CS CAPSTONE DESIGN DOCUMENT

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AUTOMATED INSTANTIATION OF DESIGNED EXPERIMENTS WITH ADDITIVE MANUFACTURING

PREPARED BY

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Abstract

This paper will provide an introduction of our project: "Statistically Optimizing Design of Experiments Software", and dive into the different tools and technology that will be utilized. This will include an in-depth look at optimization techniques, programming languages, APIs, and computer-aided design software. Working with Computer-aided Designs (CADs) and 3D printing, our tasks include: creating a statistical optimization software using design of experiments techniques, 3D printing models to experiment on and optimize, and our main focal point of automating the process of the experiments and optimization when able to: inputting parameters into a CAD and creating the variable designs, etc. In this document, we will discover the technology that we will use to satisfy our project. First we will discover the method of optimization, then we will explore different programming languages to utilize the method of optimization, and finally, the SolidWorks API and the software that will be used to manipulate it.

CONTENTS

1 Introduction

Creating optimization software that utilizes different statistical methods to optimize various object designs is the essence of this project. The main components of this project include: designing the optimization method, creating the algorithms to implement the optimization and file handling, designing the graphical user interface (GUI), and utilizing the SolidWorks API to create objects. Some secondary components this project include: designing the objects in SolidWorks, running experiments on said objects, and implementing automation where possible. The rest of this paper will focus on the implementation of the main components of the project and the technology that will be utilized.

2 Glossary of Terms

Application Programming Interface (API) - Application Programming Interface (API) - Software that is used for the user/client to be able to interface with a server to simplify the process of creating software

Computer-Aided Design (CAD) - Software such as SolidWorks that allows the user to create and modify 3D shapes to be able to 3D print them.

Design of Experiments (DoE) - A branch of applied statistics that handles planning, conducting, analysing, and interpreting controlled experiments to evaluate the variation of a parameter or group of parameters.

Graphical User Interface (GUI) - Software that provides a visual interface that the user can interact with, usually with large icons or buttons with labels on them that allow the user to navigate the application.

Least Square Method - Method that can be used to get the regression line from given points.

Regression Line - It is a line that tells us the linear relationship between many dots.

3 Optimization: Least Square Method

Our project is focused on automatically find the optimal object form. Therefore, we should collect the performance data from the samples, analyze them, and suggest the optimal form. To analyze the data, we will use the least square method. The least square method is a method that is used in linear algebra. Let there are N variables and $\vec{x_1}, \vec{x_2}, ..., \vec{x_n}$ are given points. Then the least square method gives a linear function $L(\vec{x}) = \vec{c} \cdot \vec{x}$ such that

$$\min_{\vec{c}} \sum_{i=1}^{n} (L(\vec{x_i}) - \vec{x_i})^2.$$

It means that the linear function from the least square method gives the function that has the shortest distance from all points. Therefore, the least square method gives the approximation of data to the linear function. Thankfully, by changing the form of data, the least square method can be used to approximate nonlinear functions like polynomial functions, exponential functions, logarithm functions, and more, Therefore, we will use this method to get approximate of performance function and optimize the given object.

The benefit of using the least square method is it can approximate to various forms of functions. The functions that can

be approximated by the least square method can explain the equations from physics. Since our project is dealing with the physical structure and measure physical performance, the least square method can provide proper approximation function. The second benefit of using the least square method is it gives a clear estimation of the given approximation function. It returns a non-linear function that has the least sum of the distance between data and the function. Therefore, by checking the least sum of the distance value of each function, we can find which function is the better approximation function. However, we should be careful while we are doing this because the polynomial approximation with higher-order could give over-fitting problems. Therefore, the least some of the distance value should be not 0 and allow the noise.

The other method that can be used to get the approximation function is the regression modeling method and the machine learning method. The regression modeling method is good if our project guaranty that the performance of the object is always following the linear function. In our case, it is not guaranteed to be approximated by an only linear function. Therefore, the regression modeling method is not an appropriate method. The machine learning method is also a good tool to get the performance function. However, in our project, it does not provides much data. For each case, we will have less than 30 samples to analyze. Therefore, there is a high probability that if we use machine learning then it gives some random function that only passes by the given data points. Therefore, the machine learning method can be useful if we analyze the one object for a long time so that we have a lot of data sets. However, our data sets are not randomly chosen data. The first data set is randomly chosen data but the next data set is chosen due to the performance function. Therefore, even though we use the machine learning method since it gets biased data, it will return a similar function that can be got by the least square method. Therefore, we choose to use the least square method.

4 Optimization Programming Language & Automation

There are 3 main options when it comes to statistical computing: JSL, R, and Python. Each one has their pros and cons: JSL is a paid software and has limited general programming, but a variety of statistical operations that can be done on datasets [1]; Python is free, supports a vast variety of different computing styles, is object oriented, and has sufficient DoE and statistical libraries [3]; R is free, has a lot of statistical operations, and extensive DoE support [5]. The biggest issue is how compatible each of these languages are with others. Being able to easily integrate each language into this project will play an important role in project development. With that being said, Python brings the most to the table out of the three programming languages that we looked at.

4.1 Python - pyDOE

The main library of python that we will be using is pyDOE: a design of experiments library which requires the Python libraries NumPy and SciPy [6]. pyDOE utilizes these libraries when applying design of experiments techniques on different data. These libraries play a vital role in the functionality of pyDOE [6].

4.1.1 NumPy

NumPy is a library that adds support for multi-dimensional matrices and arrays, and high-level mathematical functions to operate on these data structures [7]. This is necessary for pyDOE because pyDOE uses matrix mathematics for optimization methods, and data storage and comparison.

4.1.2 SciPy

SciPy is a Python library that provides support for high-level scientific and technical computing [8]. This includes support for:

1) Optimization
2) Linear algebra
3) Integration
4) Interpolation

These mathematical operations are necessary when doing design of experiments work on CADs, but most notably the statistical optimization method as it supports many different variants of such.

5 API: C# GUI, VBA CAD Mod

5.1 SolidWorks API

To edit a Computer-Aided-Design (CAD) file manually is as simple as clicking and dragging a corner of a given shape inside the CAD software, or manually typing in a new number for the x,y,or z axis. However, since our project is based on the idea of automating the process of editing shapes in order to prevent the hassle of manually editing these variables, our plan is to familiarize with the programming software inside SolidWorks, sometimes referred to as an API. The programming language we have decided to use is C, which is supposedly more similar to Java than C++ [9]. Manipulating the CAD through the API will hopefully look something like this: First, the user gives a manually-made CAD file. Then the program will take that CAD file, and adjust any combination of the x, y, and z axes to still maintain the total volume of the shape. The trick will be to make sure the shape stays generally consistent, and doesn't go from being an L shape to a rectangular prism or something that totally ignores the original CAD intention. Perhaps a way of dealing with that could be to limit the variables changing to be within the realm of the original, and make sure none even get to a base number that would fundamentally alter the shape of the CAD. The way we will likely handle this is by letting the user manually set the constraints, as they will know best what alterations would fundamentally alter the shape. We will also need to limit the adjustments of the variables to not exceed the volume of the original design, as this will skew our data and render the optimization pointless if it simply enlarges or shrinks the volume to more accurately perform. Will and his intern Temi have shown us how to create text files using SolidWorks that we will hopefully be able to manipulate using the SolidWorks API with a short script to allow us to modify the variables in the text files, which will then in turn create a new model with the now-adjusted variables.

5.2 C#

C# will be used almost exclusively for the GUI, since after discussing it with the client and group, we have decided that it best suits our needs regarding the GUI only. The GUI should be designed so that it is simple to use, which means it should be easy for someone to pick up the basics of how to use the software, and feature an intuitive design that conforms with the user's expectations of which buttons do what and where things would be located. It should also have a relatively low skill ceiling, as even though it will only be used by people who are already familiar with SolidWorks, CAD object manipulation, and 3D printing, it is mostly simple piece of software that probably shouldn't hold too many surprises.

5.3 Visual Basic

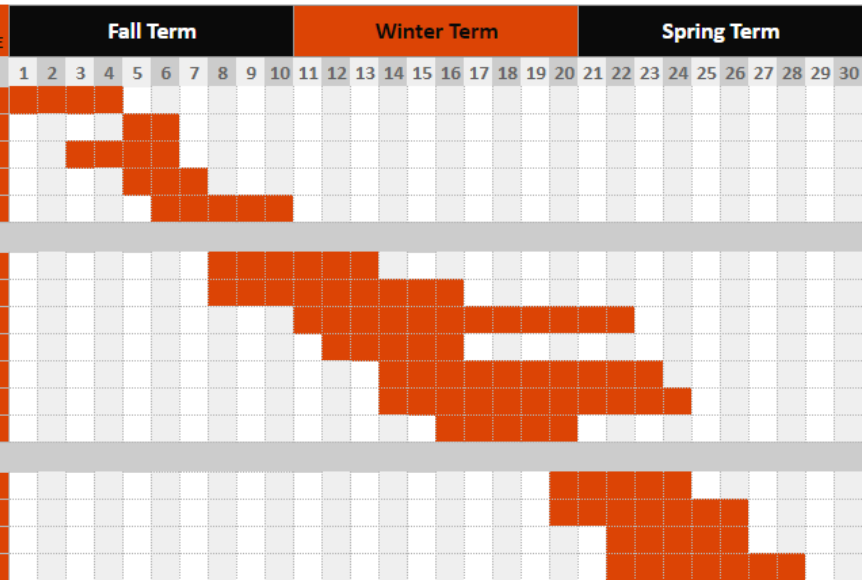
We will likely use Visual Basic for Applications for everything non-GUI related, as after talking it over as a team and with the client, it seems to be the most efficient technology we can use. We have come to this conclusion as there are several resources we can find online that will help us with our project. It is also supposed to be fairly easy to use, and its heavy-use of macros is perfect for automating simple, monotonous tasks [10] like manipulating variables in text files.

6 Gantt Chart

This chart documents our current progress on the overall project, and will help keep us accountable for where we should be. It is subject to change, as some things may take longer than we initially anticipated.

Automated Instantiation of Designed Experiments with Additive Manufacturing

TASK NAME	START WEEK	END WEEK	DURATION WEEKS	PERCENT COMPLETE
Fall Term				
Understand SolidWorks	1	4	4	100%
Create Object	5	6	2	100%
Requirements Document	3	6	4	100%
Technical Review	5	7	3	100%
Design Document	6	10	5	100%
Winter Term				
GUI	8	13	6	100%
SolidWorks Backend	8	16	9	100%
Optimization Method	11	22	12	100%
Expo Poster	12	16	5	100%
Print Propellers	14	23	10	100%
Run Experiments	14	24	11	100%
Video	16	20	5	100%
Spring Term				
Readme Instructions	20	24	5	100%
Add Extensive Comments	20	26	7	100%
Code Review	22	26	5	100%
Expo Project Site	22	28	7	100%



7 Conclusion

Picking and choosing the technical aspects of any project plays a big role in the future of any project as it the foundation of future building. With that being we play on using the least-square statistical method, python, and VBA/C as the foundation of our project. Each one plays a significantly different role and has been carefully chosen through thorough research and careful consideration of all options.

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