ECE 445 Project Proposal

Customizable Automatic Pottery Wheel-Throwing Machine

Team #22

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1 Introduction

1.1 Objective

With the advancement of digital fabrication and the increasing demand for precision in ceramic manufacturing, traditional handcrafting methods face limitations in consistency and scalability. To address these challenges, we propose the development of an automated ceramic shaping system capable of producing intricate designs with high accuracy and efficiency.

This system will incorporate a high-speed rotating pottery wheel combined with a robotic manipulator to shape the clay dynamically. The manipulator will feature at least three degrees of freedom: two for positioning along the radial and vertical axes, and one for controlling the material's contour. Apart from the automated wheel, the system will integrate six motors to execute precise movements. We would create a software module to process digital pottery models, generating height-based contour data and converting it into synchronized motor commands for an optimized sculpting process.

1.2 Background

Traditional pottery production relies on manual craftsmanship, requiring years of experience to achieve consistency in shape, thickness, and design. This requirement raise the bar for young artist to present themselves in pottery. Our design provides a chance for amateurs and non-professional to make pottery in a simpler way, expanding the community of pottery enthusiasts and making pottery more accessible.

Automation in ceramic and pottery manufacturing has been explored in industrial settings, but existing solutions are often expensive and complex [1]. Recent advancements in robotics and digital fabrication provide an opportunity to develop a more flexible and cost-effective automated wheel throwing system. These systems may face to individual, providing diversity and inspiration in this area.

To achieve the shaping of the clay body, a highly precise robotic hand design is required. We can implement the control of the robotic manipulator using the theories outlined by Craig in his book [2].

1.3 High-Level Requirements

- Realize the automatic shaping for the clay body. The process should be fully automated, requiring only basic setup by the user.
- The shaping process must be fully controlled by a user-friendly program that allows for input of custom designs. The program should enable users to adjust key parameters such as shape dimensions, wall thickness, and height with at least 95% accuracy. The interface should be intuitive, requiring minimal training.
- Minimize the number of operation points of the robotic manipulator as much as possible. Current design requires 6 operation points, considering reduce to 4. The stepper motor, using for pose control, must achieve a stepping resolution of 1 µm or less through micro-stepping.

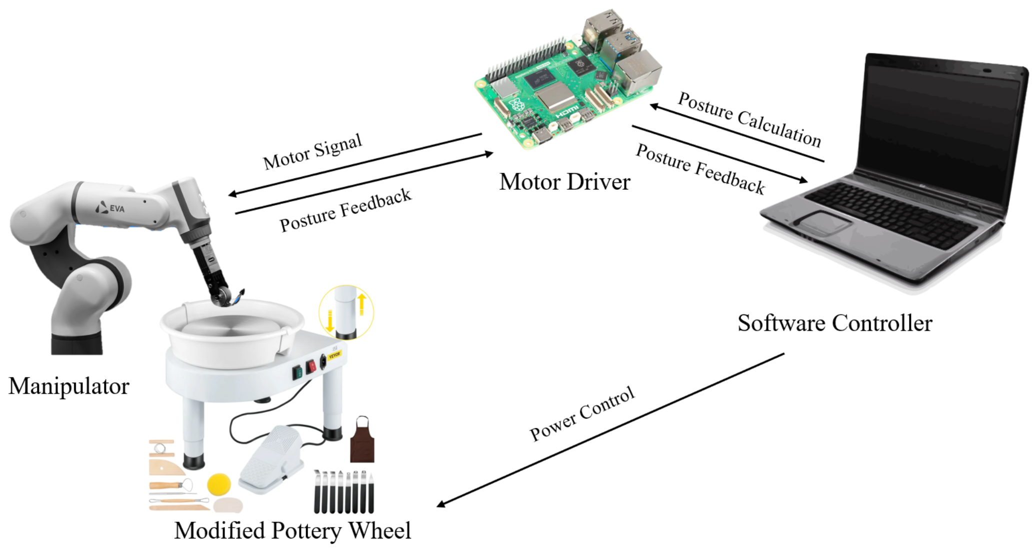

Figure 1: Visual Aid [3][4][5][6]

2 Design

2.1 Block Diagram

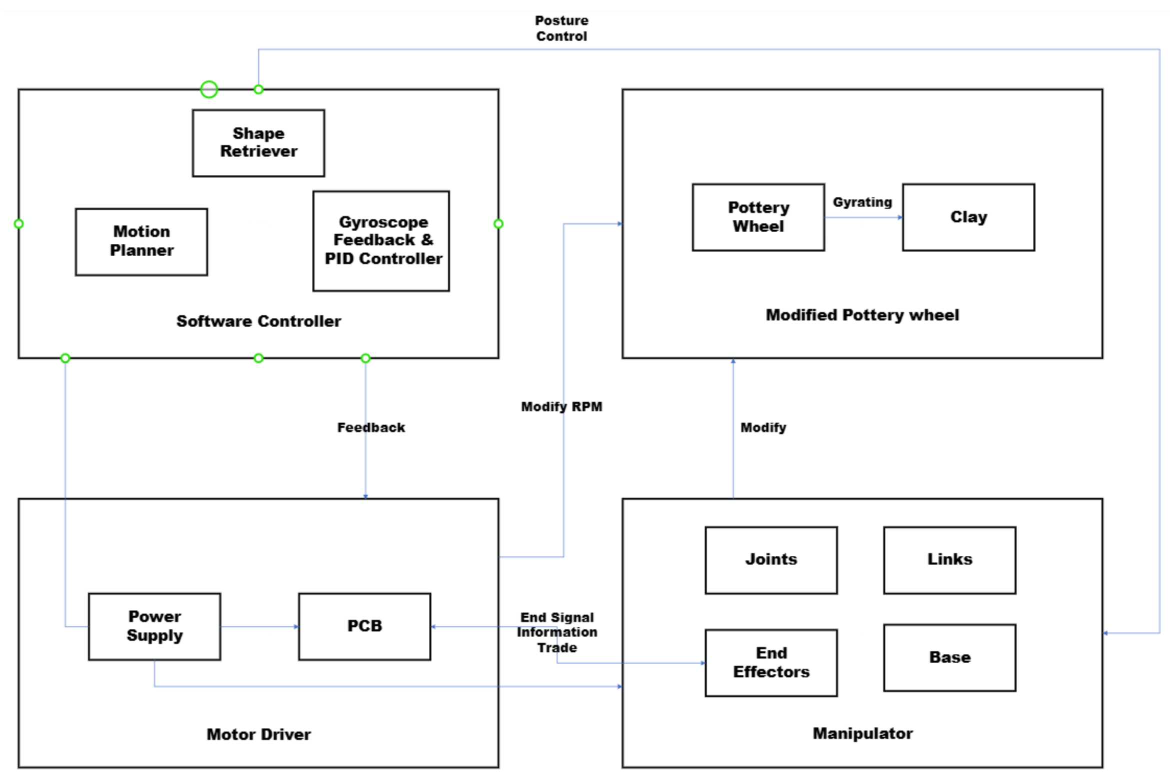

Figure 2: Block Diagram

2.2 Manipulator

The manipulator module is the core operator of our wheel-throwing machine. It is a branched 3R robotic arm, where the last two joints are duplicated to control two end effectors simultaneously, shaping the inner and outer walls of the target pottery vessel.

2.2.1 Base

The base of the manipulator refers to the stationary part where the rest of the robotic arm is mounted. It consists of a raised support to align the average working height introduced by the pottery wheel.

- The base must be able to withstand its own weight and the force exerted by the pottery on the end effectors, especially the shear force from the rapid rotation of the pottery vessel.
- The base must be able to suppress vibrations, so rigid materials must be used and a tight connection to the workbench is required.

2.2.2 Links

The links are the skeleton that extend the end effectors to specific space positions. To simultaneously locate the working positions of the inner and outer end effectors, we propose a 5-link structure, where the last two links (and joints) of a 3R robotic arms are duplicated; so there is one shared link from the base (L_1), and two links each for inner and outer controls (L_2, L_3 for inner links, and L'_2, L'_3 for outer ones).

- To prevent the inner links from colliding with the pottery wall, the link L_3 should be sufficiently thin, relatively long and approximately vertical along the central axis of the pottery vessel.
- The links must be both light-weighted and rigid, which are supposed to be made of aluminum alloy, e.g., the aluminum slot profile 2020 [7] or other types.

2.2.3 Joints

The joints are rotatable parts which connect the links together. Each joint consists of a motor and corresponding connectors. Taking the cost into account, we choose stepper motors MS42DDCR [8] instead of servo motors; and as a supplement, we attach the gyroscopes to each link to provide posture feedback for the closed-loop control.

- The joints must be robust, i.e., able to withstand the force. Due to all motor axes' perpendicular directions to the working plane, the shear force from the pottery vessel is reflected as the axial force, which has a stricter upper limit in the stepper motor.
- The joints must be able to provide sufficient torque under the pressured working scenario to precisely determine the joint angles.

2.2.4 End Effectors

The end effectors refer to the terminal modules which operate the shaping process. Due to the plasticity of clay, we will install a rolling tool to each terminal. This can not only exert sufficient pressure to shape the pottery walls, but protect the tools from rapid wear and tear by replacing the sliding friction with rolling friction.

- The end effectors must be light-weighted and small enough to be placed and to move inside the pottery vessel.

2.3 Modified Pottery Wheel

The pottery wheel is used to supply stable rotational force, which helps the manipulator better control the thickness and shape of the clay in the molding process. In the process of kneading, it can accurately adjust the speed and smooth the clay wall in the process of rotation, improving the fineness and consistency of the finished product.

2.3.1 Clay

The essence of clay is plasticity, strength, viscosity, and fineness. Considering the above four factors, we preliminarily selected two types of clay, stoneware clay and white clay. Stoneware clay is a common clay that is used with high plasticity and viscosity, which means that it can maintain a certain shape for a considerable time and is apt to perform complex operations. White clay is a clay with higher fineness and plasticity, while it is too soft with lower strength. Clay will craze when the surface is day, so both clay need certain water spray to reduce friction.

- Plasticity ensures that the clay accurately changes its local shape when pushed and pulled by the rolling tool at the end of the manipulator, rather than splitting directly through the clay wall.
- Strength ensures that the bottom clay layer can support a certain height of the top clay layer and will not directly collapse when the whole product is more than 10 to 15 cm height. The ability of the product to stand on its own is critical.
- Viscosity is vital when clay is in contact with the manipulator. It is not desired that the clay will stick to the rolling tool while the tool is manipulating and cause any kind of malfunction in the motion of the manipulator or pottery wheel.
- Fineness ensure the smooth appearance of the product. Clay with high fineness is compatible with our mean of plasticity, which is a rolling tool.

2.3.2 Pottery Wheel

Wheel is the basement of the clay, which controls the clay in the center of the turntable and ensures that the product is a rotating body. It support around 0 to 300 RPM with a power of 250W. The wheel is opearating synchronously with the whole system through the software control module.

2.4 Motor Driver

2.4.1 Power Supply

Pottery Wheel is directly driven by 220V common power supply. For manipulator, stepper motors are controlled pulse signal generated by PCBs which require a 12V DC power supply. The detailed requirements for the 12V DC power supply is shown as follows:

- Maximum current should exceed 5A to avoid the possible workload.
- The conversion efficiency must reach more than 90% to reduce energy waste and heat generation.
- The output voltage fluctuation should be less than ±5%, and the ripple noise should be less than 50mVpp to avoid interference with the circuit.

2.4.2 PCB

In this project, the PCB is not only responsible for controlling the motors, but also for information communication between hardware and software.

- PCBs will receive the signal from Robot Operating System (ROS) and then generate pulse signal to drive stepper motors.
- PCBs receives data from the gyroscopes on the manipulator and transmits it back to ROS (software part).

2.5 Software Controller

Robot Operating System (ROS) is an open source framework for robotics software development. ROS adopts a distributed computing architecture and realizes communication between different modules through a message passing mechanism. In this project, we use Python-based ROS for implementation.

2.5.1 Shape Retriever

First, the pre-input clay shape need to be processed into a detailed point graph. Because the clay is rotationally symmetric, the modeling is directly processed into a point graph containing a curve, such as a .csv file. Then it can be easily converted into the target path that the robotic arm needs to follow in ROS using Python.

2.5.2 Motion Planner

By maintaining the path point graph over time, it is very easy to get the current movement direction of the robot arm in the ideal state. Then ROS sends cmd_vel commands, including x, y, z speed and current direction, to the PCB, which processes these commands and converts them into pulse signals to control the movement of the stepper motor.

2.5.3 Gyroscope Feedback and PID Controller

In order to achieve more precise position control, gyroscopes are used as feedback to implement PID control. When the initial position is determined, since the length of the segmented robot arm is fixed and rotation is used to control the terminal, the actual position of the current terminal can be accurately calculated by using multiple gyroscopes to measure the angular velocity of each segment of the robot arm. After knowing the error between the current terminal and the ideal situation, you can use PID to calculate the actual speed required. The PID in simple-pid [9] can easily achieve this function.

2.6 Risk Analysis

The design details of the manipulator is a key factor to the project success. Due to the requirements for both robustness and precision, we must determine various hardware parameters carefully. For example, the PF60-L1 planetary reducer [10] can withstand an radial force of 320N and axial force of 260N. In the real scenarios, each link forms a lever where the force exerted by the pottery wall has a larger lever arm, which is approximately the link length, than that of the force on the axis of the motor. Therefore, it is a noteworthy point to carefully design the link structure to meet the requirement. Also, the lengths and the type of aluminum alloy links should be further tested. A too thick inner terminal link L_3 will cause overweight and decrease the flexibility and maximum range of motion due to the increased possibility of collision, while a too thin one will be easy to vibrate and break.

Another main risk is the clay. Due to the variety of clay used in pottery, we will only experiment on the stoneware clay and white clay, where the former one is stronger but easier to crack. In particular, the strength of clay will have a huge impact on plasticity. If the strength is too large, the clay will be more likely to crack during the plasticity process. It is very difficult for the robotic arms to repair these tiny cracks. If the strength is too small, the clay body will not be supported, and the currently designed robotic arms cannot provide enough support like human hands. Therefore, choosing the right clay is very important for this project.

3 Safety and Ethics

3.1 Safety

3.1.1 Electrical Safety

Before use, check whether the power supply and wires are intact. Use voltage and power supply that meet laboratory standards and comply with electrical equipment operating specifications. After the experiment, turn off the power supply in time.

3.1.2 Mechanical Safety

When designing a mechanical structure, we should fully consider the limitations and dangers of the mechanical structure and avoid any design defects. Before using the robot arm, check whether all parts are firmly connected and whether there are obstacles within the range of motion of the robot arm. When testing the robot arm, everyone should wear necessary protective equipment, such as goggles and gloves. At the same time, everyone should stay away from the robot arm in operation unless necessary.

3.2 Ethics

We will strictly obey IEEE code of ethics [11] and ACM code of ethics [12]. We understand that these rules promote social justice and help us advance in the academic field.

3.2.1 Safety first

During any experiment and test, we promise that we will take safety as the most important principle. Any behavior that may put members or other people in danger will be completely ruled out.

3.2.2 Protect the environment and reduce waste

We promise not to use materials that are extremely harmful to the environment during the experiment. During the experiment, we will try to reuse the clay used for the experiment as much as possible and reduce the waste of electricity and water.

3.2.3 Honest

We will honestly admit our mistakes and sincerely accept the advice of others. At the same time, any cheating are not allowed. If we receive any guidance from previous works, we will indicate the source in the quotation.

3.2.4 Professional

During the work process, we will strive to achieve high quality of project design. During the project process, we should conduct a comprehensive and thorough assessment of the skills required for the project and only work within our capabilities. At the same time, we should strive to improve our professional skills and maintain high standards of professional ability.

3.2.5 Teamwork

During the project, we promise to respect everyone fairly and not discriminate against others based on the task. We will not participate in any form of harassment or insults, and everyone's ideas will be respected. In the process of group cooperation, while every members should do the work they are good at, each member should be given the space to exert their abilities.

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