ROBOTIC CARVING CRAFT

Research on the application of robotic carving technology in the inheritance of traditional carving craft

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Abstract. In order to realize the inheritance of handicraft skills via digital fabrication technique, so as to preserve the traditional construction culture, this paper discusses a method of control industrial robot (six-axis KUKA kr-60 robotic arm) simulate carving craftsmen working process and explores the relationship between carving posture and different clay states. This paper starts with discussion with cultural heritage in the background of digital tools application. Next, a method to determine the pose of robotic arm by giving the angle value of the six axis is applied in the subsequent carving experimental research, which can make the robotic arm have a smoother and reasonable motion performance by disable the redundant axis movement of the robotic arm when adjusting those poses. Then, a series of carving experiments has been carried out to explore the connection between robotic movement and carved detail, together with a carving path arrangement method that allow for specific carved lines caused by given axis value. This research shows the possibility to create complex form through defining robot movement, which could fundamentally make robot manufacturing a new formal meaning.

Keywords. Clay Carving; Robotic Arm Control; Crafts Inheritance; Form Algorithm; SDG 8.

1. Introduction

1.1. BACKGROUND
1.1.1. Cultural heritage with digital technique

In recent years, digital technology application has gradually become a popular topic in the field of architecture design (Bechthold, 2010). In such a direction of academic development, the performance potential of traditional materials and crafts under the support of digital technology has gradually become the focus of attention. In the context of world integration, maintaining traditional handicraft skills is conducive to carry forward the national cultural self-confidence, and show national characteristics under the impact of various cultures in the world. Chinese traditional sculptures arts is the one of the most ancient crafts (Wei, 2006), which usually present on the wooden beams and enclosure structures of traditional buildings. The inheritance of traditional intangible heritage needs to be realized from generation to generation, this is why handicrafts are easily lost during this process.

Besides, based on the new proposal of "Revitalization plan of Chinese traditional crafts in digital age" posted by central official cultural organization, this study attempts to establish a "digital craft" workflow, in order to develop a suitable digital technique in the preservation of intangible cultural heritage. The method to solve this problem should start with analysis and digitization of motion characteristics of the craftsman's manufacturing process, which is exactly what the industrial robot be created for by simulating human real arm.

1.1.2. Adaptive technology in robotic crafts

Compared with the method of digital reconstruction for handicraft products under common processes through 3D scanning technology and converting them into virtual digital geometric data for storage (Cheng, 2009), this study is committed to developing a design and production workflow for carving process via industrial robot.

In the manufacturing process of dealing with nonlinear shape or complex surface 3D texture, additive manufacturing and CNC (such as milling and laser cutting which shapes by reducing materials) have been proved to be two suitable methods for complicated fabrication among various scales with robotic arm. Since 3D printing, or additive manufacturing, was pioneered in the 1980s, it has been widely expected to revolutionise the manufacturing method of complex components covering multiple scales, which is also specially applied in digital construction field with robotic arm using in recent years such as concrete component 3D-printing (Aghaei, 2020) and plastic shell formwork 3D-printing (Zhang, 2021). Besides, in terms of reduced material manufacturing process such as robotic milling (Brell-Cokcan, 2010) and saw cutting(Chai, 2021), industrial robotic arm, as an equipment that can be programmed and controlled automatically, has played its spatial advantages of high precision and great flexibility in many construction processes.

However, no matter which of the above manufacturing methods, the behavior trajectory data of the robotic arm is still given by reverse solving the given formal simulation results. Such as the robot milling research leaded by Sigrid Brell-Cokcan (Brell-Cokcan, 2010). In this project, the geometric surface is designed from the beginning and applied as the milling target for resolving robot control code. Compared with the above methods, this research attempts to induce the internal correlation between form and craft from the rules of mechanical movement itself. Besides, the
creature manufactured by robotic additive and milling technique surfaces shows a trace of industry-made, which runs counter to the texture beauty of hand-made artwork (see Figure 1).

1.2. RESEARCH AIM

Based on the above two research backgrounds, the significance of this research is supposed to explore a method deducing the results from the manufacturing process, and then link the form results with robot trajectory control code. Exploration is mainly carried out in three aspects, (shows in Figure 2)

- To analyze the relationship between formal results and movement mode from the perspective of robotic arm kinematics, in order to make robot simulate the action of real human hand.
- To create the robot movement coding mode of the manipulator that defines the axis value, and discuss the possible carved formal results of different robot motion postures.
- To make carving test under the influence of different trajectories that is carried out by disable some axis, from which summarize and accumulate the relationship between carving action and the carved result, in order to establish the direct link between axis value and form.
2. Methods

In the experiment-based study process, three key parts are carried out in turn, namely the establishment with mathematical model of 6-axis controlled robotic arm movement, formal relationship between material properties of clay and the influence of different movement modes of robotic arm with multi rigid carving tools on form in the process of engraving.

2.1. AXIS MOVEMENT COMMAND FOR ROBOTIC ARM

Within the scope of this study, kinematics and path planning of KUKA six axis robotic arm with off-line programming that will be applied in our design system. The movement commands of robotic arm are analyzed thoroughly and abstracted as a simple geometric mathematical model for the subsequent definition of 6-axis more intuitively.

As a general rules, industrial robot off-line programming is similar to the traditional way of using CNC (computer numerical control) machines which is also known as G codes (Mühe et al. 2010). Different from that, the KUKA Robot Language (KRL) is a proprietary programming language with similarities to Pascal and is used to control KUKA robots (Braumann, 2011). Unlike G-Code, it does not contain just tool and machine movement commands, but can also declare variables and work with conditional clauses. There are some ways of defining movement commands to a robotic arm, the most common ones are the following two (Takase et al. 1981):

- The joint coordinate programming includes an absolute axis rotation command that instructs the robot to move each of its six axes to a defined rotation value in the format like \([A1 0, A2 10, A3 90, A4 30, A5 80, A6 30]\).
- Cartesian coordinate programming defines the position and orientation of the end effector in the previously defined Cartesian coordinate system. The command format code like \([X 10, Y 30, Z 60, A 45, B 75, C 15]\).

The different between these two command method is that the Cartesian way can be a point-to-point (PTP) commands for the end-effector to move from one position to the next with the least amount of axis rotation, or a linear (LIN) commands for the end-effector to move from one position to the next along a straight line. Meanwhile, the
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Axis way only can control end-effector to move between positions in the most efficient way.

Obviously, the joint control method is more in line with the command giving method of simulating the movement of human arm. When the end-effector already reach to one certain position, no matter changing which value of any one of the 6 axis, and the angles of the other axis will be solved and transformed accordingly. The posture calculation can be simplified to the geometric relationship shows in the Figure 3. In this geometrical model, the 6 axes are expressed as $A1(\pm 185^\circ)$, $A2(-35^\circ/-135^\circ)$, $A3(+158^\circ/-120^\circ)$, $A4(\pm 350^\circ)$, $A5(\pm 119^\circ)$, $A6(\pm 350^\circ)$ and each axis end are expressed as $p_0$, $p_{1-2}$, $p_{3-4}$, $p_5$, $p_6$ and $T$ is tool center point (TCP).

When $A4$ is locked in $0^\circ$ value, all axis end point will be in one space plane called “robot plane”; When $A4$ is set free, $p_{3-4}$, $p_5$ and $p_6$ will constitute new space plane which always forms a certain angle with robot plan ($p_0$, $p_{1-2}$, $p_{3-4}$, $p_5$). In the second condition, $p_5$ is the key factor to make the axis angle solution to be set up, which is defined by vector constructed by $p_6$ and $p_5$. By this meaning, as long as the coordinates of $P_6$ (When the coordinate value of $T$ is determined, the coordinate of $P_6$ can be deduced from the geometric relationship of the tool) point in space are uniquely determined, the angle values of the axes $A1$ to $A5$ can be calculated according to the fixed length of each axis. In addition, the $A6$ value defines the interactive relationship between tools posture and working normal plane.

Figure 3. Robot axis value calculation

2.2. CARVING PROPERTIES WITH CLAY MATERIAL AND VARIOUS TOOLS

Clay as a common environmental-friendly material is selected as the initial traditional matter of carving experiment, which has good performed density and plasticity, could be the safest and cheapest way for study start. Meanwhile, clay will show some hardness under different drying stages and the moisture content of the material will also affect the edge details of the lines. On the corresponding carving tool selection, it is will know that different carving tools with varied sections shape will leave different carving lines on the clay material. Several carving tools are used for manual engraving research showed in Figure 4, through that the most suitable tools could be selected to do further robotic carve.

One complete carving action includes lowering the knife from one point, moving and lifting after material reduction. According to the length of the moving position, the
carving state will present solid surface textures with different detail characteristics (shows in Figure 4). Conclusion can be drew from one single carving movement that the shape of carved grain is determined by depth and angle of tools, which are defined by arm, wrist and fingers postures. Furthermore, the movement direction of the tool is always at an acute angle with the normal plane of the carved object.

![Figure 4. long line carve (left) and short line carve (right)](image)

In order to explore the deep relationship between motion paths and form features, four cross-section shape tools were used for manual experiments which simulates human craftsman. As can see from Figure 5, through the change of certain depth, angle and motion direction, the carved texture will produce small form diversity, and even very rich and delicate details will appear under the change of particular tools combined movement (Figure 6). Similar with hand carving, robotic arm that controlled by axis value would be able to perform like hand movement and cause these complex carved texture features. The action decomposition characteristics of craftsmen in the process of carving complex texture focus on two motion method, the overall displacement of forearm (used to control the general direction of carving lines) and the depth caused by the turnover action of wrist (which determines the local depth change of carving lines).

![Figure 5. diversity carving movement and their carved shape texture results](image)
2.3. DESIGN STRATEGIES OF CARVING MOVEMENT COMMAND

Taking the research process of robotic carving on a plane as an example (this method could be extended to any type of surfaces with arbitrary spatial curvature), the single value change and regular combination of the six axis of robotic arm would have an impact on carved shape result, such as the depth of carving and the complexity of carved grain. A complete plane-based carving process is carried out in the following order.

- Firstly, the overall trajectory of the carving tools moving on the tangent plane of target clay surface is determined, which is controlled by the A1, A2, A3, A5 and A6 axis.

- Then, the depth of carving lines is determined, which is mainly controlled by the A2 and A3 axis. Based on position points come from the first, the angle $\theta$ by axis 5 and working plane x direction is a constant value while the angle $\delta$ equal to 0. The P5 determine the tool vector n which is also a constant value defined by $\theta$ and $\delta$.

- Finally, the value of A4 and A6 that causes the section shape of carving grain could be defined if the complex carving detail on clay surface is necessary in the design expectation. In this process vector n will valued by a function consists of two variables $\theta$ and $\delta$ (also can be deconstructed into three value x, y, z).

3. Robotic clay carving experiments

Applying with the axis movement command, a series robotic carving experiments carried out to testify method discussed above. As an important factor controlling the
carved form, the axis 4 will be discussed in two states of disable and free.

3.1. DISABLE 4 AXIS

In the first carving experiment, the axis 4 of the robotic arm is disabled, and the given motion track is the depth fluctuation action perpendicular to the working plane. According to the section width of carving tools and the arrangement density of reference curves, the carving result presents the texture detail state of different resolutions (Figure 8). By giving axis 3 a relatively violent periodic changes showed in simulation graph, the tool end will produce deep and shallow fluctuations on clay surface.

3.2. SET ALL AXIS FREE

Next step, all axis free method is applied to carve the same humidity clay board. In the design of motion, the rotation of axis 6 can rotate the tool section, and then make the carving results produce rich shape changes (see figure 9). By constructing the vectors value discussed in the previous chapter, the tool end can move freely on the work plane to interact with clay surface in a more flexible way.
After realizing the experiment of mechanical engraving based on plane, this method can also be applied to spatial surfaces with arbitrary curvature to realize multi-dimensional complex carving which will explore in our further research.

4. Conclusion

The study of handicrafts in traditional culture is a reference for designers to excavate history and create new forms. In this process, preserving Chinese ancient skills especially traditional fabrication crafts is the main motivation for this research to discuss with digital manufacture tools and parametric design system.

From these research background, proposing the process-oriented design method and realizing the way of manipulating robot imitating real human craftsmen are two main goals that payed more attention to in the study. The experiments show the
possibility to create complex carving details on the material surface that can be easily carved such as clay and soft wood through defining robot movement way, which could fundamentally make robot manufacturing a new formal meaning. In this way, when facing the mechanical manufacturing tools, the designer's attention will change from backward resolving the posture of the robotic arm according to the results of the 3D model, to manipulation the movement of machine itself for “process led design” deduction. Making robot thinking and moving like a real human, which shows a great possibility and charming challenge in further research.

References


Zhang, Xiao, Yuan, Chao, Yang, Liu, Yu, Peiran, Ma, Yiwen, Qiu, Song, Guo, Zhe and Yuan, Philip F. 2021. Design and Fabrication of Formwork for Shell Structures Based on 3D-printing Technology. Stojakovic, V and Tepavecic, B (eds.), Towards a new, configurable architecture - Proceedings of the 39th eCAADe Conference (pp. 487-496), Volume 1, University of Novi Sad, Novi Sad, Serbia, 8-10 September 2021.