Bilkent University

Department of Computer Engineering

Design Project

Machine Learning for Machining Processes of Three-Dimensional Parts

Project Analysis Report

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Contents

1. Introduction

The project will be an application of machine learning (ML) techniques in the field of machining process identification (MPI). ML is defined as a branch of artificial intelligence (AI) and computer science that focuses on the use of data sets and algorithms to mimic the way humans are able to learn on computer systems [1]. ML algorithms, often called models, are fed data from data sets that gradually get better and better in their accuracy in the same ways that humans would [1]. For example, an ML model may be constructed to identify how many faces are in a picture that is supplied. In order to do this, the model would have to be trained using a known data set, which involves feeding the model data on which the aspect in question is known, and the model would then gradually get better and better at identifying how many faces there are in a supplied picture. After sufficient training, the model would be able to identify the number of faces within a picture with great confidence.

MPI is a novel area of research that aims to automate the manufacturing of mechanical parts by automatically deciding whether the part in question would be able to be manufactured using the manufacturing plants in place in an effort to make the manufacturing process more time and cost-effective and to reduce the number of faults that may occur during manufacturing [2]. Our project will investigate the applicability of ML and especially convolutional neural networks (CNNs) for MPI means. A CNN is a deep learning model that takes in an input image and by assigning importance such as learnable weights and biases to various aspects or objects within the image is able to differentiate images within a number of categories the aspects/objects within the image can belong to [3].

We will be trying to come up with an ML model that will be used to automate the processes of determining the type of manufacturing processes (additive versus subtractive manufacturing) to be used, the producibility of three-dimensional models, and cost estimation. Additive manufacturing is when processes build objects by adding materials layer by layer to form the desired product, while subtractive manufacturing is when materials are removed from an already existing object to come up with the part that is needed [4]. We are planning on developing a deep learning framework for determining which type of machining processes are suitable for producing a machine part and the producibility of these parts using the selected machining process for the provided three-dimensional models.

The machining operations we will consider are turning, milling, and drilling. Turning is a machining operation in which a workpiece is rotated while the cutting piece moves in a linear motion to achieve the desired shape, which is often cylindrical [5]. A lathe machine is usually used for turning purposes [5]. Drilling is a machining operation in which a drill press or a tapping machine is used to create a round hole in a workpiece [5]. Lastly, milling is a machining operation that involves using many multi-point rotary cutters to remove material from an object to achieve the desired outcome [5]. Our end product will also be able to determine which operations are to be performed in order to attain the desired part if the part is able to be produced using the available producing plant. Another stage for the parts that are producible using the selected machining process and the operations selected is the estimation of the cost of the production of the parts for different material properties and costs input to the system.

2. Current System

We currently have a system that takes in STL files and successfully converts them to binvox files. We also have a machine learning model that takes in a three-dimensional part model and predicts whether it can be manufactured using subtractive manufacturing and if it can be produced, the machining processes that would be required to produce the desired part.

We have a desktop application that takes an STL file, show the model, converts it to binvox, and also shows the converted model.

3. Proposed System

In this section of the report, we will be discussing the requirements of the project in detail. We will first start with the functional and non-functional requirements and then move on to the pseudo requirements.

3.1 Overview

Our project will have the main requirements of being able to be trained by being supplied binvox files and for the trained model to be able to predict whether a given three-dimensional model of a part can be produced given the specified manufacturing plant, what materials, and what methods of manufacturing and machining methods will be required to produce the part, and the estimated cost to do so. It will also be able to get STL files and transform them into binvox files. We will be considering the non-functional requirements of usability, supportability, reliability, efficiency, security, and scalability. Our project will not have any pseudo requirements required by the customer.

3.2 Functional Requirements

In this section of the report, we will be discussing the functional requirements of the project in detail. We will first be focusing on the functionalities of the model that will be trained before it reaches the user, and will then be delving into the functionalities that the end-user will have access to.

3.2.1 Functionalities of the ML Model

The model would be able to be trained by supplying it with data in the mode of binvox files. The model will have to first be sufficiently trained in order to then be able to predict and perform operations on user-supplied parts.

This training process requires long computations and depending on the CPU used can have a runtime of as little as two seconds for each epoch on an NVIDIA RTX 30 series with a total of 15 hours to completely train the model. However, it should be noted that this training will be done only once and before the project reaches its end user. Thus, the length of the duration of this process will not be of issue to the end-user.

3.2.2 Functionalities of the User

The main functionality of our project from an end-user perspective is the trained model being able to predict the user-supplied part models and accurately determine whether it is able to be produced using the given manufacturing plant, what materials will be necessary to produce the part, the method of manufacturing and the machining operations that will be required to manufacture the part, and the estimated cost that will be required to produce this part. In order to do this, the user will be able to supply to our program an STL file, have it transformed into a binvox file, have this transformed into a NumPy array, fed into the model, and have the respective output be produced. The user will be able to supply models in the form of STL files and will be able to view this model turned into a binvox file and the output resulting from the given input. The model will then predict whether a part of the given model can be manufactured using the given manufacturing plant or not, what method and manufacturing and machining operations will be used to manufacture the part and the estimated cost of doing so.

3.3 Non-Functional Requirements

In this section of the report, we will be discussing the non-functional requirements of the project in detail.

3.3.1 Usability

As our end-product will only have to be used by professionals within the field of manufacturing, we will not be required to cater to a general audience when creating our project. Thus, we can assume that the people using our project will be familiar with the technical terms within our project such as turning, drilling, and milling, and we will not be required to provide a description of such terms. We will also be able to assume some level of expertise on the abilities of the people using our project to be able to interact with computer systems, as we are expecting the large majority of our users to be engineers. As such, we will be able to assume the users will be familiar with using systems such as the one we will develop, and can be more relaxed in the way we approach the user interface elements et cetera.

3.3.2 Supportability

Our project will be able to be run on any system that runs Python3 excluding 3.8+ as it does not support the Tensorflow library that we are using for our CNN models, and we will be focusing on the interoperability of the underlying Python fundamentals to establish the supportability of our project.

3.3.3 Reliability

We aim for our ML models to be able to be accurate to a very high degree after sufficient training. We at the moment are unable to estimate the size of the data set that will be required to achieve this, but we will be putting the bar at around 95% to be able to call the model accurate.

3.3.4 Efficiency

As the model will have to be trained only once for it to be able to output accurate classifications, efficiency will not be the biggest non-functional requirement in our project. We will be putting more emphasis on our project producing more accurate results and will be ruling in favor of losing efficiency for this aim if need be.

3.3.5 Security

As there is no sensitive information that is to be stored or processed in our project, there are no security concerns for data leaks or any such considerations. Therefore, no encryption or any other method of obfuscation will be necessary for our project.

3.3.6 Scalability

Our project will be taking into consideration the machining operations of turning, drilling, and milling. Thus, it will have to be scaled if need be to have any other machining operations that are to be incorporated. We cannot comment at this time how easy or difficult it will be as we do not yet have the model, but we are assuming it will be easier to implement such scaling to our project.

3.4 Pseudo Requirements

Our project does not have any pseudo requirements enforced by the customer. However, we have decided to implement our project using Python because of its many useful libraries regarding machine learning, and will as well be using GitHub as our version control system.

3.5 System Models

In this section of the report, we will be discussing the use cases and the scenarios of our system, and will as well be providing UML diagrams for the system.

3.5.1 Scenarios

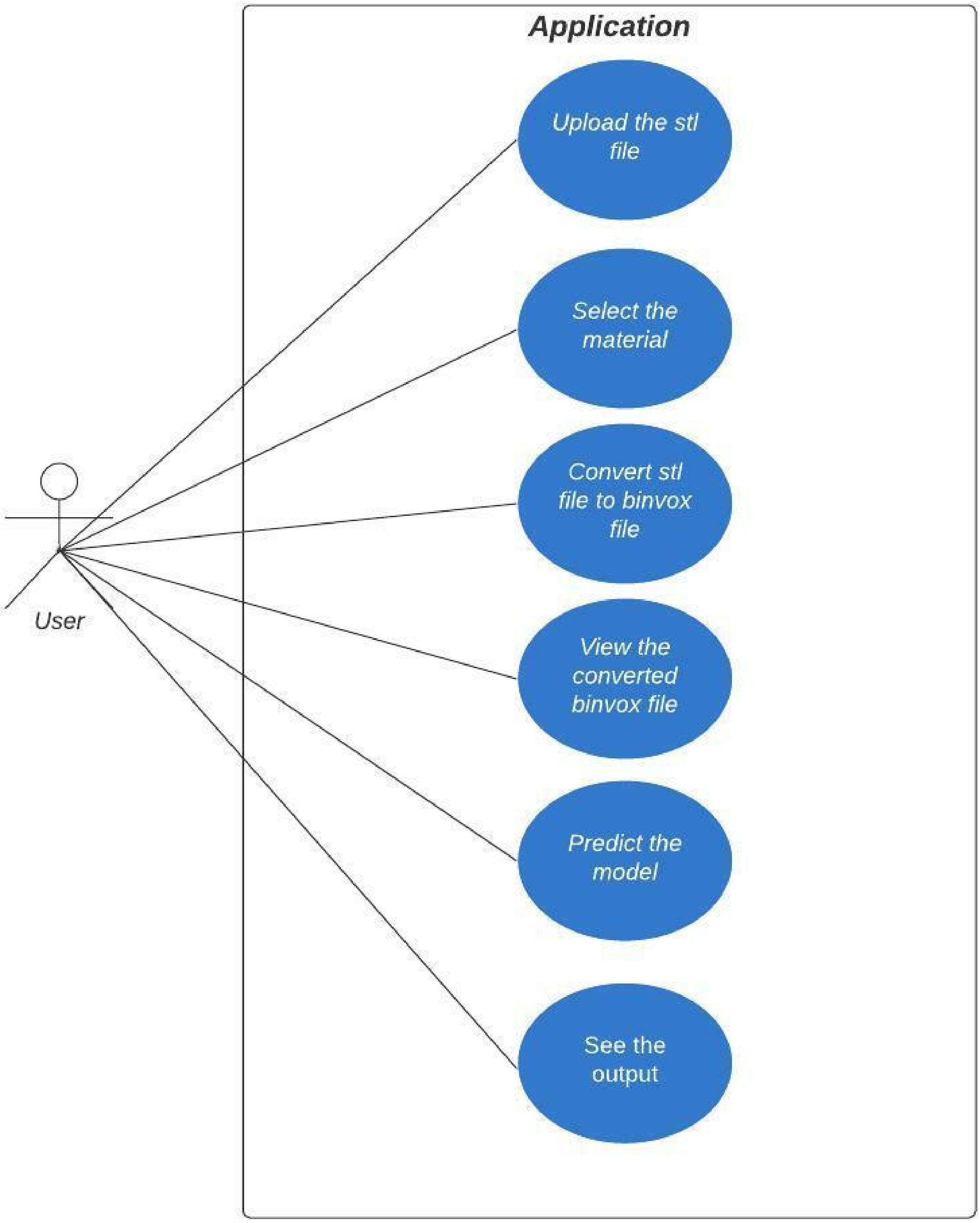
Scenario	Uploading the STL File
Participating Actor	User, system
Flow of Events	The user selects an STL file to upload to the system. The selected STL file is uploaded to the system.
Entry Condition	The user presses the “Upload STL File” button.
Exit Condition	The user presses the “Upload” button.
Quality Requirements	The system must not allow the user to upload any other type of file. The system must accurately save the STL file.

Scenario	Selecting the Material
Participating Actor	User, system
Flow of Events	The user views the available types of material within the system. The user selects a material out of the displayed list.
Entry Condition	The user presses the “Select Material” button.
Exit Condition	The user presses the “Proceed” button.
Quality Requirements	There must be a suitable number of materials that the user can choose from.

Scenario	Convert the STL file into BinVox and Display the Model
Participating Actor	User, system
Flow of Events	The supplied STL file is converted into BinVox. The BinVox model is displayed to the user. The user checks the converted BinVox model.
Entry Condition	An STL file must be uploaded and a material must be chosen. The user presses the “Convert to BinVox and View Model” button.
Exit Condition	The user either presses the “Confirm” or the “Go Back” button.
Quality Requirements	The BinVox model must be displayed clearly. The BinVox model must be able to be viewed in a three-dimensional manner with the user being able to rotate the model et cetera.

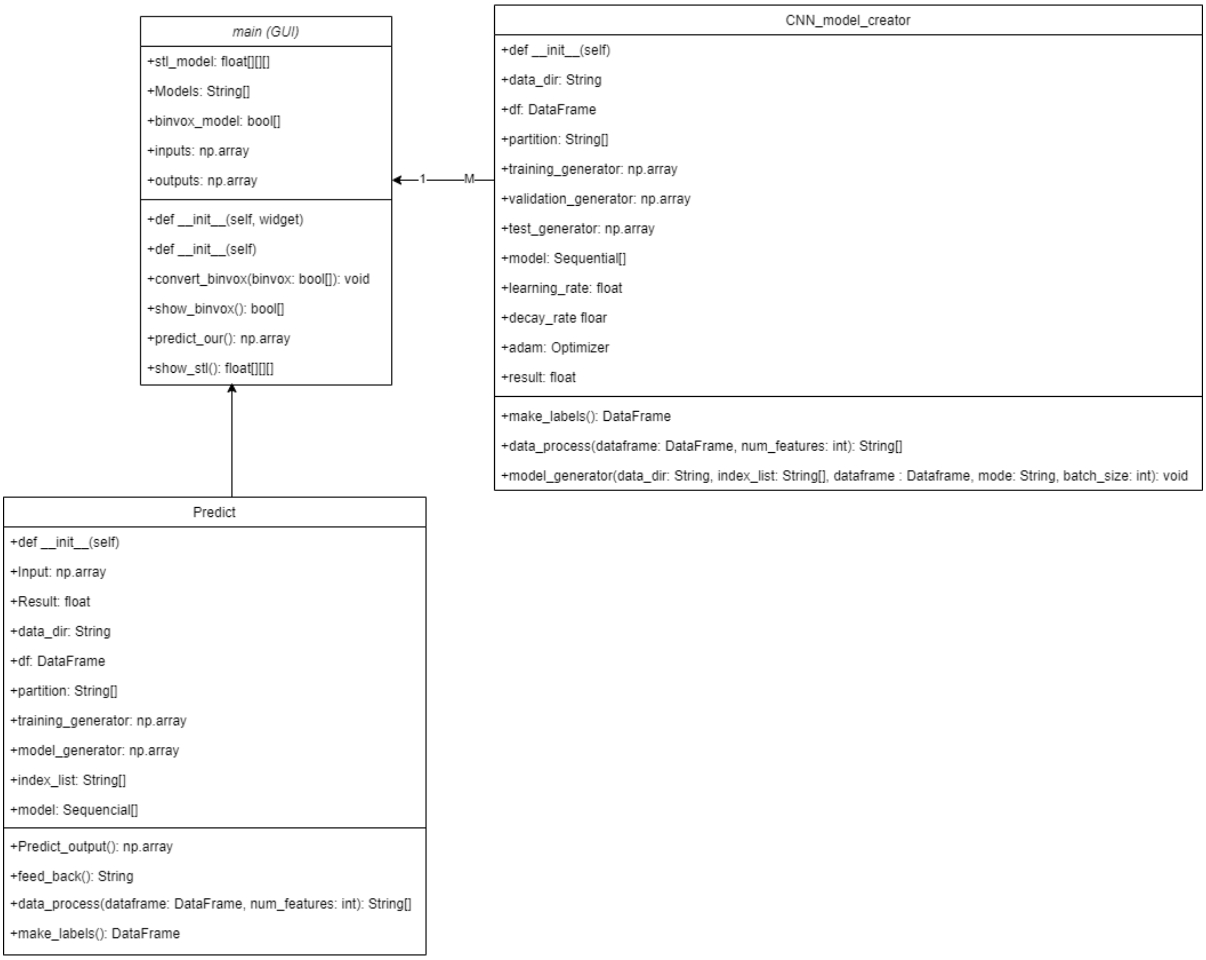
Scenario	Predict the Model and Display the Results
Participating Actor	User, system, display
Flow of Events	The user asks for the system to predict the BinVox model and display the results. The system does so.
Entry Condition	A BinVox file that has been approved by the user must be present within the system. The user presses the “Predict Model and Display the Results” button.
Exit Condition	The user presses the “Close” button.
Quality Requirements	The system must be able to predict the model with sufficient accuracy (above 95%).

3.5.2 Use Case Model



The use cases within the model are explained in detail under the “Scenarios” section.

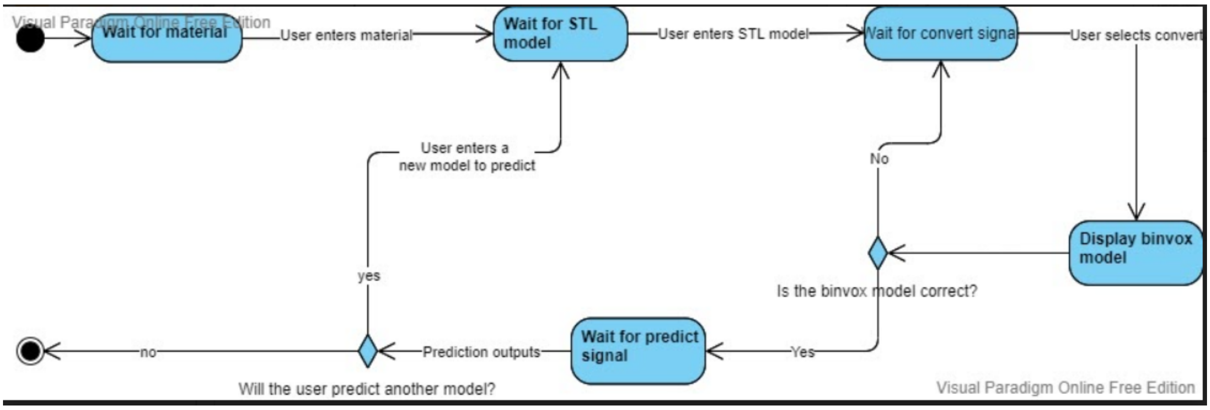
3.5.3 Object and Class Model



3.5.4 Dynamic Models

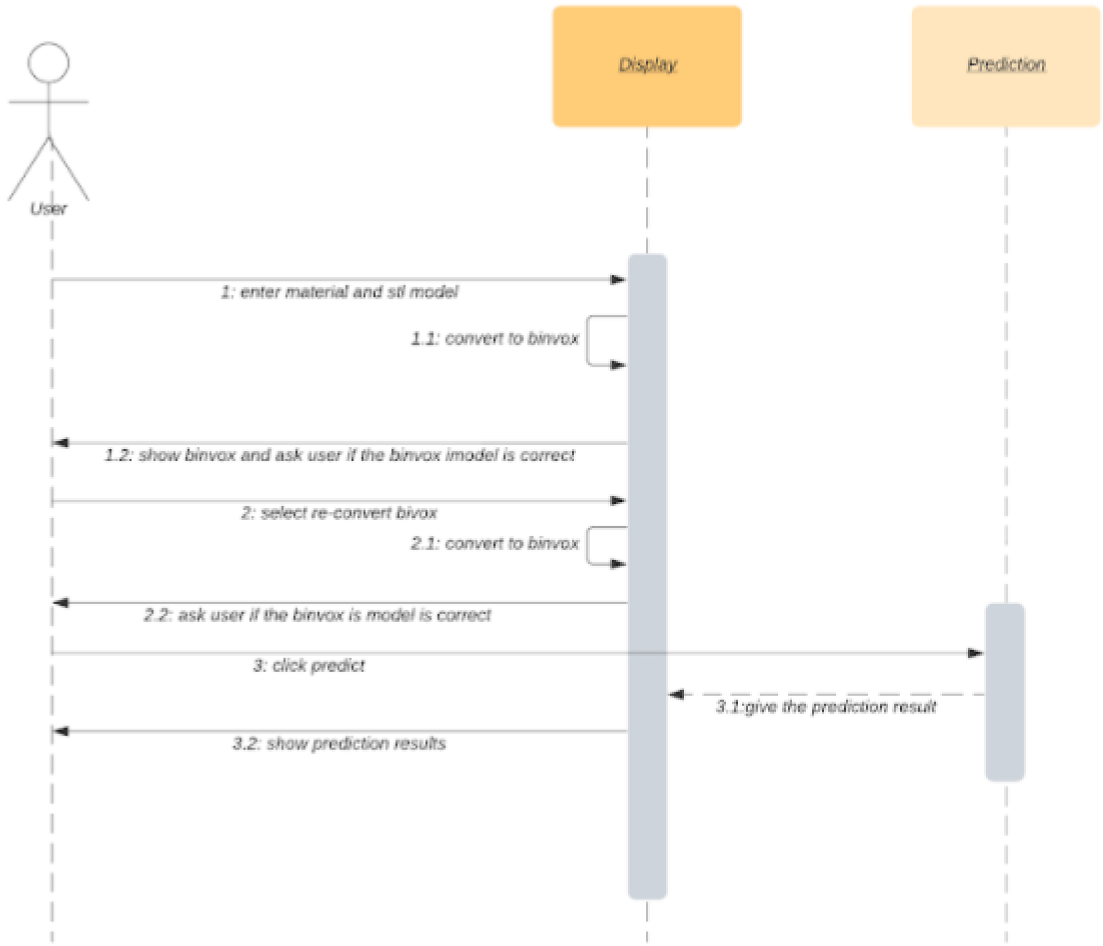
In this section, we will be discussing the state machine diagram, the sequence diagram, and the activity diagram of our system.

3.5.4.1 State Machine Diagram



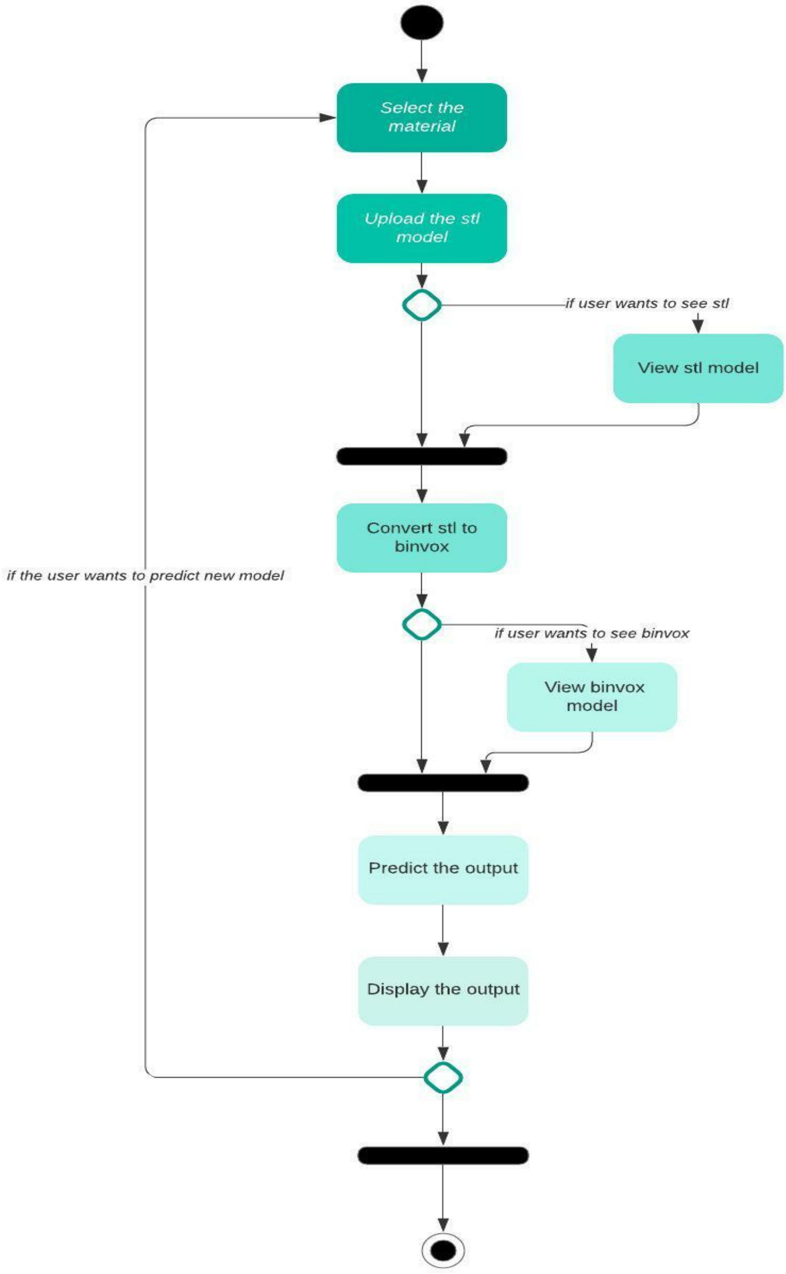
The application starts with the user selecting a material from the list of materials that are available within the system. The user then uploads a three-dimensional model of the part that is to be manufactured in the format of an STL file. Next, the system converts this file into BinVox format and displays this file for the user to check. The user then either confirms the BinVox file or goes back to reconvert the file into BinVox. Next, the user clicks the predict button and the system predicts and displays the results. If the user wishes to predict another model, they press the button to go back to the main menu and go through the explained process once more.

3.5.4.2 Sequence Diagram



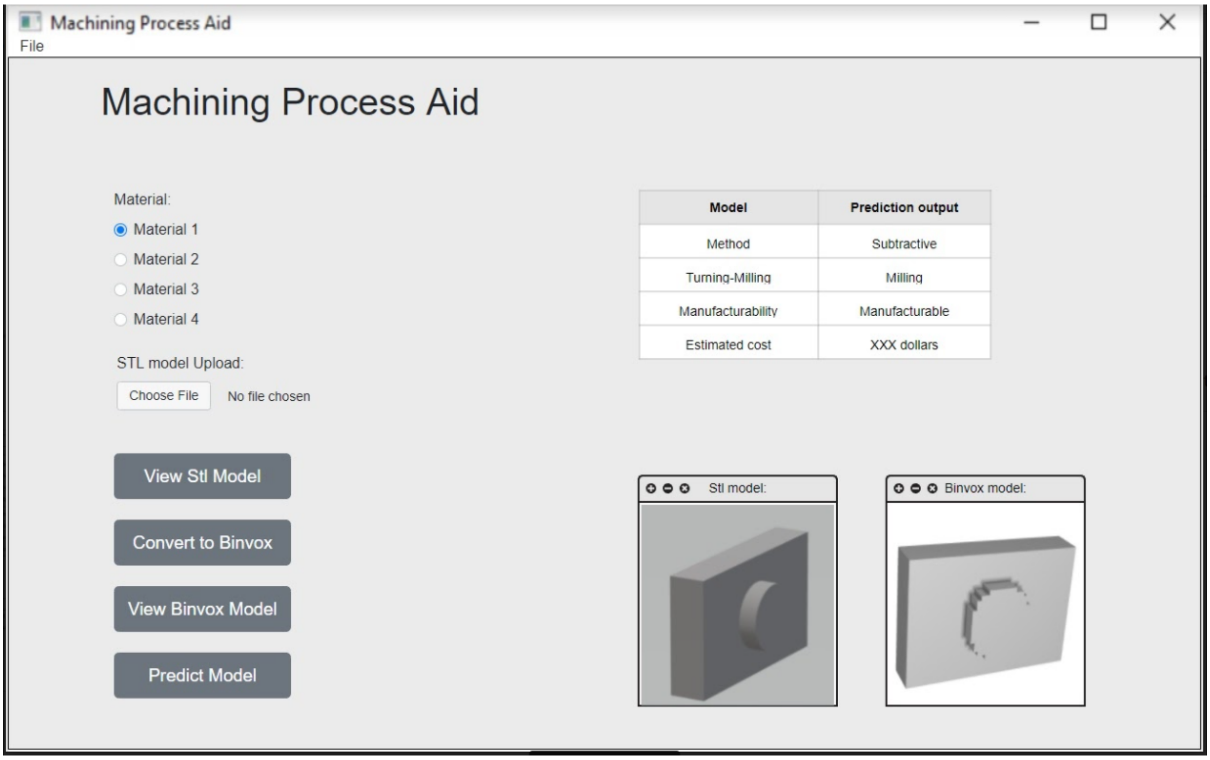
The user first chooses the material that the part will be made out of from a list of materials available within the system and uploads an STL model to the system. This is done through the GUI. This STL file is then converted into a BinVox model and this model is shown to the user. If the user spots any problems within the model and wishes to reconvert it into BinVox he does so using the GUI. After the user confirms the model, they click the "Predict and Display Results" button via the GUI and the system predicts the model using the machine learning backend of the system. The machine learning model then passes the results to the display, and they are shown to the user over the GUI.

3.5.2.3 Activity Diagram



The user will first select the material that the part will be made out of out of a list of materials that are available within the system. Next, the user will upload an STL file to the system and will be able to view it if they wish to do so. The user will next convert this STL file into BinVox format, and will likewise be able to view the BinVox model should they want to. Next, the system will predict the model and display the output. If the user wishes to predict another model, the process will start once more.

3.5.5 User Interface - Navigational Paths and Screen Mock-Ups



Our UI will have four main components, on the top left we will have the material selection and STL file upload sections, on the bottom left we will have the buttons for the use-cases of our program, on the top right we will have the prediction results, and on the bottom right we will have our model viewers.

4. Other Analysis Elements

In this section of the report, we will be discussing some rather abstract analysis elements of our project that are different from the more concrete ones given under the proposed system section. We will be discussing considerations of various factors in the design of our project, risks and alternatives to our project design, our project plan, how we plan on ensuring proper teamwork, ethics, and professional responsibilities of our group members, and finally how we are planning to tackle the need for new knowledge and learning strategies.

4.1 Consideration of Various Factors in Engineering Design

The four main factors that we deliberated on are algorithmic efficiency, memory cost, the accuracy of the model, and the time required to predict the attributes for the parts. The first two are common to all software engineering solutions, and we have decided that we would be in favor of algorithmic efficiency as opposed to lowering memory cost, and would make trade-offs in order to speed up our processes even when it means more memory would be required. We have chosen to do so because our training of the model takes quite a bit of time with a large number of epochs and a sizable amount of time per each epoch. Therefore, we have chosen to try and speed this process up as much as we can even though it might mean we would have to utilize more memory to do so. One can argue that because we only need to train the model once before providing it to the user we would not necessarily have to worry about the time it would take to complete the training of the model. However, as during testing we might change qualities about the model in an effort to increase its accuracy, and would have to train it every single time, we have chosen to favor algorithmic efficiency as opposed to a lowered memory cost. One may also argue that since the training has to only be done once the memory cost will only have to be paid once, so it is not a big problem to favor algorithmic efficiency.

The other two factors we considered are the accuracy of the model when predicting a part, and the time it takes for the model to predict a part. We would ideally like the accuracy of the model to be as high as possible, and the time it takes to predict a model to be as low as possible. We have decided that the accuracy threshold for our model in order to be considered a success is 95%, and we have decided that it can take up to a minute's time for the model to predict a part that is given, depending on the size of the part.

4.2 Risks and Alternatives

One central risk to our project is the accuracy with which our model will make decisions regarding the three-dimensional models that will be supplied to our machine learning model. As these predictions will be used to make decisions that normally a human worker would make, we are aiming to be able to provide predictions of a higher degree of accuracy than would a typical human worker. However, we always face the risk that if our predictions are inaccurate and they are used to make decisions by a company, the company may be faced with a serious loss of money or other resources. Therefore, it is important that our model be able to produce predictions that are accurate so that our product will be marketable and companies will want to purchase and use our project, yet we will always be having to deal with the risk of our model making inaccurate predictions, even though we will be doing our best to minimize the risk of it doing so.

Two of the main areas in which we had alternatives to choose from were the selection of the language that we will be using throughout the project, and the version control system that we will be using to coordinate our efforts on implementing the project. As stated previously, this project had started as a summer internship project by one of our group members, and she had started the implementation of the project using Python because of the many useful machine learning libraries that it has. Thus, we were faced with the choice of either continuing the development of the project using Python, or migrating it to a different programming language. After thorough investigation on the machine learning libraries of several different languages, we have decided to stick with Python as we had already started development on the project using the language and we found its libraries to be the most desirable.

The second area in which we had a selection of alternatives we could choose from was the version control system of the project we would be using to coordinate our efforts on the implementation of the project. Our group member had been working on Google Collab throughout the summer in which she had started the project, but we have deemed it to be too difficult to use for a group of five of software engineers, as the platform is more suited towards a team of a lower number of people, such as two or three members. We have decided to migrate the project on to GitHub, a well-known version control system that is heavily used in the development of software projects with a larger team of people. We are planning to stick with GitHub as our version control system throughout the duration of the project.

4.3 Project Plan

Our project is on a timeline of two semesters plus a period of summer development from the previous summer. This project had started as the summer internship project of one of our group members, and we will be picking up where she left off and continuing on the project with the aim of finishing it in two semesters. For the first semester we will be producing the project specification, analysis and high-level design reports, and will as well be giving a demo of our work up to that point at the end of the semester. To achieve this we will be having a two-pronged approach to the development of our project: after designing the various elements and structures within our project, some members of the team will be focusing on the implementation of said elements within the project, and other members will be working on the report writing and documentation side of the project. These will not be in the form of strict teams, but will rather have people working alongside each other when needed so that the two tasks can be completed simultaneously. In the second semester we will be having the low-level design and the final report of the project, and will as well finish development and give the final demonstration of the project. We will as well be participating in the annual CS Fair that is organized by the university.

4.4 Ensuring Proper Teamwork

We have briefly discussed how we are trying to move the project simultaneously in two activities of development, the first being the actual implementation of the project and the second being the writing of the reports and the documentation of the project within the previous section of the document. In addition to this, we will as well be having weekly meetings with both only the group members and as well meetings with our project supervisor and innovation expert. During the group member only meetings we will be focusing on task allocation for the week and ensuring that everyone has a task that they are to do, everyone knows what this task assigned to them is and that the tasks for the week have been distributed in a fair manner among the group members. In the meetings with the project supervisor and the innovation expert present, we will be presenting what we have done during the previous week and will be asking them to give us some feedback on the things that we have done over the previous week. We will as well be asking for guidance on the direction that the project is going in and whether we are on the right track or not. We have as well created two WhatsApp groups, one with just the project members and the other with the innovation expert and the project supervisor for easier and faster communication on matters that do not require a meeting. This is how we are planning to ensure proper teamwork throughout the project.

4.5 Ethics and Professional Responsibilities

As our project will likely be replacing human jobs in the future, it is our ethical responsibility to ensure that its predictions are at least as accurate as those that an average human worker would make. We also have the professional responsibility of finishing the project on time with all of the functionalities we have detailed present, and of course have the ethical and professional responsibilities to our teammates of doing tasks that we said we would be completing on time and in a decent manner. Throughout the project we will be keeping in contact with our project supervisor and our innovation expert, and we will have the responsibility to ensure that our communication is in a professional and respectful manner.

4.6 Planning for New Knowledge and Learning Strategies

For our project, we have thus far had to learn about manufacturing terms such as additive/subtractive manufacturing, methods of manufacturing and machining methods. We were able to learn these concepts with the help of our project supervisors and innovation expert, and as well private study on our own. When required, our project supervisors and innovation expert have sent us some documents that we can study on our own to grasp certain concepts better. This was all work done in order to comprehend the project itself that we would be doing. Regarding the implementation of the project, we will have to learn concepts of machine learning such as convolutional neural networks and modeling, and for that we have members of our group that are taking the machine learning course offered by the university, and we are as well doing private study regarding the concepts via individual research. For use of certain machine learning libraries in Python and other pieces of software that we will have to learn, we are reading documentation and trying to find helpful resources online to guide us. We already have a working grasp of GitHub from previous courses such as the Object Oriented Software Engineering course, but will still likely be looking up concepts or operations that we are unfamiliar with online. These are our plans and learning strategies for gathering and absorbing new knowledge.

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