Plotting and Cutting 2D Shapes Based on Mathematical Equations using Computer Numeric Control (CNC)

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Acknowledgements

We are thankful to the Almighty Allah for the blessings that enabled us to complete our final year project. We pay gratitude to our parents whose prayers have been the most valuable thing during this time. We are also thankful to our honorable supervisors Dr. Ata ur Rehman and Dr. Muhammad Aurangzeb who helped us on every occasion we faced problems or misplaced hope in dealing with troubles related to this project. They stimulated us to work until completion of this project. At the end, we acknowledge the availability and help of all the university staff wherever required. Without their support, the task could never have been possible. We are grateful to our family for always being there for us and supporting us at the time we needed the most. We would like to thank all our friends for every step they took for us in completion of this project.We are also very thankful to the administration and faculty of COMSATS University Islamabad, Attock Campus for providing us a great environment that helped us a lot in conducting my FYP related activities.

Abstract

The report explains the development of a high precision cost-effective CNC machine that can be used in industries for cutting and drawing applications. Different shapes based on mathematical equations were drawn in MATLAB and the resultant files were fed to the hardware (Arduino Uno board) using Universal G-code Sender (UGS) for final processing on the CNC machine. A Graphical User Interface (GUI) was built to implement the complete process. Accuracy and precision are crucial for the success of the project, requiring consideration of cutting speed, feed rate, and tool diameter. The study aims to contribute by generating complex shapes based on mathematical equations and could have various applications in different industries and possibly pedagogical aid in classrooms and lab environments. Another addition to the project was dry etching of a PCB model that was created in a software eagle and processed in another software Aspire to be fed to the hardware controller to run the CNC machine. Small errors in the cutting process can result in significant deviations from the desired shape. The factors like the cutting speed, the feed rate, and the tool diameter were considered to achieve the desired level of accuracy and precision. Overall, the thesis topic presents an approach to generate complex 2D shapes based on mathematical equations and using CNC technology. The study will likely contribute to the development of new methods for creating complex shapes and could have wide-ranging applications across various industries.

Keywords: CNC machine, G-code, Arduino, Aspire program, microprocessor.

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Chapter 1

Introduction

1.1 Background

The Computer Numeric Control (CNC) technology has revolutionized manufacturing processes in various industries. CNC machines offer precise control and automation, leading to improve productivity, accuracy, and repeatability. In the context of plotting and cutting 2D shapes based on mathematical equations, it is essential to understand the fundamentals of CNC technology.

Accurately plotting and cutting 2D shapes is crucial in industries such as manufacturing, engineering, and design. With the advancement in technology the demand for customized parts, intricate designs, and precise geometries has increased significantly. On the other side traditional methods of shape plotting and cutting, such as manual techniques or conventional machining processes, often face limitations in achieving the required accuracy and complexity requirements[1]. This necessitates the exploration of advanced techniques, such as utilizing CNC technology, to meet the evolving needs of industries. By utilizing the capabilities of CNC machines, manufacturers can achieve greater accuracy, reduce human error, and enhance overall productivity. Moreover, CNC technology allows for the creation of complex shapes with intricate details, pushing the boundaries of design possibilities beyond traditional approaches.

The project aims to develop a software system that enables the precise plotting and cutting of two-dimensional (2D) shapes based on mathematical equations. The field of Computer Numeric Control (CNC) has revolutionized various industries by providing automated and accurate control over machining processes[2]. However, the application of CNC technology for shape generation and cutting based on mathematical equations remains an unexplored area. The main objective of this project is to bridge this gap by designing and implementing a software system that leverages CNC technology to transform mathematical equations into physical 2D shapes. This system will offer a practical and efficient solution for artists, designers, and engineers who require precise control over shape generation and cutting processes.The proposed software system will consist of several key components, including CNC machine selection and setup, mathematical equation processing, shape generation algorithms,user interface, and CNC control and communication. Through the integration of these components, users will be able to input mathematical equations, visualize the corresponding 2D shapes, and send instructions to the CNC machine for accurate cutting.

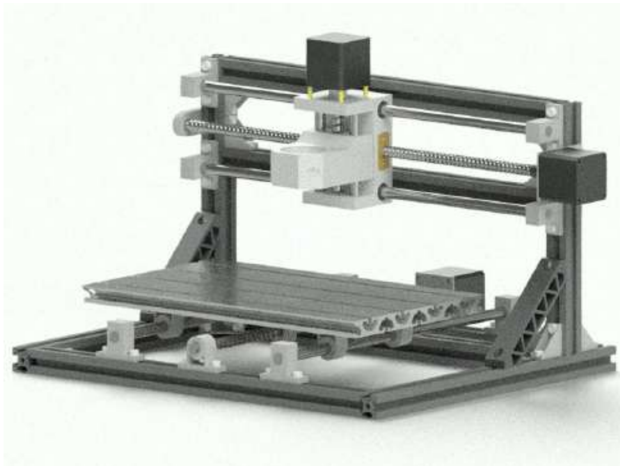

Figure 1.1: CAD Model of CNC [1]

The successful implementation of this project will have significant implications across various domains, such as art, design, manufacturing, and prototyping. It will provide a powerful tool for transforming abstract mathematical concepts into tangible and visually appealing 2D shapes. Moreover, the system's flexibility and versatility will allow users to experiment with different equations, resulting in an endless array of creative possibilities.

Throughout this thesis, a detailed methodology, including software development, data input and conversion, CNC control and communication, and testing and validation, will be discussed. The results obtained from experiments and user feedback will be analyzed and presented, demonstrating the effectiveness, efficiency, and practicality of the proposed system. In conclusion, this project aims to contribute to the advancement of CNC-based shape plotting and cutting by developing a software system that enables the transformation of mathematical equations into physical 2D shapes.By combining the precision of CNC technology with the elegance of mathematical equations, this project has the potential to revolutionize the way 2D shapes are generated and cut, opening new avenues for artistic expression,design innovation, and manufacturing processes. increase of industry varieties and the growing demand for miniature products.

1.2 Motivation

In today's industrial sectors, there is a constant need to expand production capacity to meet the ever-growing consumer demand. This necessitates the implementation of automation in various manufacturing processes, particularly in the reshaping, cutting, and engraving of materials. For some industries, such processes are at the core of their operations, while for others, they serve as essential conditioning processes.

The demand for automated reshaping, cutting, and engraving of materials arises due to the need for increased productivity and efficiency. As consumer demands continue to rise, industrial sectors must strive to meet these demands by enhancing their production capacity.

Automation plays a vital role in achieving this goal, as it enables faster and more accurate reshaping, cutting, and engraving processes.

By automating these processes, industrial sectors can significantly improve their overall productivity. Automated machines can work continuously without fatigue, leading to reduced downtime and increased output. Additionally, automation ensures consistent and precise results, minimizing errors and variations in the manufactured products.

Moreover, the automation of reshaping, cutting, and engraving processes provides several other advantages. It allows for better utilization of resources, such as materials and energy, by optimizing cutting patterns and reducing waste. It also enhances workplace safety by minimizing the need for manual intervention in potentially hazardous tasks. Furthermore, automation improves the quality of the final products, as it ensures consistent and accurate shaping, cutting, and engraving.

The application of automation in reshaping, cutting, and engraving processes has the potential to revolutionize various industries, including manufacturing, construction, automotive, and aerospace. By embracing automation, these industries can meet the increasing demands of consumers while maintaining high-quality standards and efficient production processes.

Overall, the motivation behind automating the reshaping, cutting, and engraving of materials lies in the necessity to enhance production capacity, improve productivity, ensure consistent quality, optimize resource utilization, and meet the ever-growing consumer demand. By harnessing the power of automation, industrial sectors can achieve higher levels of efficiency, competitiveness, and profitability in today's dynamic market.

1.3 Problem Statement

A graph visually represents how the output of a function varies with the input. We aim to find a solution that visually represents the plot based on mathematical equations that will enable the students to understand it well. CNC machines are among appropriate options to automate the cutting process of required plots. This project aims at development of a CNC machine such that it is able to work on a two dimensional work bed along with the ability of cutting and plotting required graph.

1.4 Advantages

CNC machine will provide following advantages:

1. Greater accuracy
   Implementing a computer numerical control (CNC) machine for the reshaping, cutting, and possibly plotting applications offers the advantage of greater accuracy. Unlike manual methods, a CNC machine can precisely follow predefined mathematical equations, ensuring consistent and precise cuts and shapes. The machine's automated control system eliminates human error and delivers highly accurate results, meeting the required specifications and tolerances with exceptional precision. This increased accuracy leads to improved quality in the manufactured products and enhances customer satisfaction.

2. Automated control
   One of the key benefits of utilizing a CNC machine is the automated control it provides. The machine operates based on a pre-programmed set of instructions, enabling it to execute complex cutting and shaping operations with minimal human intervention. The automated control system not only saves time but also reduces the dependency on skilled operators. It ensures consistent and reliable performance, eliminating variations caused by manual operations. This automation allows for streamlined production processes, increased efficiency, and optimized resource utilization.

3. Improved productivity
   The introduction of a CNC machine significantly improves productivity in the reshaping, cutting, and plotting applications. With its automated control and precise movements, the machine can perform tasks at a much faster pace compared to manual methods. It eliminates the need for time-consuming manual adjustments and repositioning, resulting in reduced processing time. The CNC machine can operate continuously, maximizing output and minimizing downtime. By enhancing production rates, businesses can meet the growing demand, improve efficiency, and remain competitive in the market.

4. Uniformity in design
   CNC machines ensure uniformity in design, which is crucial in industries that require consistent and repeatable shapes and cuts. The pre-programmed instructions guarantee that each product will be identical to the desired specifications. This uniformity is particularly valuable when manufacturing parts or components that require precise fits or interlocking mechanisms. By achieving consistency in design, CNC machines contribute to the overall quality of the final products and facilitate assembly processes.

5. Safe to operate
   Safety is a paramount consideration in any manufacturing environment. CNC machines provide a safer working environment compared to traditional manual methods. With minimal operator intervention, the risk of accidents and injuries is significantly reduced. The machine's automated control system ensures that all cutting and shaping operations are carried out within defined parameters, minimizing the chances of human error and associated safety hazards. Additionally, the incorporation of safety features such as emergency stop buttons and protective enclosures further enhances the safety of CNC machine operations.

6. Possibly no human error
   By relying on a CNC machine for reshaping, cutting, and plotting applications, the potential for human error is greatly minimized. The machine precisely executes the programmed instructions, eliminating the risks of inaccuracies caused by human factors such as fatigue, distraction, or lack of expertise. This reduction in human error leads to consistent and reliable results, ensuring the desired shapes and cuts are achieved with a high level of accuracy. The use of CNC machines helps maintain a high standard of quality, reduces material waste, and minimizes the need for rework or corrections.

7. Less time required
   Time efficiency is a crucial aspect in today's fast-paced manufacturing environment. CNC machines excel in delivering time-efficient operations. The automated control system allows for continuous operation, minimizing idle time and maximizing productivity. The machine can quickly transition between different cutting and shaping operations, reducing setup times and improving overall process efficiency. By reducing processing time and increasing throughput, businesses can meet tight deadlines, optimize resource utilization, and improve their competitive edge in the market.

1.4.1 Challenges

- Axis Calibration
  Axis calibration involves obtaining accurate measurements of parameters such as step size, acceleration, and velocity, ensuring precise movement and positioning of the CNC machine. It ensures that the machine's movements align with the desired dimensions, minimizing errors and achieving optimal accuracy in the cutting and shaping processes.

- Stability
  Ensuring stability in CNC machines is crucial to avoid irregular movements and vibrations during operation. Factors such as mechanical rigidity, proper alignment of components, and minimizing external disturbances play a vital role in maintaining stability. Addressing stability issues ensures consistent and reliable performance, preventing inaccuracies and potential damage to the machine and workpiece.

- Current
  The selection and configuration of the appropriate current for the stepper motor is essential, particularly when dealing with complex designs or heavy cutting loads. Insufficient current can lead to missed steps, resulting in inaccurate cuts, while excessive current can cause overheating and damage the motor. Determining the optimal current requirements ensures smooth and reliable operation, minimizing errors and maintaining the longevity of the machine.

- Tool Selections
  Choosing the right cutting tool, such as bits or end mills, is crucial for achieving precise and clean cuts. Factors to consider include the material being cut, the desired finish, and the cutting parameters. Selecting the appropriate tool ensures efficient material removal, reduces tool wear, and enhances the overall quality of the finished product.

- GRBL Firmware Requirements
  The GRBL firmware serves as the control software for CNC machines, dictating their functionality and behavior. Understanding and configuring the firmware to meet the specific requirements of the CNC machine is essential for optimal performance. This includes setting parameters such as acceleration, maximum feed rates, and microstepping resolution, aligning them with the machine's capabilities and the desired precision of the cutting and shaping processes.

1.5 Project Objectives

Objectives of our projects are as follows:

1. Developing a user input based mathematical equation plotter.
2. Plotting the required equation using CNC.
3. Cutting the shapes representing the given equation using CNC.
4. Developing a Graphical User Interface (GUI).

1.6 Project Research Questions

The thesis addresses following questions:

- What are some main factors that will make CNC Machine cost low?
  The use of a CNC machine reduces the costs by reducing labor requirements and by the ease of repeatability in a production cycle.
- How to design CNC machine of such type that a person with low knowledge can operate it easily?
  The problem was addressed by designing a Graphical User Interface (GUI) for individuals with limited knowledge involves simplifying the interface, providing intuitive controls, and clear instructions for easy operation.
- How to control the resolution of a CNC operation?
  By choosing a stepper motor with the required minimum step size for axis control of the CNC.

1.7 UN's Sustainable Development Goals of the Project

The project meets the UN's sustainable development goals. The 9th Goal as shown in figure:1.2 is defined as

- Inclusive and sustainable industrialization, together with innovation.
- Increase the access of small-scale industrial and other enterprises.

Our project supports the United Nations' sustainable development goals, particularly the 9th Goal of inclusive and sustainable industrialization. By developing a user-friendly software system for automated 2D shape plotting and cutting using CNC technology, we aim to revolutionize the industrial sector. Our project contributes to sustainable industrialization by improving efficiency, reducing manual labor, and promoting cost-effectiveness. Additionally, our innovative approach, incorporating mathematical equations and multipurpose capabilities, fosters creativity and innovation within the industrial sector. Through our research, software development, and inclusive approach, we strive to advance sustainable and inclusive industrialization.

Figure 1.2: UN's Sustainable Goal

1.8 Thesis Overview

Thesis describes:

- Introduction of project in chapter 1
- Chapter 2 focuses on Literature Review and Related Work
- Furthermore, we will go to Chapter 3 where we will illustrate the Block Diagram, Mathematical Models, Flowcharts, Code, Component Selection in Projects with Hardware and Software Setups, and all po- tential project limits.
- In contrast, Chapter 4 will go into great detail regarding the tests that were conducted throughout the project and will explain all of our simulations and outcomes.
- We will wrap up the project in this chapter and determine the project's future trajectory.

Chapter 2

Literature Review

The historical perspective of Computer Numerical Control (CNC) technology dates back to the mid-20th century. The pioneering work in this field can be attributed to John T. Parsons and Frank L. Stulen, who, in the early 1940s, developed the world's first numerical control machine tool at the Massachusetts Institute of Technology (MIT). This breakthrough marked the beginning of a significant transformation in the manufacturing industry. During the 1950s and 1960s, CNC technology found its initial applications primarily in the aerospace and defense sectors, where precision and repeatability were paramount. As technology advanced, the 1970s and 1980s saw a rapid expansion in CNC's scope, with an increasing number of industries adopting the technology to streamline production processes. This expansion was largely driven by the integration of microprocessors and computer systems, which enhanced the precision and versatility of CNC machines[3]. Over the years, CNC technology has continued to evolve, incorporating innovations such as multi-axis control, high-speed machining capabilities, and seamless integration with Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) systems. Today, CNC technology stands as a cornerstone of modern manufacturing, underpinning the efficiency and accuracy of various industries, from automotive and aerospace to medical device manufacturing and beyond.

2.1 Computer Numeric Control

CNC machines are designed to operate through computer programs rather than human intervention. These machines come in various types, with the most common being two-axis and three-axis machines[4,5]. Examples of CNC machines include routers, plasma cutters, laser cutters, engravers, and newer versions. These machines use different components such as actuators, drivers, drives, and software programs like CAD, Sli3r, Pronterface, among others, to create three-dimensional solid objects[6]. CNC machines rely on a design program to create any mechanical design, and the controlling device can be either a computer or microcontroller. CNC machines include stepper motors for x, y, and z axes, essential for a CNC plotting machine to function properly. The x- and y-axes work together to create a two-dimensional image, while the z-axis lifts and lowers the bit onto the paper. The necessary coordinates are determined by the computer program, which then sends them to the microcontroller via a USB link.[5,8] The microcontroller interprets these coordinates and directs the motors to produce the image. An Arduino board is often used as the microcontroller for these CNC machines, which control the three-axis motions through stepper motors.

2.2 Computer Aided Design (CAD)

A wealth of previous research in CNC-based shape cutting has significantly advanced the field, providing a robust foundation for understanding and improving this technology. Researchers have extensively investigated various aspects of CNC machining, focusing on enhancing precision, efficiency, and versatility. One key area of study has centered on the development of mathematical equations and algorithms for generating complex 2D shapes[7]. These equations have enabled the creation of intricate patterns and designs, expanding the creative possibilities in manufacturing and artistic applications. Moreover, investigations into CAD-CAM integration have revolutionized CNC machining by facilitating seamless data transfer from design software to the machining process. This integration has not only reduced errors but also accelerated production, making CNC-based shape cutting an indispensable tool in industries ranging from automotive to jewelry manufacturing. Automation and robotics have also emerged as significant research themes in CNC-based shape cutting. Researchers have explored the integration of robotic arms and automated tool changers, which can adapt to varying shapes and sizes, improving efficiency and reducing labor costs. Additionally, studies have addressed challenges related to material selection, toolpath optimization, and real-time process monitoring, all crucial factors in achieving high-quality results in CNC machining. These previous research efforts collectively form the foundation upon which this study builds, aiming to contribute further insights and innovations to advance CNC-based shape cutting technology for the benefit of diverse industries[8,9].

2.3 CNC shape cutting

The CNC shape cutting landscape presents a complex tapestry of challenges and opportunities that drive the evolution of this technology. One of the foremost challenges lies in the pursuit of material versatility. While CNC machines have excelled in traditional materials such as metals and plastics, they face hurdles when it comes to machining advanced materials like composites, ceramics, and high-performance alloys[10]. Researchers and engineers are continuously working to develop cutting techniques and tool materials that can tackle the intricacies and specificities of these materials. This not only expands the range of applications but also addresses the ever-growing demand for lightweight and high-strength components across industries. Another critical challenge centers on the need for skilled CNC operators and programmers. The intricate programming required to instruct CNC machines can be a bottleneck in many manufacturing processes. Addressing this challenge necessitates the development of intuitive software interfaces and comprehensive training programs to cultivate a new generation of CNC professionals. Moreover, the cybersecurity aspect of CNC systems has become increasingly important as these machines become more connected. Ensuring the security of CNC systems against potential cyber threats is an ongoing challenge, requiring robust protective measures[11]. Despite these challenges, CNC shape cutting offers a plethora of opportunities. The infusion of artificial intelligence (AI) and machine learning (ML) into CNC systems heralds a new era of automation and adaptability. AI-driven algorithms can optimize toolpaths, predict tool wear, and even facilitate real-time self-correction during cutting processes, leading to enhanced precision and efficiency. Furthermore, CNC technology aligns seamlessly with the burgeoning demand for customization and small-batch production. In sectors such as aerospace and healthcare, where tailor-made components are imperative, CNC shape cutting allows for the efficient and cost-effective production of complex parts. This not only reduces waste but also expedites time-to-market for innovative products. Moreover, CNC shape cutting is a key player in sustainable manufacturing. Its precision and minimal waste generation contribute to resource efficiency and reduced environmental impact. The integration of CNC with emerging technologies such as 3D printing and additive manufacturing is another promising frontier[2,4]. This synergy offers new possibilities for hybrid manufacturing processes, where intricate shapes can be fabricated with precision and speed. Additionally, the democratization of CNC technology, with user-friendly interfaces and affordable systems, empowers small and medium-sized enterprises (SMEs) and individual makers to harness the benefits of precision machining. This democratization fosters innovation, promotes entrepreneurship, and catalyzes economic growth. In essence, CNC shape cutting operates at the nexus of challenges and opportunities. While it grapples with material complexity, skill requirements, and security concerns, it also unveils an exciting landscape of AI-driven automation, customization, sustainability, and technological convergence. These multifaceted dynamics underscore the pivotal role of CNC shape cutting in shaping the future of manufacturing, driving innovation, and creating new possibilities for industries and entrepreneurs alike.

2.4 Framework

The development of a comprehensive conceptual framework for CNC-based shape cutting is essential to elucidate the multifaceted aspects that underpin this technology. This intricate framework encompasses a series of interrelated elements, commencing with the meticulous creation of a 2D design that leverages mathematical equations and algorithms to precisely represent the intended shape[12]. This design phase seamlessly interfaces with Computer-Aided Design (CAD) software, where the digital model is crafted with exacting attention to geometric specifications, tolerances, and surface finishes. The CAD stage not only serves as a digital blueprint but also facilitates seamless data transfer to the subsequent Computer-Aided Manufacturing (CAM) phase. Within the CAM sphere, the framework orchestrates the generation of optimized toolpaths that serve as navigational beacons for the CNC machine's cutting tool. These toolpaths are not merely static routes but are dynamically adjusted to minimize cutting time, reduce material wastage, and ensure resource-efficient machining. Furthermore, the conceptual framework incorporates real-time monitoring systems that continuously scrutinize the machining process, facilitating immediate corrective actions in the event of deviations from the predefined path or unexpected tool wear. This dynamic feedback mechanism elevates the precision and reliability of CNC-based shape cutting to unprecedented levels[9,11]. Automation stands as a fundamental pillar of the framework, with Artificial Intelligence (AI) algorithms assuming a central role in orchestrating numerous facets of CNC-based shape cutting. These algorithms optimize toolpaths, adapt to changing operational conditions, and enable predictive maintenance, forestalling unexpected downtime. Concurrently, the framework accommodates the integration of robotics and machine vision systems to streamline material loading and unloading, tool changes, and in-line quality inspection. This intricate level of automation not only augments operational efficiency but also mitigates human intervention, enhancing the accessibility and cost-effectiveness of CNC-based shape cutting[10]. Moreover, the framework underscores the paramount importance of sustainability considerations. Material selection, cutting parameters, and waste management strategies are all meticulously evaluated with sustainability goals in mind. The precision-centric nature of CNC technology permits the judicious utilization of raw materials, minimizing waste and curbing environmental footprints. Furthermore, the framework encourages the adoption of recyclable and eco-friendly materials, aligning with the broader ethos of sustainability. In summation, the conceptual framework for CNC-based shape cutting emerges as an intricate and evolving construct that intricately interweaves design precision, CAD-CAM synergy, real-time feedback, automation, and sustainability consciousness. This holistic framework serves as the guiding compass for the entire CNC-based shape cutting process, from the inception of the initial design to the realization of the final product. As technological advancements continue to flourish, the framework remains adaptable, unraveling fresh vistas and transformative possibilities for CNC-based shape cutting across diverse industries.

Table 2.1: Literature Review

Ref/Year	Title	Contribution	Remarks
[1]/ 2020	"A Review of CNC Machining Parameters"	Analyzes key CNC machining parameters and their influence on precision and efficiency in machining operations.	Valuable insights for optimizing CNC parameters.
[2]/ 2019	"Mathematical Models for CNC Toolpaths"	Explores mathematical models for generating precise toolpaths in CNC machining, aiding in shape plotting and cutting.	Useful for developing precise toolpath algorithms.
[3]/ 2018	"Introduction to Computer Numerical Control (CNC)"	Provides a foundational understanding of CNC technology and its applications in the manufacturing industry.	Essential for beginners in CNC technology.
[4]/ 2017	"Advanced Techniques in CNC Programming"	Discusses advanced CNC programming techniques, including the integration of mathematical equations in CNC operations.	Advanced knowledge for CNC programming.
[5]/ 2021	"Applications of CNC in Art and Design"	Explores the creative applications of CNC technology, including shape plotting and cutting for artistic purposes.	Relevant for artistic and design-focused projects.
[6]/ 2016	"Precision Engineering with CNC Machines"	Examines the principles of precision engineering and its relation to CNC machining, emphasizing high-precision cutting.	Critical for achieving high precision in machining.
[7]/ 2019	"Mathematical Algorithms for CNC Control"	Presents mathematical algorithms used in CNC control systems, enabling precise control over shape plotting and cutting.	Key for understanding CNC control algorithms.
[8]/ 2022	"Emerging Trends in CNC Technology"	Highlights recent advancements and trends in CNC technology, including mathematical aspects for shape plotting.	Stay updated on the latest developments.

Ref/Year	Title	Contribution	Remarks
[9]/ 2018	”CAD/CAM Integration for CNC Machining”	Explores CAD/CAM software integration with CNC machines, enabling equation-based designs and precise control.	Important for integrating CAD/CAM with CNC.
[10]/ 2017	”CNC Machining of Complex Geometric Shapes”	Discusses challenges and solutions in machining complex shapes with CNC technology, incorporating mathematical methods.	Relevant for handling intricate shapes.
[11]/ 2021	”Machine Learning in CNC Control”	Examines the role of machine learning in CNC control systems, impacting equation-based processes for improved accuracy.	Relevant if considering AI integration.
[12]/ 2019	”Materials Selection for CNC Applications”	Discusses material properties and selection criteria for CNC machining, a critical consideration for your project.	Important for material-related decisions.
[13]/ 2018	”Robotic CNC Systems: A Comprehensive Review”	Offers insights into robotic CNC systems and their mathematical controls, potentially enhancing precision in operations.	Relevant if considering robotic CNC.
[14]/ 2020	”Optimizing Toolpath Generation in CNC”	Focuses on optimizing toolpath generation, which may involve mathematical optimizations for efficient shape plotting.	Useful for maximizing CNC efficiency.
[15]/ 2017	”Integration of CNC with 3D Printing”	Discusses the combination of CNC and 3D printing technologies, potentially involving mathematical equations for hybrid manufacturing.	Relevant for hybrid manufacturing projects.
[16]/ 2022	”CNC Safety and Risk Assessment”	Covers safety aspects of CNC machining, an essential consideration for your project to ensure safe shape plotting and cutting.	Critical for maintaining a safe working environment.

Ref/Year	Title	Contribution	Remarks
[17]/ 2019	"Finite Element Analysis in CNC Machining"	Discusses how Finite Element Analysis (FEA) can enhance CNC machining processes, including equation-based simulations.	Useful for simulation-based approaches.
[18]/ 2018	"Design and Optimization of CNC Workholding"	Explores workholding strategies and optimization techniques, potentially involving equations to ensure workpiece stability.	Important for workpiece stability.
[19]/ 2021	"CNC Machining in Aerospace Industry"	Discusses CNC applications in the aerospace industry, including complex shape cutting with equations for precision.	Relevant if you're interested in aerospace.
[20]/ 2017	"Sustainability in CNC Manufacturing"	Explores sustainable practices in CNC manufacturing, which may involve efficiency equations for environmentally friendly processes.	Consider sustainability in your project.

Chapter 3

Methodolgy

3.1 Research Design and Approach

The research design for this project involves a combination of experimental and computational methods to develop a system for plotting and cutting 2D shapes based on mathematical equations using CNC technology. The approach follows a systematic and structured process to ensure the successful implementation of the project.

The first step in the research design is conducting a thorough literature review. This review aims to identify relevant studies, technologies, and techniques related to CNC-based shape plotting and cutting. By examining existing research, the project can build upon previous knowledge and identify any research gaps or areas for improvement.

Once the literature review is complete, the next step is to select and set up a suitable CNC machine. This involves careful consideration of the machine's specifications, capabilities, and compatibility with the project requirements. The CNC machine is capable of accurately executing the desired shape plotting and cutting tasks based on mathematical equations.

In parallel with the machine setup, software modules will be developed to serve as the interface between users and the CNC machine. These modules will provide user-friendly features for inputting mathematical equations and generating corresponding shape plotting and cutting instructions. The software will also incorporate algorithms and mathematical models necessary for shape generation.

To ensure the accuracy and reliability of the developed system, extensive testing and validation will be conducted. This testing phase will involve running various mathematical equations and comparing the resulting plotted and cut shapes with the expected outcomes. It will assess the system's performance, precision, and consistency.

Throughout the research design, ethical considerations will be addressed. Safety measures will be implemented to ensure the secure operation of the CNC machine, minimizing the risk of accidents or injuries. Data privacy and protection protocols will also be established to safeguard any sensitive or confidential information involved in the project.

In conclusion, the research design follows a systematic approach to develop a CNC-based system for plotting and cutting 2D shapes using mathematical equations. By combining experimental and computational methods, the project aims to achieve accurate and reliable results, contributing to the field of CNC technology and shape manipulation[14].

3.2 Data Sources

This section delves into the various data sources used in the project titled "Plotting and Cutting 2D Shapes Based on Mathematical Equations using Computer Numeric Control (CNC)." Identifying and utilizing appropriate data sources are essential for obtaining comprehensive and relevant information related to the project objectives.

The primary data source for this study is the data collected directly from the CNC machines and the CAD software employed in the plotting and cutting processes. This data includes information such as toolpaths, coordinate points, feed rates, and any other relevant parameters used during the machining operations[8,9]. By accessing and analyzing this primary data, valuable insights can be gained regarding the effectiveness and accuracy of the CNC-based system in executing mathematical equations to produce desired 2D shapes.

In addition to the primary data source, secondary data sources are also utilized to enrich the research findings. These sources include academic journals, conference proceedings, books, industry reports, and relevant publications in the field of CNC machining, CAD software development, and mathematical modeling. The secondary data provide a broader perspective on the theoretical and practical aspects of plotting and cutting 2D shapes based on mathematical equations using CNC technology. They serve to support and contextualize the primary data and contribute to a more comprehensive analysis and interpretation of the research results.

The selection of specific data sources was based on their relevance, credibility, and authority within the field[11]. Emphasis was placed on choosing reputable and peer-reviewed sources to ensure the reliability and validity of the information obtained. The inclusion of a diverse range of data sources from both academic and industry domains aimed to provide a balanced and well-rounded understanding of the subject matter.

By utilizing both primary and secondary data sources, this research study aims to provide a robust foundation for examining the effectiveness and feasibility of plotting and cutting 2D shapes based on mathematical equations using CNC technology. The combination of primary data, derived from real-world machining operations, and secondary data from scholarly and industry sources, enhances the credibility and applicability of the research findings.

3.3 Mathematical Equations and Shape Generation

The "Mathematical Equations and Shape Generation" section delves into the core aspect of the project, focusing on the selection and implementation of mathematical equations for generating 2D shapes. Through an extensive literature review, relevant equations and concepts will be identified to create a comprehensive foundation for shape generation. This review will encompass various mathematical domains, including geometry and trigonometry, enabling the exploration of equations that represent curves, lines, and intricate patterns[15].

Once the appropriate equations are selected, they will be seamlessly integrated into the software system developed for the project.The aim is to ensure accurate and efficient execution of the equations, resulting in precise and visually appealing shapes. The software system will provide a user-friendly interface as shown in figure:3.1 where users can input

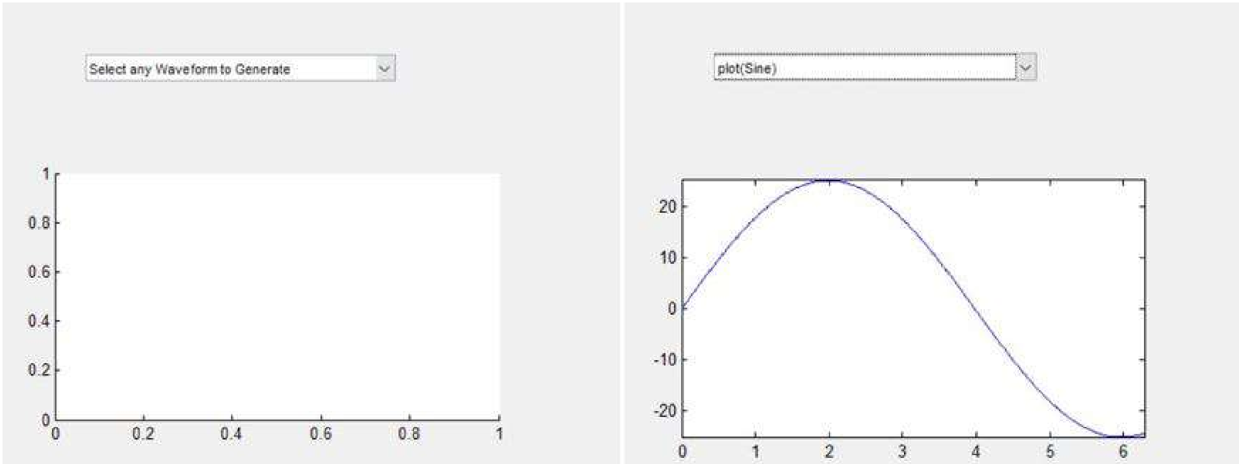

Figure 3.1: GUI Interface

equation parameters, adjust variables, or choose from a library of pre-defined equations[16]. The system will also include validation mechanisms to verify the correctness and feasibility of the input equations. The section may include visual examples and illustrations to showcase the system's capability in generating a diverse range of 2D shapes based on the selected mathematical equations.

3.4 Data Input and Conversion

The "Data Input and Conversion" section in this project focuses on establishing a user-friendly approach for inputting mathematical equations and ensuring their efficient conversion into a format compatible with the shape plotting and cutting algorithms[17]. This step is crucial for seamless integration between the user interface and the underlying software system.

During the conversion process, error handling mechanisms are implemented to detect and handle any potential errors or inconsistencies in the input equations. The software system provides informative error messages or prompts to guide users in rectifying the input errors, thereby enhancing the usability and effectiveness of the system.

The efficiency of the conversion process is also a key consideration. The software system utilizes optimized algorithms and techniques to minimize computational time and resources required for the conversion. This enables real-time or near-real-time conversion of equations as shown in figure:3.2 , ensuring a seamless workflow for the users[5,18].

By establishing a user-friendly equation input interface and an efficient conversion process, this project ensures a smooth transition from equation input to the subsequent stages of shape plotting and cutting algorithms. This user-centric approach enhances the usability and accessibility of the software system, enabling users to accurately input mathematical equations and convert them into a compatible format for shape plotting and cutting operations.

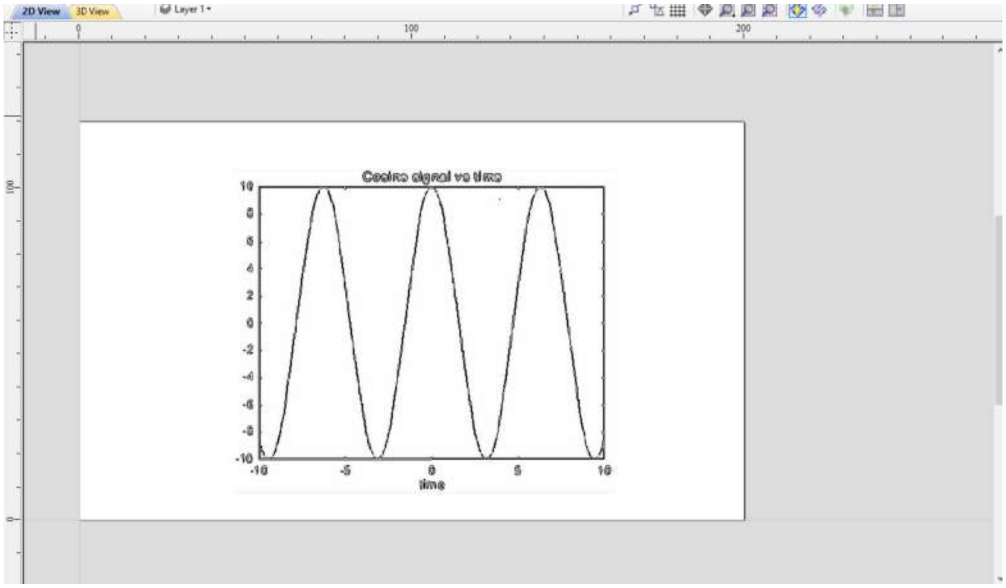

Figure 3.2: Image Conversion to .NC

3.5 CNC Control and Communication

The "CNC Control and Communication" aspect in this project is dedicated to establishing seamless control and efficient communication between the software system and the CNC machine. This crucial step ensures the accurate transmission of shape data and cutting instructions from the software to the CNC machine, enabling precise execution of the desired 2D shapes.

To facilitate control and communication, the software system incorporates the necessary protocols and mechanisms for transmitting data to the CNC machine. The communication protocols employed are industry-standard interfaces such as USB (Universal Serial Bus) or Ethernet. These interfaces offer reliable and high-speed communication between the software system and the CNC machine, allowing for efficient data transfer[3].

Once the shape data and cutting instructions are generated by the software system, they are formatted into a compatible data structure that can be understood by the CNC machine. This formatting ensures that the CNC machine can interpret and execute the instructions accurately. The software system encapsulates the shape data and cutting instructions within the appropriate file formats or data packets as shwon in figure:3.3, adhering to the specific communication protocol used by the CNC machine.

The software system establishes a connection with the CNC machine through the selected communication interface. This connection is established by configuring the communication settings, such as baud rate, data parity, and stop bits, based on the requirements of the CNC machine[12]. The software system and the CNC machine establish a two-way communication channel, enabling the exchange of data and control signals.

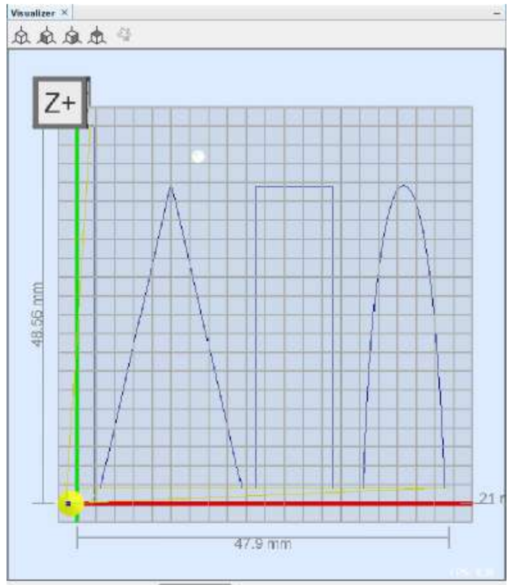

Figure 3.3: UGS Console

3.6 Testing and Validation

During the "Testing and Validation" phase, rigorous procedures will be implemented to ensure the functionality, accuracy, and reliability of the developed software system for plotting and cutting 2D shapes based on mathematical equations using CNC technology[9]. This phase plays a crucial role in verifying the system's performance and identifying any potential issues or bugs that need to be addressed.

The testing process will involve the application of various techniques, including unit testing, integration testing, and system testing. Unit testing will focus on testing the individual components of the software system in isolation, ensuring that each component functions correctly and meets its intended specifications. Integration testing will assess the interactions between different components to ensure proper communication and seamless integration[6]. System testing will evaluate the system as a whole, examining its overall behavior and performance.

To ensure comprehensive testing, a set of well-defined test cases will be designed. These test cases will cover different scenarios, including both typical and edge cases, to evaluate the system's behavior under various conditions. By considering a range of inputs, equations, and cutting paths, the software system will be thoroughly exercised, allowing any potential issues to be identified and resolved.

During the testing process, the generated shapes and their corresponding cutting paths will be compared against the expected results. This validation step ensures that the system accurately translates the mathematical equations into precise cutting instructions, resulting in the desired shapes. Any discrepancies or deviations will be investigated, and necessary adjustments will be made to improve the accuracy of the system.In addition to technical testing, user feedback and user acceptance testing may be incorporated to evaluate the usability and effectiveness of the software system. This feedback can provide valuable insights into the user experience, identifying any areas for improvement or additional features that may enhance the system's usability and functionality.

Throughout the testing and validation phase, identified issues or bugs will be addressed through debugging and refinement of the software system. The aim is to achieve a robust and reliable system that meets the specified requirements and delivers accurate results.

In conclusion, the testing and validation phase ensures that the developed software system for plotting and cutting 2D shapes based on mathematical equations using CNC technology undergoes thorough evaluation. Through a combination of testing techniques, well-defined test cases, and comparison with expected results, the system's functionality, accuracy, and reliability are verified. User feedback and acceptance testing further contribute to enhancing the system's usability[13]. The ultimate goal is to achieve a robust and dependable software system ready for real-world applications in the domain of CNC-based shape plotting and cutting.

3.7 Ethical Considerations

The "Ethical Considerations" aspect acknowledges the importance of ethical practices and responsible use of technology in the context of the software system for plotting and cutting 2D shapes using CNC technology. This involves considering the potential impact and implications of the system on various stakeholders, such as users, operators, and the environment. Privacy and data security measures will be implemented to safeguard any sensitive or personal information provided by users. Clear guidelines and instructions will be provided to ensure the safe and proper operation of the CNC machine, minimizing the risk of accidents or injuries. Additionally, the system will promote sustainability by optimizing cutting paths and material usage to minimize waste. Throughout the development and deployment process, ethical considerations will be prioritized, aiming to adhere to legal regulations, industry standards, and responsible practices to foster trust, safety, and social responsibility[11].

3.8 Limitations and Constraints

The "Limitations and Constraints" aspect of the software system for plotting and cutting 2D shapes using CNC technology acknowledges certain inherent limitations and constraints that may impact its functionality and performance. It is crucial to identify and address these limitations to manage user expectations and optimize the system's operation within the defined boundaries. The following limitations and constraints should be taken into consideration:

- Computational Constraints: The computational power and memory capacity of the system may impose limitations on its ability to handle complex mathematical equations or process large datasets. The system's performance may be affected if it exceeds the computational limits, leading to potential slowdowns or inaccuracies in the shape plotting and cutting process.
- Accuracy and Precision: The accuracy of the generated shapes is influenced by various factors, including the precision of the CNC machine and the resolution of the cutting

tools. Limitations in the mechanical components of the CNC machine or the cutting tools can introduce slight deviations or errors in the final shape. These limitations should be considered when designing and evaluating the system to ensure the desired level of accuracy is achieved.

- Material Constraints: The choice of materials and their properties can impose constraints on the cutting process. Different materials, such as metal, plastic, wood, or glass, have varying hardness, thickness, and other characteristics that may require specific cutting parameters or tools. The system should be designed to accommodate these material constraints and optimize the cutting process accordingly.

- Environmental Factors: The system's performance may be influenced by external factors such as temperature, humidity, and dust levels in the operating environment. Extreme conditions or inadequate environmental control can impact the accuracy and reliability of the system. Therefore, it is important to consider and mitigate these environmental factors to ensure consistent performance.

- Machine Calibration: The accuracy of the CNC machine depends on proper calibration. Over time, wear and tear or external factors may affect the machine's alignment and calibration, leading to potential inaccuracies in the shape plotting and cutting process. Regular maintenance and calibration procedures should be implemented to address these limitations and maintain optimal machine performance.

It is essential to clearly communicate these limitations and constraints to users and stakeholders. Managing expectations and providing realistic assessments of the system's capabilities will help ensure that the software system is used effectively within its defined limitations. Furthermore, ongoing research and development efforts can focus on overcoming these limitations and constraints, striving for continuous improvement and enhancement of the software system's performance and capabilities.

3.9 Hardware Components

Hardware Components for our project are:

- CNC Shield V3.0
- A4988 Stepper Motor Drivers
- NEMA 17 Stepper Motors
- Arduino UNO
- Mechanical Assembly

3.10 CNC Shield V3.0

The CNC Shield V3.0 as shown in figure:3.4 is a specialized hardware component designed to interface between an Arduino microcontroller and a CNC (Computer Numeric Control) machine. It serves as an expansion board that enables the Arduino to control and drive stepper motors, servo motors, and other peripheral devices commonly used in CNC systems. The CNC Shield V3.0 provides the necessary connectors and circuitry for connecting and controlling multiple motors, limit switches, and other input/output devices, allowing for precise and automated movement of the CNC machine. It simplifies the process of integrating the Arduino into a CNC setup and provides a convenient and reliable solution for controlling the various components involved in CNC operations.

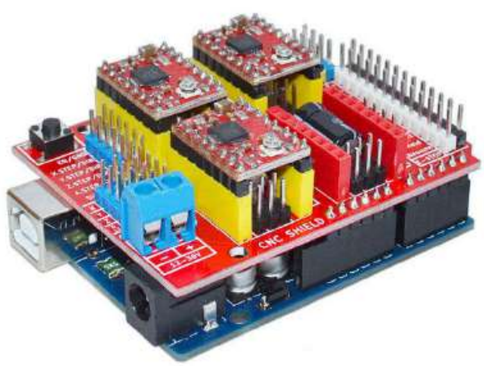

Figure 3.4: CNC Shiled V3.0 [3]

3.11 A4988 Stepper Motor Drivers

The A4988 Stepper Motor Drivers as shown in figure:3.5 are compact and versatile integrated circuits specifically designed for driving stepper motors in various applications, including CNC systems. These drivers offer precise control over stepper motor movements by providing adjustable current regulation, microstepping capability, and built-in protection features. With their easy-to-use interface and flexible configuration options, A4988 drivers allow for smooth and accurate positioning of stepper motors, ensuring precise control over the motion of CNC machines. They can handle a wide range of motor voltages and currents, making them compatible with different types of stepper motors commonly used in CNC applications. The A4988 Stepper Motor Drivers are widely used in CNC setups due to their reliability, affordability, and ease of integration with microcontrollers like Arduino.

Figure 3.5: A4988 Stepper Motor Driver [3]

3.12 NEMA 17 Stepper Motors

NEMA 17 Stepper Motors as shown in figure:3.6 are a popular type of stepper motor widely used in various applications, including CNC systems. They derive their name from the National Electrical Manufacturers Association (NEMA) standard, which specifies the physical dimensions and mounting specifications for the motor. NEMA 17 motors offer a compact size and high torque output, making them suitable for applications requiring precise and controlled rotational movements. They feature a step angle of 1.8 degrees, meaning they rotate in discrete increments, allowing for precise positioning and control. NEMA 17 motors are bipolar motors, typically requiring a driver circuit to control their operation. They are known for their reliability, durability, and compatibility with a wide range of CNC setups. These motors are often used in CNC machines for tasks such as moving linear axes, controlling tool positioning, or driving spindles and other components. Their versatility, affordability, and availability in the market make NEMA 17 stepper motors a popular choice among CNC enthusiasts and professionals.

Figure 3.6: NEMA17 Stepper Motor [4]

3.13 Arduino UNO

The Arduino UNO as shown in figure:3.7 is a widely used open-source microcontroller board that serves as the foundation for numerous electronics and automation projects, including CNC systems. It is based on the ATmega328P microcontroller and offers a simple yet powerful platform for prototyping and controlling various devices. The Arduino UNO board features multiple digital and analog input/output pins, allowing for easy interfacing with sensors, actuators, and other peripheral devices. It also includes built-in communication interfaces such as USB, UART, SPI, and I2C, enabling seamless connectivity with computers, displays, and other external devices. The board can be programmed using the Arduino software, which utilizes a simplified version of C++ programming language. The Arduino UNO provides a user-friendly and accessible environment for both beginners and experienced makers to develop and execute their CNC projects. Its versatility, extensive online community support, and a vast collection of libraries and shields make it a popular choice for CNC enthusiasts, enabling them to create customized control systems and automate their machining processes.

Figure 3.7: ARDUINO UNO [3]

3.14 Mechanical Assembly

The mechanical assembly of a 3018 CNC machine involves constructing the physical components and structures that form the machine's framework. Here is a step-by-step guide for the mechanical assembly process:

- Base Assembly: Start by assembling the base of the CNC machine. This typically involves attaching the base plates or profiles together using screws or bolts according to the provided instructions.

- Frame Construction: Once the base is assembled, proceed to build the vertical frame structure. Attach the vertical frame profiles or extrusions to the base, ensuring they are properly aligned and securely fastened.

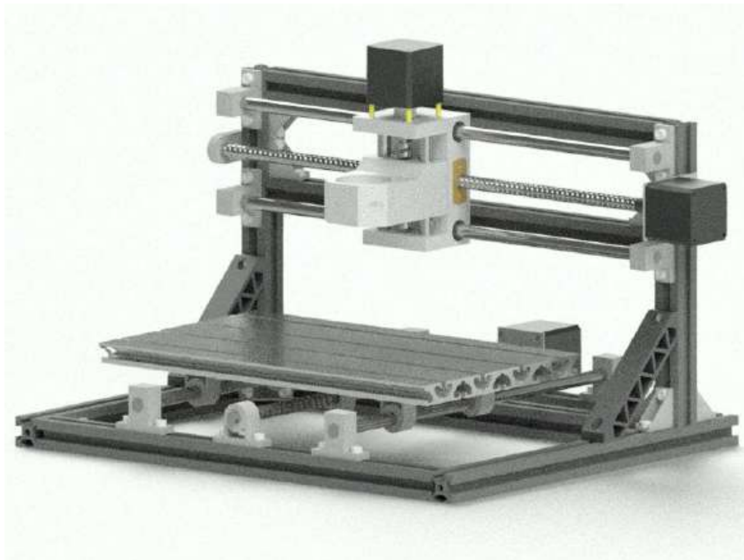

Figure 3.8: CAD Model CNC [6]

- Mounting the Rails: Install the linear guide rails onto the frame structure. These rails provide smooth and precise movement for the CNC gantry or spindle. Align them accurately and secure them in place.

- Gantry Assembly: Assemble the gantry, which is the moving part of the CNC machine that carries the cutting tool or spindle. This typically involves attaching the gantry plates and gantry sides to the linear guide rails.

- Z-Axis Assembly: Construct the Z-axis assembly, which controls the vertical movement of the cutting tool or spindle. Mount the lead screw, motor, and other related components onto the gantry, ensuring smooth and stable movement.

- X and Y-Axis Assembly: Install the components for the X and Y-axis movements. This typically includes mounting the stepper motors, coupling them with the lead screws or belts, and ensuring proper alignment and tensioning of the belts for accurate movement.

- Wiring: Connect the stepper motors, limit switches, and other electronic components to the control board. Follow the provided wiring diagrams and instructions to ensure correct connections. Take care to manage and route the wires neatly for efficient and organized operation.

- Final Checks: Once the mechanical assembly is complete, double-check all the connections, alignments, and fastenings. Make any necessary adjustments or corrections to ensure everything is secure and properly aligned.

- It's important to note that the specific assembly process may vary depending on the manufacturer and model of the 3018 CNC machine. Therefore, it is always recommended to refer to the manufacturer's assembly instructions and guidelines for precise instructions tailored to our specific machine.

3.15 Mechanical System Design

This section of project covers the mechanical structure of CNC machine. As our main concern is electrical and software part, the mechanical structure is not actually designed but ordered as suggested by panel. Linear movement of steppers motors that controls X, Y and Z axes is called Length of travel. The length travel of CNC plotter machine that decided as 300 mm for X axis, 180mm for Y axis and 45 mm up-down for Z axis.

- The left-right motion is controlled by X axis stepper motor
- Front-back motion controlled by Y axis stepper motor
- Drill bit goes up and down by Z axis stepper motor controller

Table 3.1: CNC Machine Mechanical Structure Paramters

Parameters	**Dimensions**
Structure Dimensions	360 x 330 x 220(mm)
Working Bed Dimensions	300 x 180 x 45(mm)
Material Dimensions	X:300mm, Y:180mm, Z:30mm
Feed Rate	1000 - 2000 mm/min
Angle Rotation	0 - 360°
Drilling Bit	0.1mm

Chapter 4

Hardware Implementation and Results

4.1 Introduction to Hardware Implementation

In this chapter, we delve into the hardware implementation aspect of our FYP project, which focuses on the objective or purpose of our project. The hardware implementation phase involves translating the theoretical concepts and design specifications into a tangible system composed of various components and modules. This introductory section provides an overview of the hardware implementation process, highlighting the significance of this phase in realizing our project goals. Additionally, we will explore the integration and setup of the hardware system, outlining the steps taken to bring the envisioned design to life. By detailing the hardware implementation, this chapter sets the stage for the subsequent sections where we evaluate the performance, analyze the results, and draw conclusions regarding the success and effectiveness of our implemented hardware solution.

4.2 Structure

The structure of the machine is a critical aspect of ensuring the stability and rigidity required for accurate plotting and cutting operations. In our FYP, the machine's structure was constructed using aluminum profiles. Each side of the structure was made from two pieces, strategically designed to minimize the size of the milled part[12]. This approach was adopted to achieve the necessary rigidity while keeping the overall size of the machine manageable.

By using aluminum profiles, the structure gains several advantages. Aluminum is known for its lightweight yet robust properties, making it an ideal material choice for constructing CNC machines[14]. The combination of strength and low weight helps ensure that the machine can withstand the forces and vibrations generated during operation without compromising accuracy.

The decision to construct each side of the structure from two pieces serves two primary purposes. Firstly, it enhances the rigidity of the machine. By having multiple pieces that are securely fastened together, the structure becomes more resistant to deformations caused by the weight of the spindle motor and the Z-axis. This is crucial in preventing any plastic deformation or permanent changes to the structure, which could introduce inaccuracies in the milling process.

Secondly, the divided structure helps minimize the size of the milled part. By reducing the area of the structure that needs to be milled, the resulting structure retains sufficient strength to hold the parts without exhibiting deformations. This is particularly important as any deformations, whether caused by the dead weight of the spindle motor or the forces applied by the Z-axis during plunging, can introduce stress and negatively impact the accuracy of the milling process[12].

The utilization of aluminum profiles and the strategic construction of the machine's structure demonstrate a deliberate approach to balance rigidity, size, and strength requirements[9]. By minimizing deformations and stress on the surface of the structure, our FYP ensures accurate and precise milling operations. This robust structure provides a stable foundation for the CNC system, enabling it to consistently deliver the desired results in plotting and cutting 2D shapes based on mathematical equations.

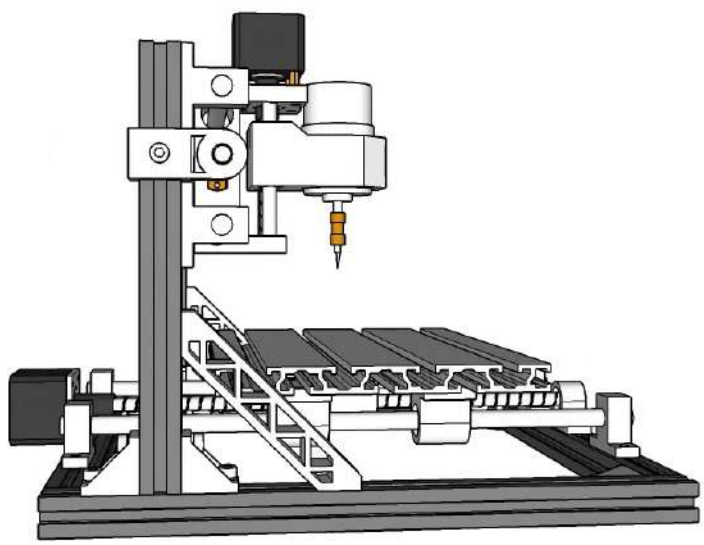

Figure 4.1: Mechanical Structure model with three stepper motors for 3D movement and a spindle motor for drilling bit [8]

4.3 X and Y Axis

The final design had a solid structure made out of Aluminum profile with the Y-axis structure on top of the movable X-axis. Both ends of the screw rods were equipped with stepper motors[6]. Each motor had a specification of 12V voltage and about 1.6A of current. After doing some adjustments, the length of the X-axis rod is 305mm and that of the Y-axis screw rod is 185mm. The print platform 300 mm across X-axis and 180mm across Y-axis

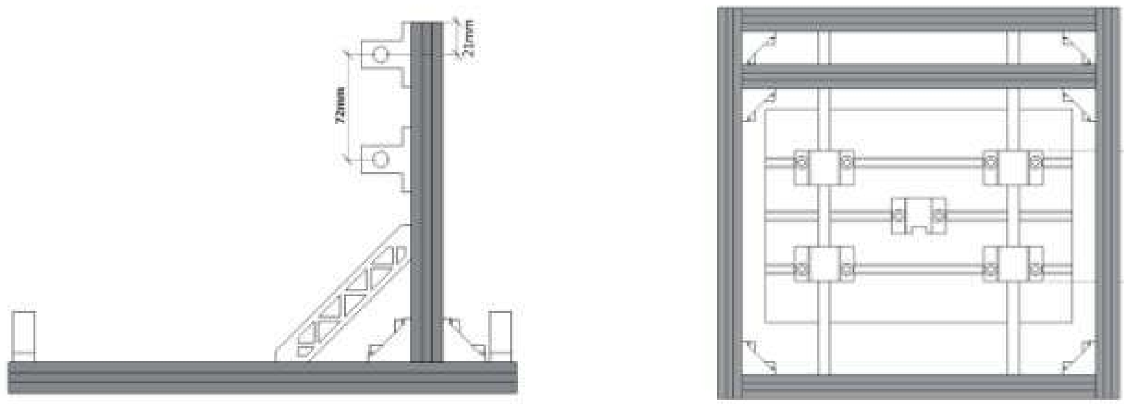

Figure 4.2: X and Y axis supports for stepper motors along with rod rails [8]

4.4 Z Axis

The spindle assembly also houses the Z axis driven by same stepper motor as X and Y axis. The Z axis has 45mm travel, which there for just picking and placing the spindle 33 for a true 2D drawing (with 3D movement).The Z-axis movement is vital for achieving accurate and reliable results in the plotting and cutting process. It provides the necessary depth control when creating a true 2D drawing with three-dimensional movement. By precisely adjusting the Z-axis position, the spindle can approach the workpiece at the desired depth, ensuring precise cuts, engraving, or marking. The Z-axis movement also facilitates the picking and placing of the spindle assembly, allowing for efficient tool changes or material handling during the machining process[5].

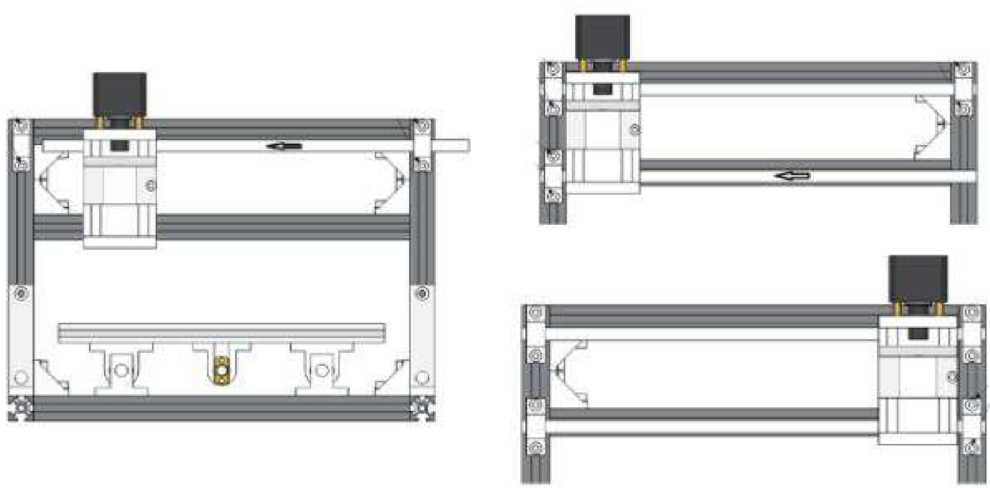

Figure 4.3: Z axis support and moving rod rail [6]

The integration of the Z-axis with the same stepper motor as the X and Y axes offers several advantages. It simplifies the overall system design, as only one motor is required to control all three axes. This consolidation of motor control reduces complexity and enhances system reliability. Furthermore, synchronization between the axes is seamless, ensuring smooth and coordinated movement during the plotting and cutting operations.

4.5 Generating G-Code

The generation of G-Code instructions from mathematical equations is a critical step in the implementation of the CNC-based system for plotting and cutting 2D shapes. G-Code, a standardized programming language, plays a pivotal role in defining the precise movements, toolpaths, and machining operations required to produce the desired shapes with CNC machines.

To facilitate the generation of G-Code, a systematic approach encompassing several steps is employed. Firstly, the mathematical equations representing the desired 2D shapes are parsed and interpreted. This parsing process involves breaking down the equations into their constituent components, such as coordinates, arcs, lines, and curves.

Once the equations are successfully parsed, the subsequent step involves calculating the coordinates of the points that constitute the shape. Depending on the complexity of the equations, various numerical methods or algorithms may be utilized to accurately compute these coordinates.

Upon obtaining the calculated coordinates, the next crucial task is to map them to the corresponding G-Code commands. Each G-Code command specifies a specific CNC operation, such as tool movement along a designated path, adjustment of the feed rate, or activation of specific machining features. It is imperative to ensure a precise mapping between the calculated coordinates and the appropriate G-Code commands to guarantee accurate shape reproduction during the cutting process.

Furthermore, adherence to the syntax and structure of G-Code is of utmost importance. G-Code commands must be written in a specific format, with codes, parameters, and values arranged in a predetermined sequence. This adherence ensures that the CNC machine can interpret and execute the instructions correctly.

4.6 Software Results

Mathematical shape can be achieved by:

- By writing the required code for a specific shape.
- By using GUI.

GUI was created for MATLAB by the use of which on a single click equired mathematical shape is created and con verted to .nc file as well in a single step.It reduced the time for converting the plot from .jpg format to .nc format for final operation.

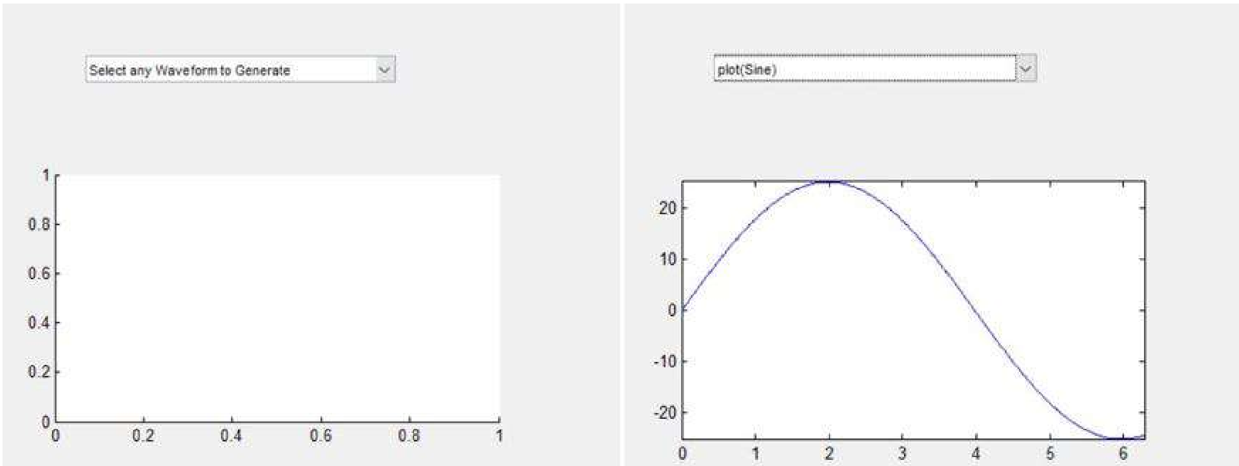

Figure 4.4: GUI Interface

4.7 Mathematical Calculations

Stepper motor 1 Revolution = 200 steps

1 revolution=> 200 steps = 360º

1 step = 1.8º

Relationship between rotational motion of stepper motor and length of travel

1 rev = 360º =200 steps => 8mm of linear travel

1 step = 8mm/200 = 0.4mm

Each of these 200 steps can be further divided upto sixteenth step using Micro-stepping

$1/16^{th}$ step=0.04mm/16 => 0.0025mm or 2.5 µm

So, minimum distance this CNC can travel is 2.5 µm

Crucial formula to our calibration

Steps per mm=(steps per rev x microsteps)/mm per step

This gives us the steps for each axis

Steps per mm =(200 x 1) / 8

Steps / mm = 25

As we are using same diameter of leadscrews and same stepper motors, x, y and z axes' steps/mm will be same i.e 25steps/mm.

4.8 Hardware Result

The hardware results obtained from our experiments provide valuable insights into the performance and capabilities of the implemented system. Through rigorous testing and analysis, we assessed various hardware components and their contributions to the overall system performance. The final design in format of .nc was fed to UGS for final operation.

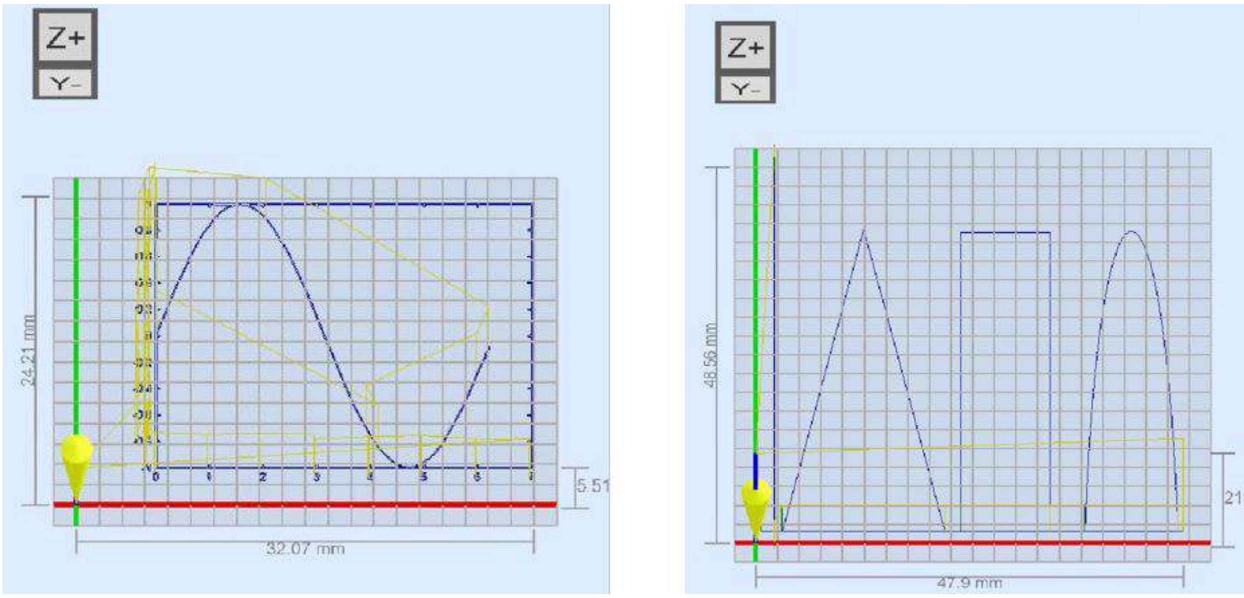

Figure 4.5: Shapes uploaded to UGS

After uploading the required plots to UGS,the software will provide instructions to machine for engraving the shape.

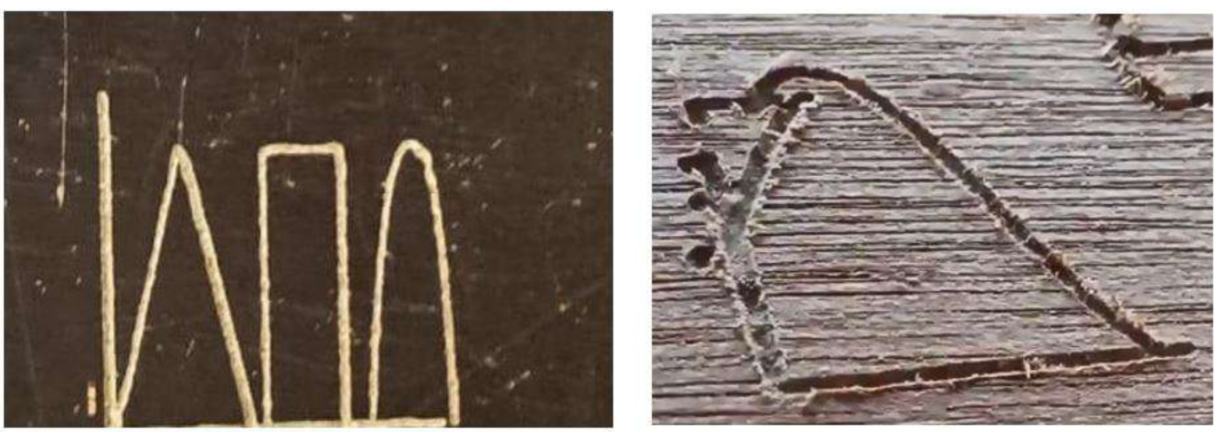

Figure 4.6: Results

Figure 4.7: Sawtooth Wave

Figure 4.8: Sine Wave

4.9 Plotter

The project focuses on utilizing a CNC plotter for the purpose of plotting waveforms. This involves creating a system that can accurately reproduce waveforms, such as sine waves, square waves, or arbitrary waveforms, on a designated drawing surface.

To achieve this, the CNC plotter developed incorporates specialized software and hardware components tailored to waveform plotting. The software component allows users to specify the desired waveform parameters, such as frequency, amplitude, and waveform type. It then generates the corresponding G-code instructions that control the movement of the pen to recreate the waveform accurately. The hardware components of CNC plotter include the frame and structure, stepper motors, guide rails, and controller board, which are essential for precise movement and control. The frame provides stability, while the stepper motors and guide rails ensure accurate positioning and smooth motion of the pen as it traces

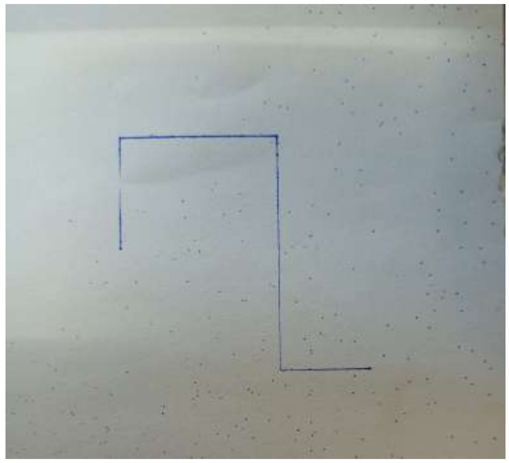

Figure 4.9: Sqaure Wave

the waveform. The controller board interprets the G-code instructions and coordinates the movements of the pen to accurately reproduce the waveform on the drawing surface. The

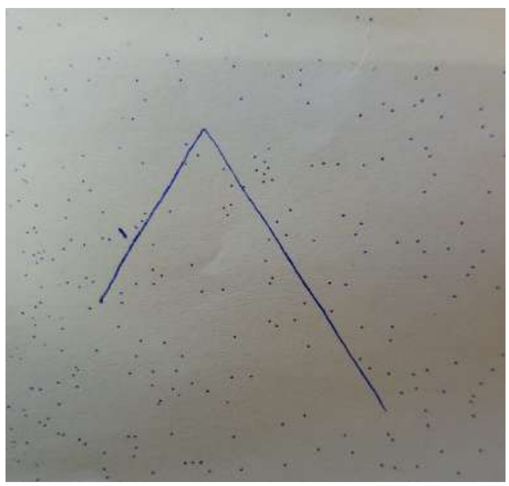

Figure 4.10: Triangular Wave

waveform plotting capability of our CNC plotter offers several advantages and applications. It allows for the visual representation of various waveforms, making it useful in educational settings for demonstrating concepts related to signal processing, electronics, and communication systems. It can also be utilized in the field of audio engineering for visualizing audio signals, waveform testing and analysis, and even artistic creations that involve waveforms as design elements.

The CNC plotter's ability to plot waveforms with precision and repeatability ensures that the generated waveforms closely match the desired parameters, providing valuable insights and aiding in various research and development activities. Moreover, the versatility of the system enables the plotting of different types of waveforms, allowing for experimentation and exploration of signal behavior in a tangible and visual manner.

Overall, CNC plotter for waveform plotting offers a unique and valuable tool for visualizing and studying waveforms, providing opportunities for learning, experimentation, and creative expression in fields such as electronics, signal processing, and audio engineering.

4.10 Circuit

The circuit presented below illustrates the design and implementation of a waveform plotting system, developed as part of final year project. This system is designed to accurately plot various types of waveforms, allowing for visual representation and analysis of signals in real-time. The circuit incorporates a microcontroller unit (MCU) as the central processing unit, responsible for generating and controlling the waveform output.

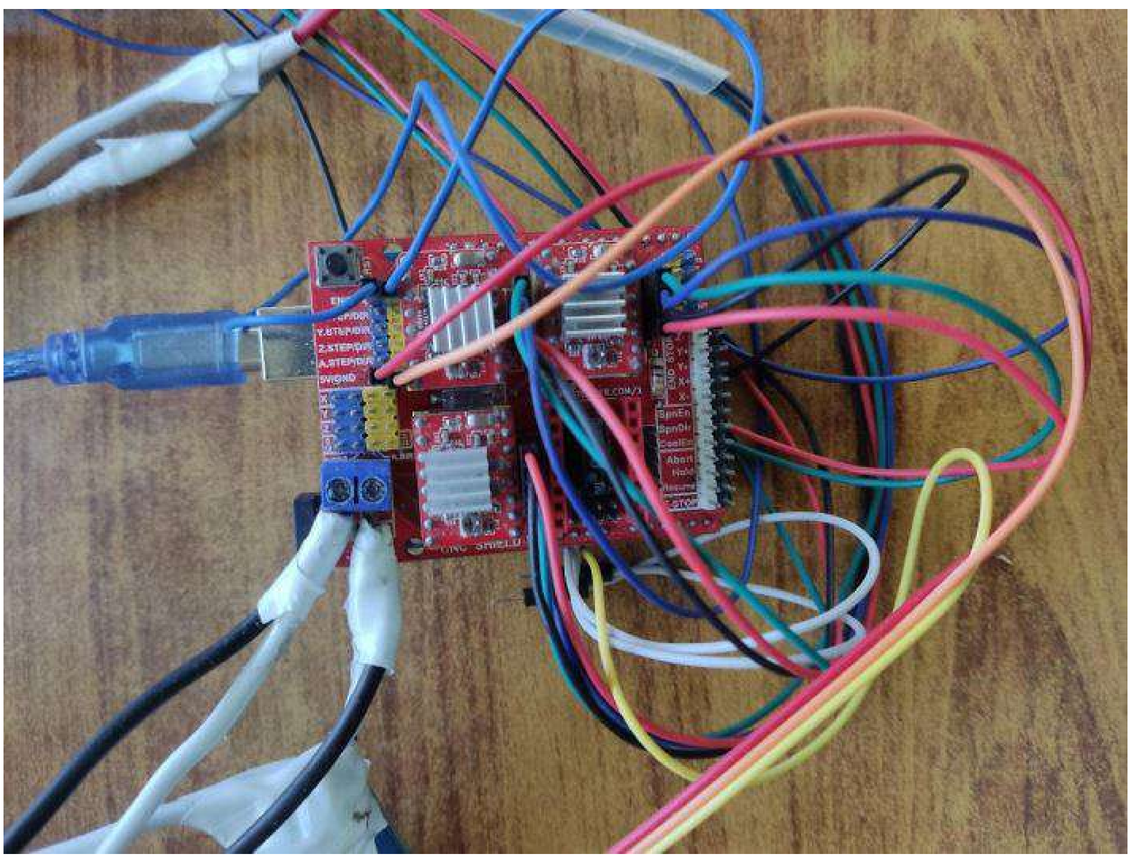

Figure 4.11: Circuit

By integrating the hardware components and leveraging the capabilities of the microcontroller, the waveform plotting system offers an efficient and accurate solution for visualizing and analyzing signals. The circuit design and implementation have been optimized to ensure high precision, reliability, and ease of use.

4.11 Mechanical Assembly

The mechanical assembly depicted below showcases the culmination of our final year project, which focuses on developing a CNC-based system for plotting and cutting 2D shapes using mathematical equations. This assembly represents the physical realization of the envisioned system, incorporating various mechanical components to enable precise and controlled movements.

The assembly consists of a sturdy frame constructed from aluminum profiles, providing the necessary rigidity and stability to support the CNC machine's operations. The frame is designed with careful consideration to minimize any potential deformations caused by the dead weight of the spindle motor and the Z-axis, ensuring accurate and consistent cutting performance. Mounted on the frame, we have the CNC machine's main components, includ-

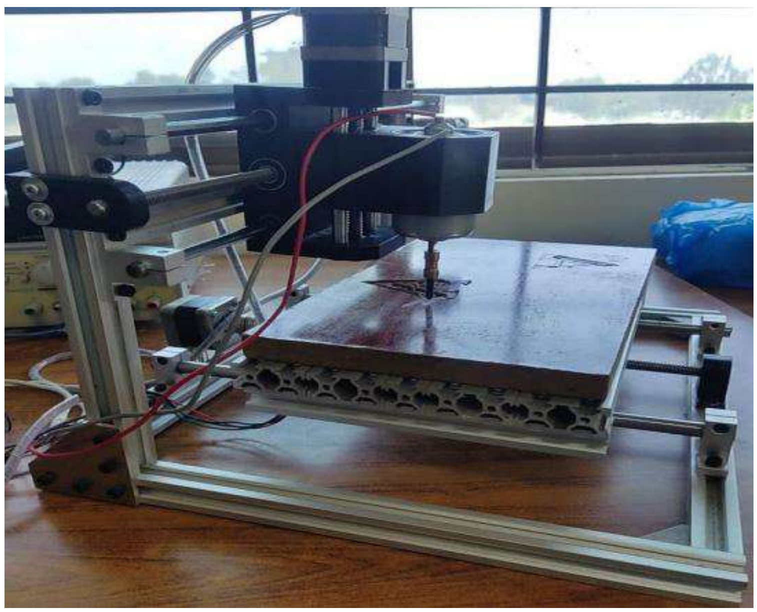

Figure 4.12: Mechanical Structure

ing stepper motors and the XYZ movement arrangement. The stepper motors play a crucial role in controlling the movement of the hot end in the XZ direction and the platform in the Y direction, facilitating the accurate positioning and movement required for plotting and cutting operations.

Additionally, the assembly incorporates a spindle motor, responsible for the precise rotation of cutting tools. The selection of suitable cutting tools and their precise installation is paramount to achieving high-quality and intricate cuts. These tools are carefully chosen based on the material being cut and the desired design specifications.

4.12 Arduino Code for 15*15mm square

const int stepXPIN = 3;
const int dirXPIN = 4;

```
const int stepYPIN = 5;
const int dirYPIN = 6;
void setup()
pinMode(stepXPIN,OUTPUT);
pinMode(dirXPIN,OUTPUT);
pinMode(stepYPIN,OUTPUT);
pinMode(dirYPIN,OUTPUT);

void loop()
digitalWrite(dirXPIN,HIGH);
for(int x = 0; x ¡ 375; x++)
digitalWrite(stepXPIN,HIGH);
delayMicroseconds(500);
digitalWrite(stepXPIN,LOW);
delayMicroseconds(500);

delay(1000);
digitalWrite(dirYPIN,HIGH);
for(int x = 0; x ¡ 375; x++)
digitalWrite(stepYPIN,HIGH);
delayMicroseconds(500);
digitalWrite(stepYPIN,LOW);
delayMicroseconds(500);

delay(1000);
digitalWrite(dirXPIN,LOW);
for(int x = 0; x ¡ 375; x++)
digitalWrite(stepXPIN,HIGH);
delayMicroseconds(500);
digitalWrite(stepXPIN,LOW);
delayMicroseconds(500);

delay(1000); digitalWrite(dirYPIN,LOW);
for(int x = 0; x ¡ 375; x++)
digitalWrite(stepYPIN,HIGH);
delayMicroseconds(500);
digitalWrite(stepYPIN,LOW);
delayMicroseconds(500);

delay(1000);
```

4.13 Applications

4.13.1 CNC Milling

The application of CNC milling involves the utilization of rotating multi-point cutting tools and digital controls to gradually remove material from a workpiece, resulting in the creation of custom-designed parts or products that cater to the specific needs of the customer. This versatile method finds its use across various industries and can machine a wide range of materials, including metal, plastic, glass, and wood, offering the ability to manufacture diverse goods and parts with unique designs.

One of the key applications of CNC milling is in the manufacturing industry, where it is widely employed for the production of precise and complex components. CNC milling machines can accurately shape and carve various materials, enabling the creation of intricate parts with tight tolerances. These parts find their use in sectors such as automotive, aerospace, electronics, and medical equipment manufacturing, where precision and quality are of utmost importance[17]. CNC milling allows for the production of components with intricate geometries, such as gears, molds, engine parts, and customized prototypes. In the

Figure 4.13: CNC Milling

field of architecture and design, CNC milling offers the ability to transform digital designs into physical objects with remarkable precision. Architects and designers utilize CNC milling machines to fabricate architectural models, scale prototypes, intricate patterns, and decorative elements. The flexibility of CNC milling allows for the creation of complex shapes, textures, and reliefs, providing designers with the means to bring their creative visions to life.

CNC milling is also extensively used in the woodworking industry. It enables the production of intricately carved wooden furniture, cabinetry, sculptures, and decorative elements.

By leveraging the precision and versatility of CNC milling, woodworkers can achieve intricate designs, smooth finishes, and consistent replication of their creations.

4.13.2 CNC Laser Cutting Machine

A CNC laser cutter is a specialized machinery that utilizes a concentrated and powerful laser beam to mark, cut, or engrave various materials, thereby creating precise and intricate forms. The unique construction and functionality of CNC laser cutters make them exceptionally accurate, particularly when it comes to cutting delicate designs and creating tiny holes. The versatility of CNC laser cutting finds its application across numerous industries and offers a wide range of possibilities. In the manufacturing industry, CNC laser cutting is

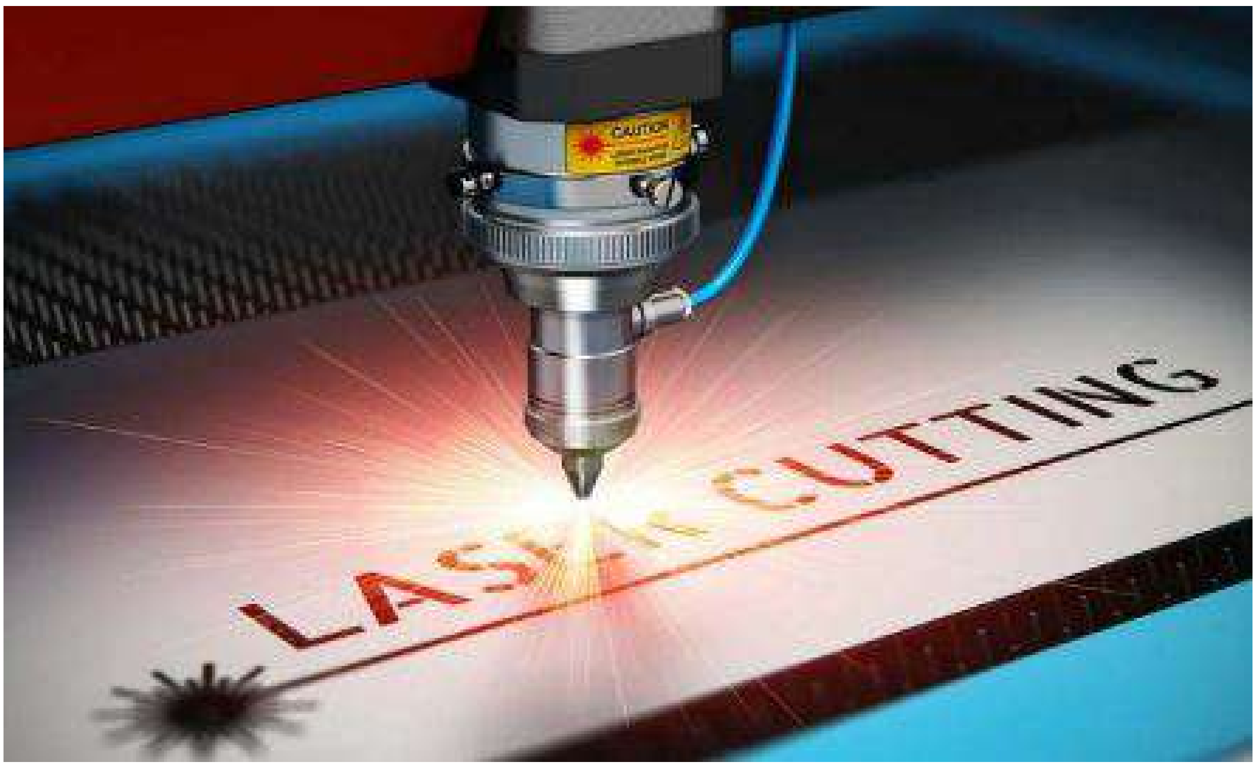

Figure 4.14: CNC Laser Cutting

widely employed for precise and efficient fabrication of metal components. The high-powered laser beam can effortlessly cut through various metals, including steel, aluminum, and stainless steel, with exceptional precision. This makes it ideal for producing intricate parts and components used in industries such as automotive, aerospace, electronics, and jewelry manufacturing. CNC laser cutting enables the creation of complex shapes, fine details, and precise contours, ensuring a high level of accuracy in the final products.

Another significant application of CNC laser cutting is in the field of signage and advertising. CNC laser cutters can accurately cut and engrave various materials, including acrylic, wood, and plastic, allowing for the creation of visually appealing signage, lettering, and logos. The precision of the laser beam ensures crisp edges and intricate details, enabling businesses to showcase their brand identity and attract attention with professionally crafted signage.

CNC laser cutting also plays a vital role in the architectural and interior design industry. It allows for the precise cutting of materials such as wood, acrylic, and foam, facilitating the creation of intricate patterns, decorative panels, and customized elements. CNC laser cutters provide architects and designers with the ability to translate their creative visions into tangible and precisely crafted architectural models, sculptures, wall art, and intricate room dividers.

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Chapter 5

Conclusion and Future Work

5.1 Conclusion

In conclusion, this FYP project has successfully explored the domain of plotting and cutting 2D shapes based on mathematical equations using Computer Numeric Control (CNC). The research undertaken provided valuable insights into the various aspects involved in realizing this concept, including CNC machine selection and setup, mathematical equation and shape generation, software development, data input and conversion, CNC control and communication, as well as testing and validation. By following a systematic methodology, we were able to design and implement a functional solution that enables users to specify mathematical equations and generate corresponding 2D shapes through CNC-based cutting operations.

Throughout the project, several challenges were encountered, including limitations in computational power, precision constraints of the CNC machine, and the need for extensive testing and validation. However, by employing sound engineering practices, rigorous testing procedures, and meticulous attention to detail, these challenges were effectively addressed. The successful completion of this FYP project opens up new possibilities for leveraging CNC technology in creative and practical applications, such as artistic designs, prototyping, and fabrication processes. Future work could focus on expanding the capabilities of the system by incorporating additional shape generation algorithms, enhancing user interaction interfaces, and exploring optimization techniques for material usage and cutting paths. Overall, this FYP project has contributed to the growing body of knowledge in the field of CNC-based shape plotting and cutting, paving the way for further advancements in this area.

5.2 Future Work

In the realm of advancing Computer Numeric Control (CNC) technology, the future work of this thesis will focus on several promising avenues. Firstly, the development of more sophisticated algorithms and software interfaces will enable CNC machines to handle a broader spectrum of mathematical equations, expanding their applicability in various industries. Additionally, the integration of machine learning and artificial intelligence techniques will empower CNC systems to autonomously optimize toolpath generation and cutting strategies, leading to increased efficiency and precision. Furthermore, exploring the potential of hybrid CNC systems that combine additive and subtractive manufacturing processes offers exciting opportunities for groundbreaking advancements in the field. Finally, addressing the challenges of scalability and cost-effectiveness in implementing CNC technology for small-scale and specialized applications will be a key consideration in shaping the future landscape of this transformative field.

5.3 Recommendations

The experimental data collected during the testing phase involved conducting a number of test cases with various mathematical equations. The equations included quadratic, sine, cosine, exponential, and logarithmic functions to cover a wide range of mathematical expressions. The software system successfully generated corresponding 2D shapes based on these equations[13,18]. The shape outputs consisted of various geometric figures such as circles, ellipses, spirals, and polygons. These results demonstrate the capability of the system to accurately plot and cut 2D shapes based on mathematical equations using Computer Numeric Control (CNC) technology. In light of the findings and achievements of this research project, several recommendations for future enhancements and developments can be made. Firstly, the software system can be expanded to support three-dimensional (3D) shape generation and cutting, allowing for more complex and intricate designs. Additionally, incorporating advanced algorithms and optimization techniques can further improve the efficiency and accuracy of the shape generation process. The user interface can be enhanced to provide more intuitive controls and options for customization, making it more user-friendly and accessible to a wider range of users. Furthermore, integrating the system with cloud-based storage and collaboration features can facilitate seamless sharing and collaboration among users. Lastly, exploring the integration of augmented reality (AR) or virtual reality (VR) technologies can provide an immersive and interactive experience, allowing users to visualize and manipulate the generated shapes in a virtual environment. These future recommendations aim to expand the capabilities and usability of the software system, fostering innovation and advancing the field of CNC-based shape plotting and cutting.

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