Powder Bed Metal Printer

DESIGN DOCUMENT

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Executive Summary

Development Standards & Practices Used

List all standard circuit, hardware, software practices used in this project. List all the Engineering standards that apply to this project that were considered.

Summary of Requirements

- Refactor and convert source code from C# to Matlab
- Be able to print 3 cm^3 metal blocks
- Adjustable laser scan line spacing
- Adjustable voxel count per box
- Create a defect at a specific location
- Extend capabilities of existing/new sensors

Applicable Courses from Iowa State University Curriculum

The Iowa State University Computer Engineering courses that were applicable to this project were CPR E 185, 186, and 288. The Iowa State University Computer Science courses that were applicable to this project were CS 227, 228, 309, and 311. The Iowa State University Electrical Engineering course that was applicable to this project was EE 224. The Iowa State University Aerospace Engineering course that was applicable to this project was AERE 161 (Introduction to Matlab).

New Skills/Knowledge acquired that was not taught in courses

C# and MATLAB are two programming languages that were not taught in required courses at Iowa State, so it is necessary to learn and become familiar with both languages in order to complete the project. G-Code, a language used by 3D printers and CNC machines, was also not taught to students, so creating

software to interface with CNC machines will also need to be understood to complete the project.

Table of Contents

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

1 Introduction

1.1 ACKNOWLEDGEMENT

Dr. Timothy Bigelow, Associate Professor of Electrical and Computer Engineering at Iowa State University, has served as the faculty advisor for this project. Professor Bigelow has and continues to provide excellent guidance, technical advice, and other assistance to this project. Professor Bigelow has also provided the necessary funding for this project. His assistance is greatly appreciated and needed in order to complete this senior design project. Additionally, Franklin Sullivan is an undergraduate student that assisted Dr. Bigelow last semester by adding helpful comments to the last senior design group's code.

1.2 PROBLEM AND PROJECT STATEMENT

Problem Statement:

The general problem is that Professor Bigelow and his graduate students are having issues debugging and modifying the C# implementation of software for their 3D Printer.

Solution Statement:

The general solution is to rewrite the code using MATLAB, which is software that the users are familiar with and conduct tests to make sure that the software works properly.

1.3 OPERATIONAL ENVIRONMENT

The end product will be used inside a lab in the Applied Sciences II building. The metal prints will be done in a sealed container filled with Nitrogen to prevent oxidation. Due to the possibility of excess nitrogen venting into the lab, training will be required to prevent suffocation by the operators of the 3D printer.

1.4 REQUIREMENTS

Functional Requirements:

- Refactor and convert source code from C# to Matlab
- Be able to print 3 cm^3 metal blocks
- Adjustable laser scan line spacing
- Adjustable voxel count per box
- Create a defect at a specific location
- Extend capabilities of existing/new sensors

Environmental Requirements:

- Metal Printer operates in a nitrogen rich environment
- Metal powder used is hazardous to the lungs
- Must be able to obtain proper respirators for lab work
- Obtain proper training in order to work in the lab

Economic Requirements:

- Most of the funding required for this project has already been used for items such as the metal printer, sensor systems, and other equipment
- May need additional funding for respirators, and other miscellaneous items such as auxiliary sensors

1.5 INTENDED USERS AND USES

The intended use is for Graduate Students and Professors at Iowa State University to operate a metal 3D printer for the purposes of generating metal cubes and other structures.

1.6 ASSUMPTIONS AND LIMITATIONS

Assumptions:

- The 3D printer will be able generate small metal cubes
- Only one person will be controlling the 3D printer software at a time

Limitations:

- The 3D printer may not be able to generate more complex structures by the end of the project
- Tests will only be performed once personnel have received sufficient safety training

1.7 EXPECTED END PRODUCT AND DELIVERABLES

One deliverable for this project will be refactored code to control the printer and generate G-Code. The refactored code will be delivered by the end of the Spring 2021 semester, May 7, 2021. The refactored code will consist of MATLAB functions that will function the same as the old C# code or better. The refactored code will also be functional instead of object-oriented.

Another deliverable for this project is the testing of the 3D printer. The 3D Printer tests and code revisions will be completed by the end of the Fall 2021 semester, December 17, 2021. The 3D Printer tests will consist of generating and printing metal cubes and debugging the refactored code. The end result of the testing and debugging will be a working 3D printer that will be easier for Dr. Bigelow and his Graduate students to modify as needed.

2 Project Plan

2.1 TASK DECOMPOSITION

- Port the object oriented C# code from previous groups to function-oriented Matlab code
  - Slicer program which converts .stl files that represent 3D objects into gcode which represents instructions for the motors of the printer.
    - Slice the object into several layers
    - Slice the layer into several voxels with infill supports
    - Print a gcode line for each point of the layer
  - Printer Control Unit which manages the motors of the printer
    - Read a gcode file, translate the changes into motor movements

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    - Write the motor movements to the corresponding COM port
  - Build and code usable external sensors using arduino
    - Create and test different external sensors
    - Test and debug sensors within the actual printing machine

2.2 RISKS AND RISK MANAGEMENT/MITIGATION

The only real risks that exist in the printing process are the laser blinding eyesight, the room becoming too enriched with nitrogen, and the aluminum powder that is hazardous when inhaled. The laser risk is mitigated by the shield door being correctly placed on the machine before printing is started. The risk created by the nitrogen can be mitigated using sensors that ensure the oxygen level of the room is normal. Air is 70% nitrogen to begin with so it only creates a risk when oxygen is driven from the room. The risk created by the aluminum powder is more severe and may be difficult to deal with because it is required for printing to be completed. The only option is to be cautious when measuring the aluminum powder and ensuring that an excess is not created. There are not any procedures or products that would mitigate this risk, rather just precautions and proper steps to be taken.

2.3 PROJECT PROPOSED MILESTONES, METRICS, AND EVALUATION CRITERIA

- Port the object oriented C# code from previous groups to function-oriented Matlab code
- Build and code usable external sensors using arduino
- Print metal cube

2.4 PROJECT TIMELINE/SCHEDULE

Action/Task	Completion Date
Finish porting code	End of Semester 1
Be ready to test working sensors	End of Semester 1
Finish laser control	End of Semester 2
Ensure sensors are working	End of Semester 2
Print metal cube	End of Semester 2

2.5 PROJECT TRACKING PROCEDURES

The group has set up a Git Repository to share and store all necessary documentation and code. The group also uses a team discord to communicate with each other and share documents and links.

2.6 PERSONNEL EFFORT REQUIREMENTS

Action/Task	Time required for completion
Port the object oriented C# code from previous groups to function-oriented Matlab code	30-60 hours
Build and code usable external sensors using arduino	20-40 hours
Troubleshoot and debug	10-30 hours
Print metal cube	~

2.7 OTHER RESOURCE REQUIREMENTS

- External sensors
- Arduino parts

2.8 FINANCIAL REQUIREMENTS

n/a

3 Design

3.1 PREVIOUS WORK AND LITERATURE

There was a significant amount of research done by the two teams preceding this team on the project and as such we are inheriting much of and are largely constrained by their design decisions. Notably, these decisions entail the exact types of hardware and how the actual 3D printing takes place. The design of the printer came out to be a 2 part system including 1) a roller which deposits metal powder from a supply bed and 2) a laser which then sinters that metal into place. This system is seen in figure 1. The documentation for this work is available from archives of previous semesters or on request.
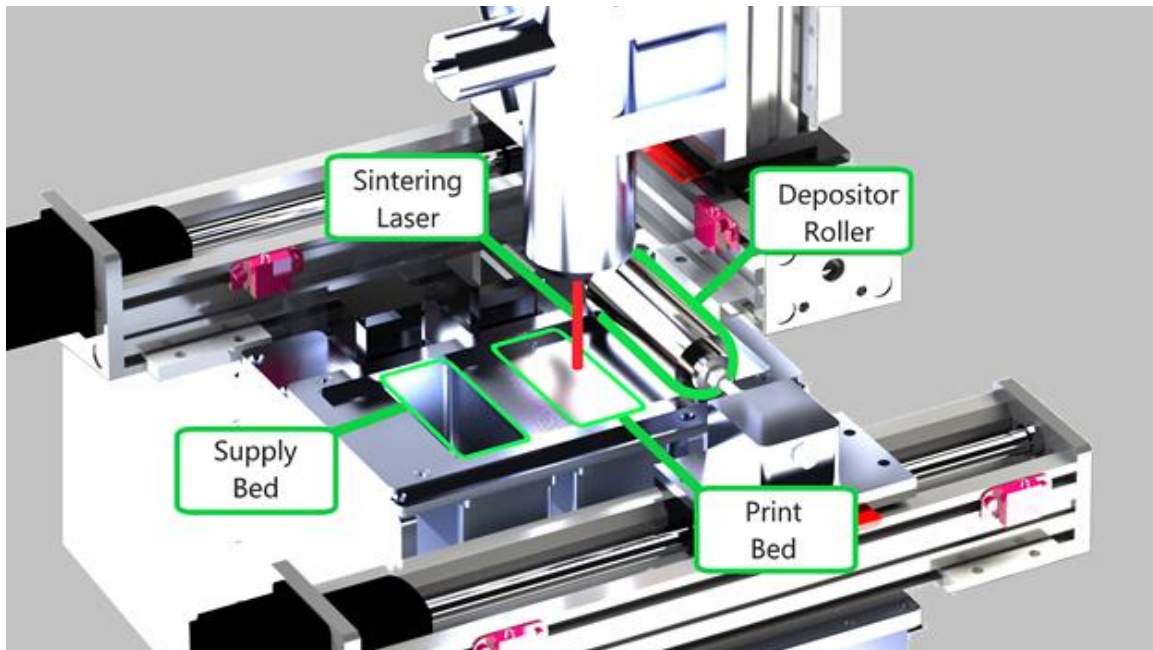

Figure 1: Previously designed Powder Metal Printing System

3.2 DESIGN THINKING

The two main approaches the team developed in the "define" stage of development were to either a) stick with the previous team's software approach or b) start anew and rewrite the software from scratch in MATLAB. Both approaches had some benefits and drawbacks.

Notably for option a, the team could write software in a much more clean and clear way insofar as we would be the ones who are the original authors and therefore have the best understanding of the code. Further, the previous team's approach appeared to have some issues as far as extensibility that may hold back the approach at the end. In terms of drawbacks, this approach would take significantly more time and effort in how the team would have to look into alternative ways of creating a slicer program from scratch, for example.

As for option b, the team saw the main benefit as being able to work off the previous team's work and not have to rewrite the entire software. This would mean far less work as far as reaching the mandatory goal Dr. Biglow laid out. Reaching the stretch goals may become an issue however, and there is a possibility there was a mistake in the original approach which makes it untenable. After this "define" stage, the team opted for option a.

In the "ideate" stage the team came up with some ideas such as:

- Breaking gcode generation functionality into smaller, more manageable chunks
- Develop a new algorithm for generating infill voxels (to be more in line with requirements)
- Create a more intuitive way for defects to be placed
- Create more options for types of shapes and potential defects

3.3 PROPOSED DESIGN

The software design of the project consists of 3 main parts: the slicer, the printer control unit, and the sensor system. First, the slicer program divides up a 3D object .stl file into a series of instructions for the printer in a gcode file. Then the printer control unit will read this file line by line, and translate the instructions to commands to send to the motor controllers that move the laser and the printer bed. The sensor system will check that the conditions within the chamber are nominal before any action is conducted.

To print a 3cm cube, the 3D printer can't just print the layers of material that make up the walls of the cube. To provide support, the slicer program must divide up the object into layers with support structures called infills. The image below illustrates the "scanline rasterization" method that the infill pattern must be drawn in.

Figure 3: Example voxel

We will be working with 2 standards. The slicer works with the STL files, an ASCII text file format produced by most 3D CAD software defined in the ISO / ASTM52915 - 20 standard. The other standard that we will be handling is the gcode file defined in the ISO 6983 standard. Because of the nature of our hardware, we may have to deviate from the gcode standard, as our printer may need to support actions not specified within the standard.

The printer control unit acts as the brain of the printer. Each instruction in a gcode file maps to certain motor movements. The Velmex Motor Controllers (VXM) which handle the printer bed and laser communicate with the computer via COM ports.

The sensor system is composed of an oxygen, temperature, and pressure sensor connected to an Arduino. This system is crucial because of the specific conditions within the printer's chamber that are necessary for operation. The printer operates in a pressurized, nitrogen filled environment, to prevent the high temperature laser from igniting any oxygen. All three sensors must detect a safe environment before any printer actions are performed.

So far our group has implemented various helper functions for the slicer and printer control units. More specifically, the slicer group has completed gen_voxel(), which generates a tileable square with an infill pattern. The printer control group has completed gcode_reader() which reads in the

gcode and maps them to VXM commands. Both have been functionally tested and confirmed to have expected results. The sensor team has acquired the arduino and sensors and is actively working on implementing the sensor functions.

These functions are easily testable as their results can be verified through console log messages. Ideally we want to complete as many parts of the project that can be tested remotely first. In-person testing with the hardware will require setting a meeting at the lab in ASCII, and completing a lab safety certificate.

3.4 TECHNOLOGY CONSIDERATIONS

The team is constrained to the technology made available to the team at the beginning of the project as well as in the requirements. Notably this means the team must use the available VXM system, oxygen and pressure sensors, lab computer, laser, and other such hardware. In terms of software the team is constrained by the requirements to use MATLAB to refactor the code.

3.5 DESIGN ANALYSIS

The team is in the beginning stages of implementing the proposed design in 3.3 and it does not appear to need any modifications or iterations at the moment. We are prepared to make any alterations as additionally information arises.

3.6 DEVELOPMENT PROCESS

The group is moving forward with an Agile approach for development of the system. We are utilizing the system provided by GitLab to track issues and label them according to their respective milestones (sprints). While the team will not be performing Agile in the exactly proper way insofar as daily meetings go, the team is using Agile as a starting point and adapting it to our needs.

The team decided on Agile because it is a system some members were quite familiar with from previous experience and those members felt that it would be an effective way of organizing the work for a project of this scale. The project has many concurrent pieces of working going at the same time, and so Agile provides an effective way of keeping track of these sets of tasks and making sure the team is completing each set of tasks in a desirable amount of time in accordance with the other sets of tasks.

3.7 DESIGN PLAN

Although we are inheriting this project from 2 other senior design groups, Dr. Bigelow has authorized a rewrite of the software in MATLAB. The main non-functional requirement asked of us by Dr. Bigelow is "clarity". We will use this opportunity to redefine design choices and write code under an imperative programming paradigm instead of the object oriented one used by previous senior design groups.

The figure below shows the architecture of the project, as well as how the data flows from one module to another:
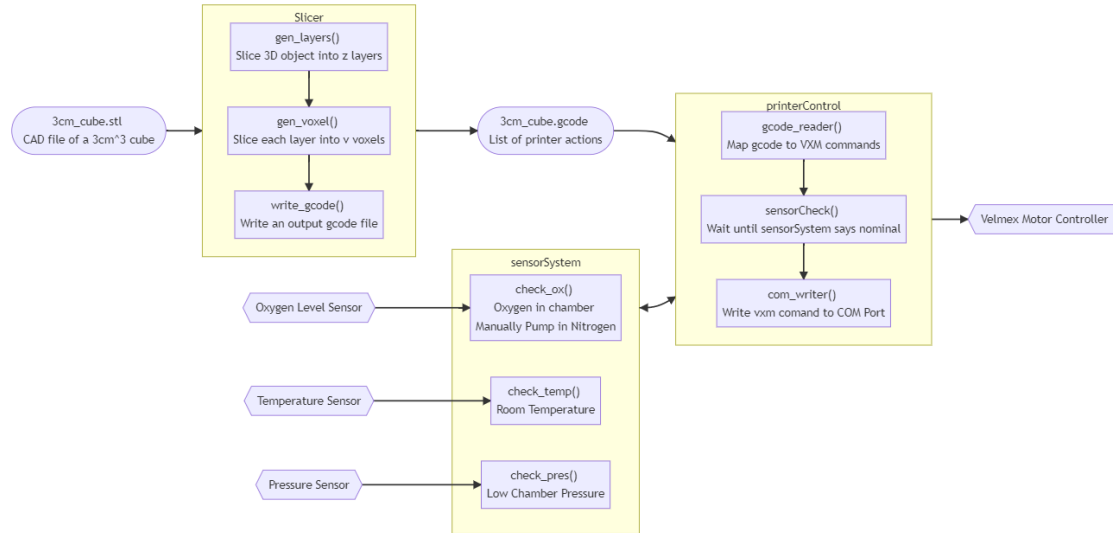
Figure 2: Software Flowchart

This project architecture is largely based on the previous group's i.e. there are three modules used to break up the software into parts. Each module has an input and output:

Module	Input(s)	Output
Slicer	STL File	Gcode File
Sensor System	Oxygen Sensor Data Temperature Sensor Data Pressure Sensor Data	Sensor Status
Printer Control	GCode File Sensor Status	Velmex Motor Control

Importantly the Slicer is independent from the other two modules; it is run separately before the print whereas the Sensor System and Printer Controller are run together during execution of the print. As a result, both the Slicer and Printer Controller will have two separate interfaces. Further, the Sensor System will be run asynchronously and will send information about the status of the sensors if an error occurs when the sensor safety conditions are not met.

4 Testing

4.1 UNIT TESTING

This project is made up of both hardware and software components. Therefore, both hardware and software units will require testing in order to accomplish the project goals.

This project will be composed of a MATLAB program that will take a stl file (CAD like file) and input parameters that will be used by our slicer program in order to convert the stl file into a gcode

file that can be read by the 3D metal powder printer. The 3D metal powder printer will read these commands and activate stepper motors and first use a roller in the vacuum chamber to push metal powder into the printing area. The 3D metal powder printer will then use the motors and laser to shape the metal powder into the intended object (in our case a metal cube). The vacuum chamber that contains the 3D printer will also house a camera so we can watch the printing process. The chamber also contains a temperature and pressure sensor at the moment.

To start out with, one software component we will be unit testing will be the infill MATLAB file. This program will be responsible for tracing the infill design for each voxel in the object being printed. We will need to make sure that this file works in isolation of the rest before integrating it. Another software component we will need to test will be the overall slicer file. This MATLAB file is in charge of taking the stl file and other input parameters, and converting it into gcode for the 3D printer to read. Another file we will need to test in isolation is the gcode to vxm files. These Matlab files will be responsible for taking the gcode files the slicer program makes and converting them into commands that the stepper motors for the 3D printer can read and interpret.

There will be a few hardware components that will require unit testing. One hardware component that will be unit tested is the pressure sensor located in the vacuum chamber. This sensor will be in charge of measuring the pressure in the vacuum chamber. Since the chamber takes oxygen out of the chamber and replaces it with a pure nitrogen environment, we will need to make sure the pressure sensor is working properly to measure these pressure changes. Another item that will be unit tested is the temperature sensor. This sensor will measure the temperature in the vacuum chamber. Another hardware component that will be unit tested is the camera located inside of the vacuum chamber. We will need to make sure that this camera is working properly if we are to monitor the printing process inside the vacuum chamber. Another hardware item that will be unit tested is the laser. The laser is responsible for turning the metal powder into solid metal. We will need to make sure that the laser works if we are to print any objects. One of the last hardware objects that will be unit tested is the motors. The motors are responsible for moving the printer.

4.2 INTERFACE TESTING

1. Slicer GUI

   This GUI is responsible for interfacing with the user in order to get printer parameters such as the stl file and other input parameters needed for the slicer file. This GUI will interact with the files that make up the GUI and the slicer files. First we will unit test all of the files and functions that make up the GUI and make sure they all work. Then, we will start integration testing with the Slicer GUI. Since this interface is a user interface, we may decide to use a tool such as Selenium in order to do integrated testing on the GUI.

2. Main Menu GUI

   This GUI can be thought of as the "main menu" for starting the printing process. This GUI will start the printer, stop the printer, and take you to the slicer GUI. After unit testing all of the functions and files that make up the GUI and interact with the GUI, we will begin integration testing the GUI. Like stated above, we will probably use an automation tool such as Selenium in order to test the Main Menu GUI.

4.3 ACCEPTANCE TESTING

The team will demonstrate that the design requirements are being met for both function and non-functional requirements by demoing the project to our client (Professor Bigelow) and showing that each component of our project is meeting the design constraints and requirements. Such functional testing, nonfunctional testing, and modeling and simulations that we will demo to the client are the following.

Functional Testing:
- Test slicer program
- Test gcode to vxm motors program
- Test infill algorithm
- Test that vacuum chamber seals correctly
- Test camera
- Test temperature and pressure sensors
- Test stepper motors
- Test Main Menu GUI
- Test Slicer GUI

Nonfunctional Testing:
- Test the speed at which printing is taking place
- Test structural integrity of part being printed
- Test that the GUI is easy to use

Modeling and Simulation Testing:
- Test how the CAD models look in a modeling environment
- Simulate how the gcode will trace the printing process
- Simulate how the actual 3D printer will trace the object

4.4 RESULTS

So far we have not done a lot of testing overall at this stage of the project. So far we have only done some unit testing on helper functions that will be used in the slicer file. We have also done some testing on the Main Menu GUI which is not done yet. There have only been minor successes so far. The unit testing that has been accomplished so far have had successful results. We have learned that it is best to approach this project in iterative steps, starting with developing simple implementations of the project and working our way up to more complicated implementations. This project requires a lot of doing our own research so it is best to start with simple implementations and increase with complexity as we learn more.

5 Implementation

Within the first semester, we plan to complete the first deliverable of having finished porting over the object oriented C# application to a functional programming MATLAB application. This includes the slicer program and the aspects of the printer control unit necessary for motor movement, whose functionality can be confirmed safely. Additionally, we plan to incorporate features requested by Dr. Bigelow, as well as add some simple documentation, as the program will be modified by his grad students.

Around the end of the 1st semester, we plan to complete the ASCII lab certification to be able to test our application within the lab environment. In this lab environment we can test and integrate the sensor system into the printer.

The second deliverable, incorporation of melt laser control, can be completed during the first half of the 2nd semester. This involves rigorous in-person testing and monitoring of the melt laser which melts down the aluminum powder.

If the first 2 deliverables can be satisfied successfully, we should be able to complete the final deliverable which is being able to print a metal cube by the end of the 2nd semester.

6 Closing Material

6.1 CONCLUSION

Currently, we are still working on translating all of the previous C# code into MATLAB, as well as continuing to work on our own splicer program, and understanding the Arduino code for the sensors as well. Our end goal at the present moment is to be able to print 3cm^3 metal cubes. The more specific items we are in the process of working on are: to have adjustable laser scan line spacing, adjustable voxel count per box, creating intended defects in specific locations, as well as extending the capabilities of the current sensors, and adding new sensors as well. We still have yet to enter any of the testing stages with the printer itself, and we all still need to receive proper training in order to use the metal printer as well. Currently, it seems that we are on a good pace to accomplish all of the goals that we currently have set in place.

6.2 REFERENCES

"Makers of MATLAB and Simulink," *MathWorks*. [Online]. Available: https://www.mathworks.com/. [Accessed: 10-Mar-2021].

S. Gaisford, R. J. Crawford, and J. L. Throne, "Powder Bed," *Powder Bed - an overview | ScienceDirect Topics*, 2017. [Online]. Available: https://www.sciencedirect.com/topics/engineering/powder-bed. [Accessed: 10-Mar-2021].

6.3 APPENDICES

No appendices currently applicable