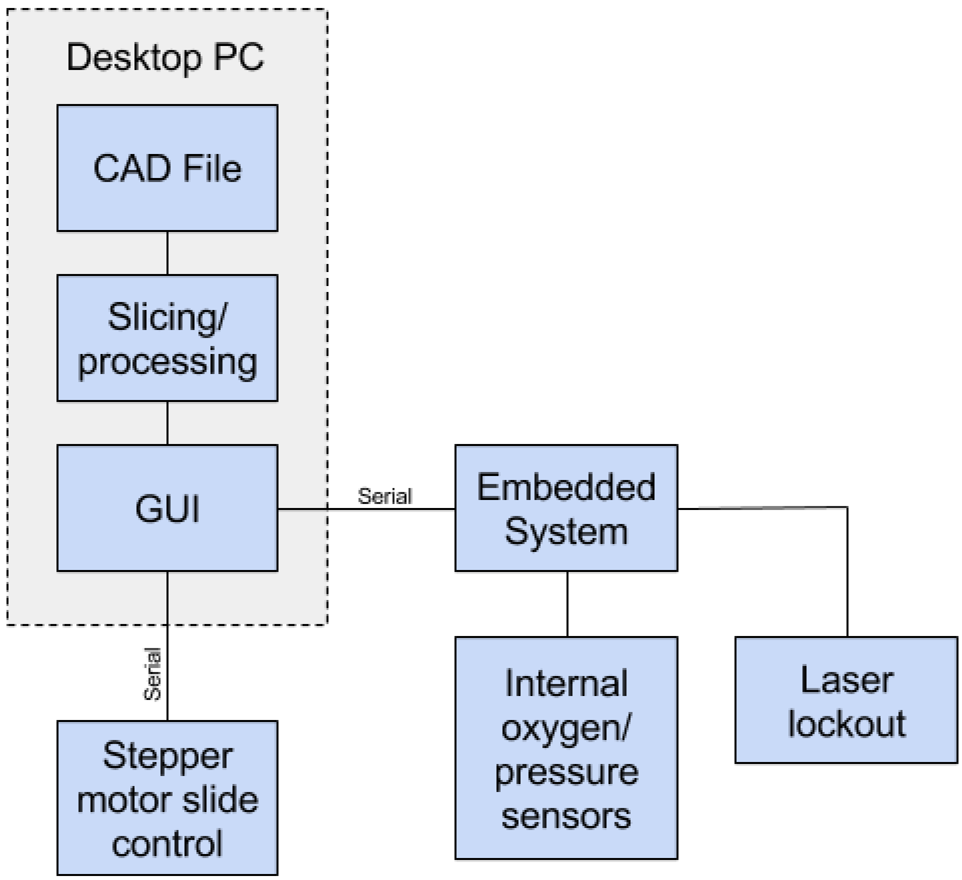

Figure 1, Software high level block diagram

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.

2.2 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.

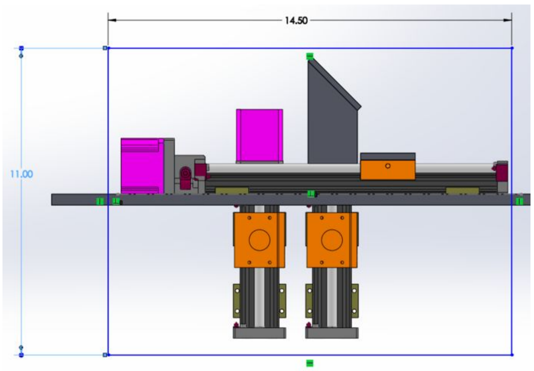

Figure 2 the mirror method

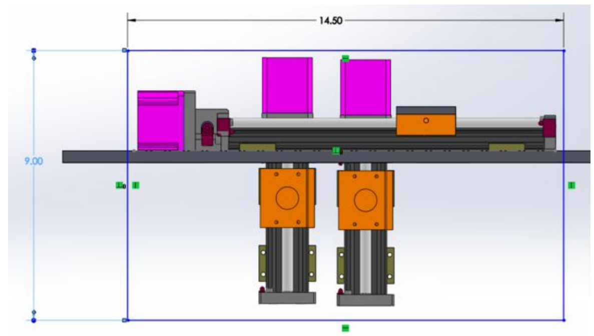

Figure 3 the window method

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.

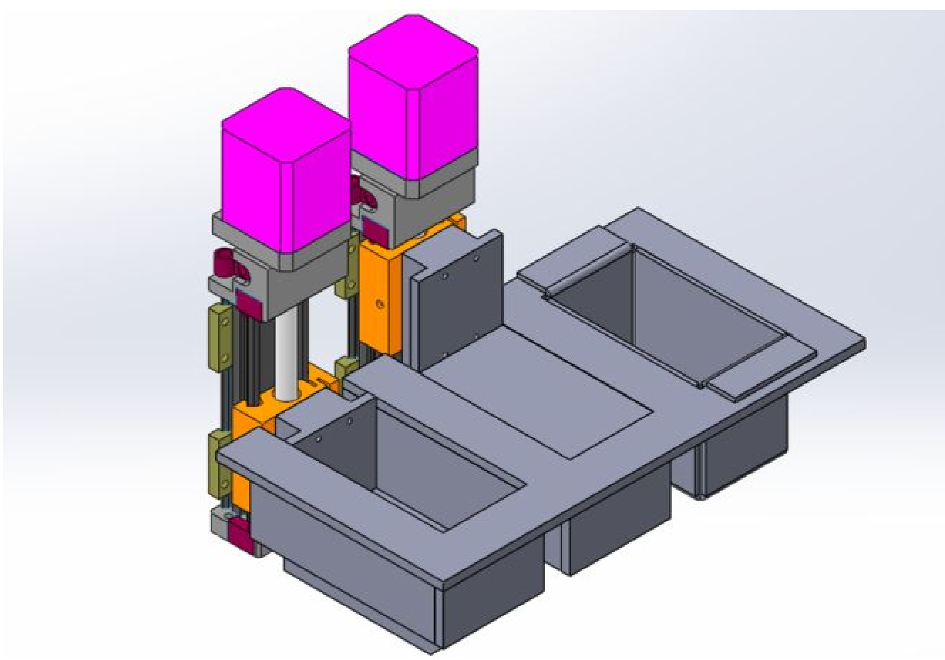

Figure 4 The current print bed configuration.

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 from the right in Figure 5.

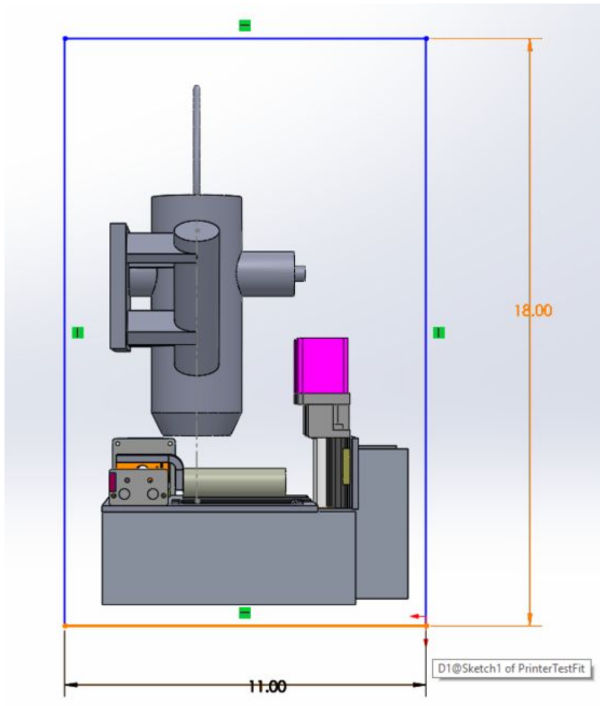

Figure 5 A side view estimating the size of the printer

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. We ordered a pc for interfacing with the device which we will likely also use this in a number of testing applications. 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 Process

At this stage in the process, we do not have enough information to reliably describe the testing process for each method in Section 2. In the coming revisions, we will have a much more thorough understanding of our testing process, and thus a complete process section. A flow diagram of the testing process is not possible at this time.

3.4 Results

We have not reached the testing phase to this point. As we continue progressing, we will have results, lessons, and data to include here. We will begin approaching this section within a month or two limited by hardware acquisition speed.

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

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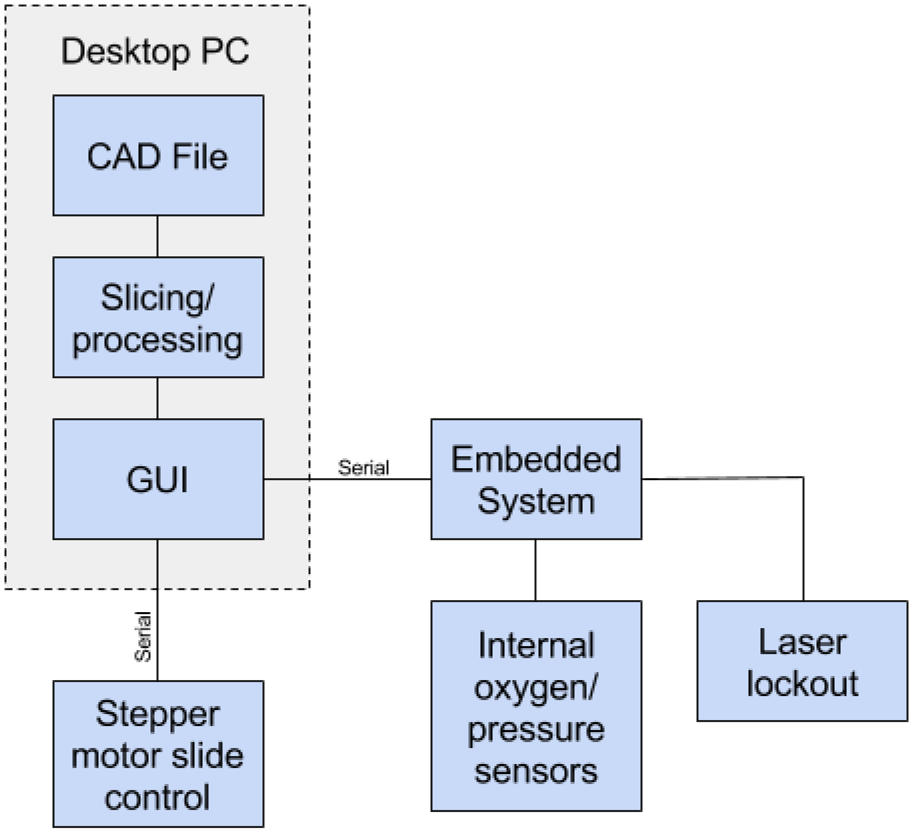
4.3 Appendices



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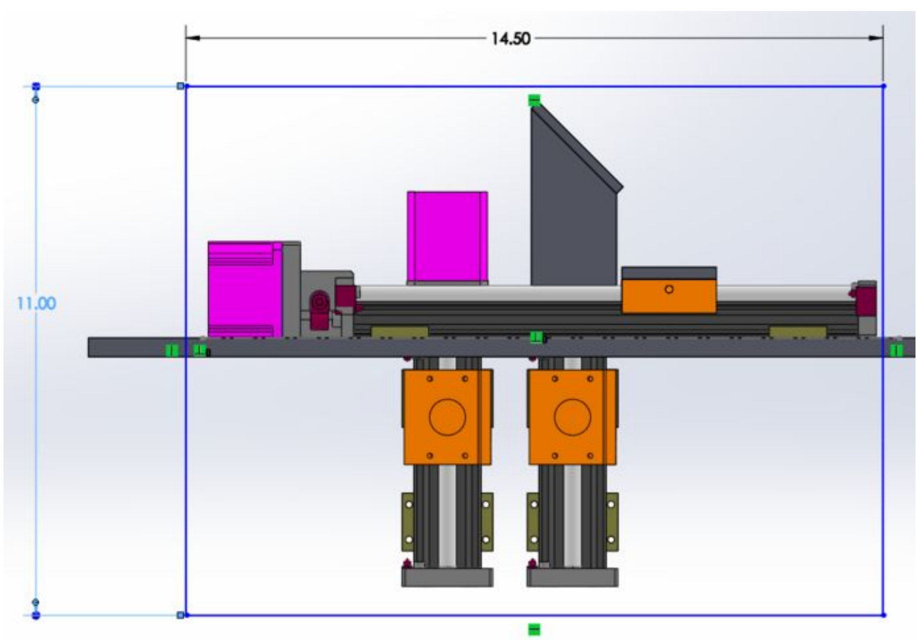

Figure 2 the mirror method

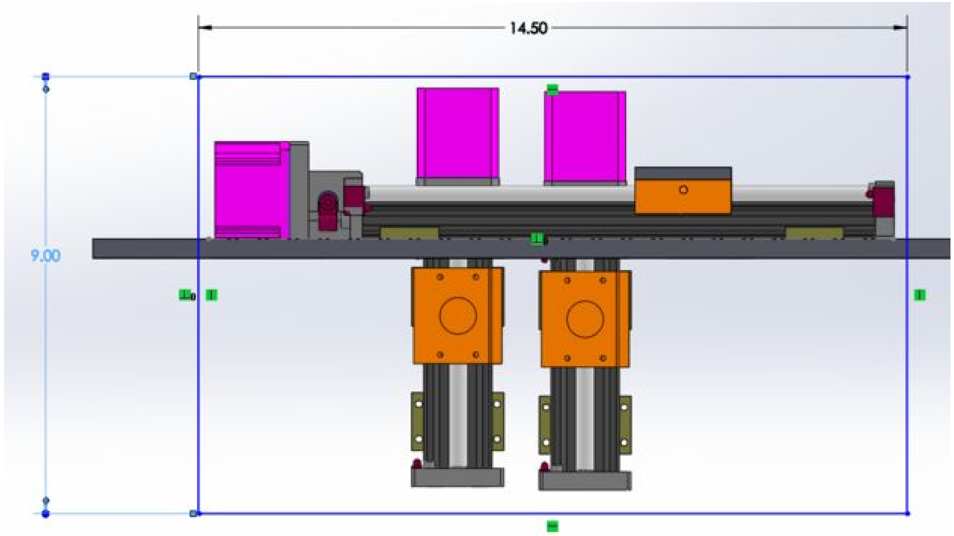

Figure 3 the window method

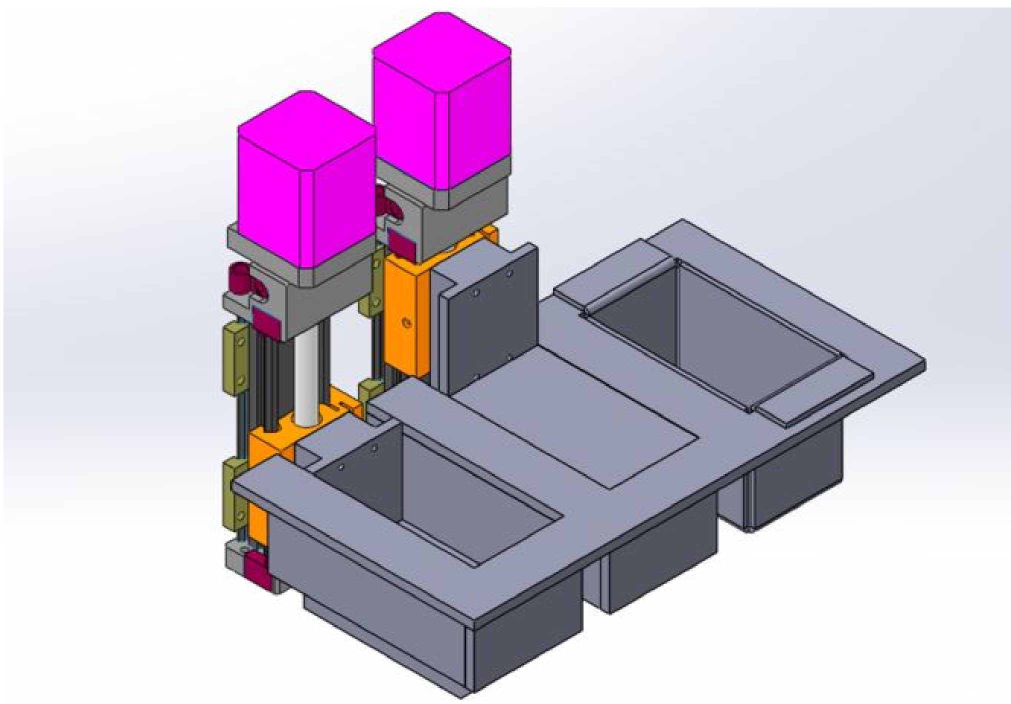

Figure 4 The current print bed configuration.

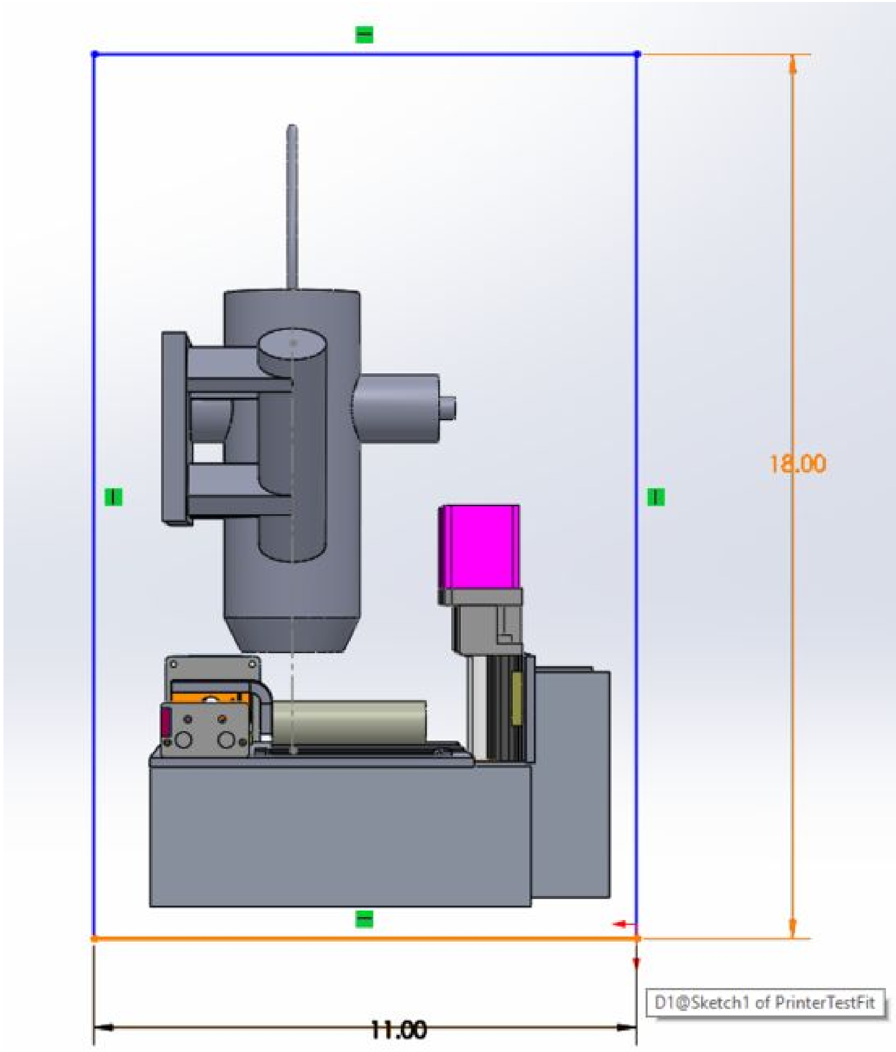

Figure 5 A side view estimating the size of the printer