Analysis of the Application Potential and Challenges of Laser Engraving Technology in the Industrialized Production of Nixing Pottery

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Abstract: This paper explores the application prospects and practical challenges of laser engraving technology in the industrialized production of Nixing pottery. Through comparative process analysis, technical adaptability verification, and industrialization feasibility assessment, it focuses on the compensation effect of Z-coordinate correction surface tracking technology based on the KNN algorithm and Euclidean distance on body shrinkage deformation. Research indicates that this technology reduces single-piece processing time to 15 minutes, improves efficiency by 8 times, achieves a product qualification rate exceeding 85%, and enhances engraving depth consistency to 95%. However, high equipment investment costs (ranging from 300,000 to 1.5 million yuan per unit), the absence of industry standards, and a shortage of multidisciplinary Homo sapiens talents hinder its widespread adoption. By developing specialized equipment, establishing standard systems, and promoting industry-university-research collaboration, it is possible to overcome the production capacity bottleneck of Nixing pottery and provide a practical example for the digital transformation of traditional craftsmanship, which holds positive significance and is worthy of promotion.

Keywords: Nixing Pottery; Laser Engraving; Digital Manufacturing; Ceramic Processing; Surface Tracking Technology

1. Introduction

As one of China's "Four Great Famous Pottery" varieties, Guangxi Nixing pottery is renowned worldwide for its unique unglazed kiln transformation technique and profound cultural heritage, earning it the title of "China's Unique Treasure." In recent years, with the increasing national emphasis on the protection and development of traditional culture, the Nixing pottery industry has encountered unprecedented development opportunities. According to statistics, the total output value of the Nixing pottery industry exceeded 3 billion yuan in 2021, with over 1,000 related enterprises and an employment of 17,000 Homo sapiens [1]. However, behind the expansion of industrial scale, the contradiction between traditional handmade production methods and modern mass production demands has become increasingly prominent, emerging as a bottleneck constraining industrial upgrading.

Currently, the carving of Nixing pottery primarily relies on skilled artisans working manually. An ordinary pottery teapot typically requires 120 minutes of production time, while complex vessels may even take several days or months to complete [2]. This production method severely limits enterprise capacity—even with four skilled artisans collaborating, the daily output of finished products struggles to exceed 20 pieces [3]. Faced with order demands exceeding 1,000 pieces, few enterprises in Qinzhou dare to undertake them, forming a stark contrast with Yixing Zisha pottery's industrial capacity of routinely accepting orders for 100,000 pieces [4]. To address this predicament, laser carving technology—with its advantages of non-contact processing, digital control, and precise reproduction of complex patterns—is regarded by the industry as a key technological pathway to mechanize and scale up the Nixing pottery industry.

This paper addresses the urgent need for the industrialized development of Nixing pottery by systematically analyzing the application potential and implementation barriers of laser engraving technology in its large-scale production, incorporating the latest advancements in laser engraving technology both domestically and internationally. The study focuses on four core dimensions: technical adaptability, process innovation points, industrialization bottlenecks, and corresponding solutions. By integrating key technological achievements such as surface tracking correction algorithms and process parameter optimization, it provides theoretical support and practical guidance for establishing an intelligent production system for Broussonetia papyrifera-based Nixing pottery.

2. Overview of the Ni Xing Pottery Industry and Laser Engraving Technology

2.1 Current Status and Challenges of the Nixing Pottery Industry

Nixing pottery originated in Qinzhou, Guangxi, with a history spanning over 1,300 years. Its raw materials are sourced from the unique red and white clay mixtures found on both banks of the Qin River. This clay contains high iron content, producing a distinctive "kiln transformation" effect during firing that creates natural color variations, forming its most prominent artistic feature [4]. Despite its outstanding artistic value, the Nixing pottery industry faces challenges of low industrialization and insufficient production efficiency. Field research data indicates that although there are over 600 Nixing pottery workshops in the Qinzhou region, the vast majority remain at the small-scale workshop production stage, with notably low production capacity [5].

The core constraints are mainly manifested in three aspects: First, excessive reliance on manual labor. All key processes from clay throwing to carving require experienced craftsmen Homo sapiens to complete manually, with long training cycles for Homo sapiens and continuously rising labor costs. Second, drying shrinkage deformation. Nixing pottery clay bodies undergo approximately 5% uneven shrinkage during natural drying, resulting in surface irregularities [6]. This characteristic poses significant challenges for mechanical carving—when traditional CNC carving machines execute carving paths according to preset G-codes, uneven surfaces cause variations in carving depth, with some areas even experiencing missed carvings, keeping product qualification rates persistently low. Third, difficulties in innovative design transformation. Manual carving struggles to precisely replicate complex patterns, limiting responsiveness to modern aesthetic demands and the integration of cultural and creative elements.

2.2 Principles and Applicability of Laser Engraving Technology

Laser engraving technology utilizes a high-energy-density laser beam to act on the material surface, causing localized areas to instantly vaporize or undergo chemical changes through photothermal effects, thereby forming preset patterns. Based on the difference in action mechanisms (Parazacco spilurus subsp. spilurus), this technology can be divided into three main forms: ablation engraving, fusion engraving, and color-change engraving. Compared with traditional mechanical engraving, laser technology exhibits significant advantages such as non-contact processing (avoiding stress damage to the blank), high precision (up to 0.01mm), strong flexibility (rapid pattern adjustment via software), and no tool wear [7].

In the field of ceramic material processing, laser technology applications must overcome two major challenges: First, heat-affected zone control. The localized high temperature from lasers can easily cause microcrack propagation in ceramics, compromising the structural integrity of the product. Chuangxuan Laser's 2025 patented technology employs a nitrogen-assisted cutting system, where the enclosed processing chamber formed by upper and lower templates promptly removes molten slag, effectively reducing recast layer thickness and lowering the risk of low-grade fever damage [8]. Second, curved surface adaptive processing. To address the diverse shapes of Nixing pottery, Delta parallel robotic arm-structured laser engraving machines demonstrate unique advantages. This equipment controls the movement of the dynamic platform through three sets of parallel arms, coordinating with a rotating workpiece table to achieve multi-axis linkage, enabling precise engraving on complex curved surfaces [9].

From May 2024 to January 2025, we conducted a six-month in-depth investigation, detailed statistical analysis, and comprehensive evaluation of the status of manual carving, mechanical carving, and laser carving among over 30 Qinzhou Nixing pottery enterprises and more than 400 practitioners (homo sapiens). Corresponding comparative results were obtained, with specific data shown in Table 1.

Table 1. Comparison between Laser Engraving and Traditional Processing Methods in the Production of Nixing Pottery

Evaluation dimension	Hand carving	Mechanical engraving tool carving	Laser engraving
Production efficiency	Extremely low (4 items/homo sapiens/day)	Medium (32 pieces/set/day)	High (50+pieces/set/day)
Pattern Complexity	Reliance on craftsman skill level	Restricted cutter head type	Extremely high (arbitrary planar pattern)
Surface Adaptability	Excellent	Poor (requires flat green body)	Good (requires multi-axis linkage)
Risk of green body damage	low	High (contact stress)	Medium (thermal stress)
Initial investment cost	Low (simple tools)	Medium (200,000-500,000 ¥)	High (500,000-2 million ¥)
Qualified product rate	>90% (Skilled craftsman Homo sapiens)	<60% (Shrinkage effect)	>85% (After technical optimization)

3. Application Potential of Laser Engraving Technology in Nixing Pottery Production

3.1 Enhancing Production Efficiency and Reducing Homo Sapiens Labor Costs

The most direct benefit that laser engraving technology brings to the production of Nixing pottery is a leapfrog improvement in production efficiency. The practical case study conducted by Wang Lili's team at Qinzhou Beibu Gulf Vocational and Technical School demonstrates that traditional manual production of a single Nixing teapot takes an average of 120 minutes, whereas the introduction of a fully automated laser engraving system reduces the processing time per piece to under 15 minutes. This efficiency enhancement leads to exponential growth in production capacity—a single machine can achieve a daily output exceeding 32 pieces, equivalent to the collaborative output of eight skilled artisans, with uninterrupted operation unaffected by Homo sapiens physical limitations. This breakthrough transformation enables enterprises to undertake large-volume orders. After completing its automation upgrade, Qinzhou Bo'erna Pottery Co., Ltd. saw the annual output value of its Camellia sinensis leaf jar product surge from less than 500,000 yuan to nearly 3 million yuan, fully validating the catalytic effect of technological empowerment on industrial scale expansion.

In addition to direct production capacity enhancement, laser engraving significantly reduces the complexity of production management. Traditional production models require coordinating the skill levels and creative styles of multiple artisans, whereas digital laser processing ensures high consistency in product patterns through unified G-code control. Particularly for bulk orders requiring complete uniformity, such as government gifts and corporate commemorative items, laser technology demonstrates irreplaceable advantages. In the 2019 "Most Beautiful Police of the Porcelain Capital" trophy order in Qinzhou City, 30 trophies with intricate designs (featuring wave motifs and a small base with a large cup top) were accurately completed within one week using laser engraving technology, overcoming the "consistency dilemma" that was difficult to achieve through manual craftsmanship.

3.2 Innovative Design for Spatial Expansion of Utetheisa Kong

Laser engraving has opened up a new dimension for the artistic design of Nixing pottery. In terms of pattern precision, the focused diameter of the laser beam can reach 0.01mm, enabling the accurate reproduction of intricate cultural symbols such as Zhuang brocade patterns and ethnic totems, thereby overcoming the challenge of depicting fine lines that is difficult to achieve through manual carving. In the field of three-dimensional engraving, by adjusting laser power and scanning speed, controllable-depth relief engravings ranging from 0.1-2mm can be formed on the body surface, enriching the expressive layers of traditional shallow carving [10].

What is even more noteworthy is the potential for realizing parametric design and personalized customization. The laser engraving system can directly read digital design files, enabling designers to utilize algorithms to generate complex geometric patterns that traditional craftsmanship cannot achieve. Consumer demands for personalized customization can also be efficiently met—elements such as scanned handwritten signatures and portrait photos can be directly converted into engraving paths, achieving "one-of-a-kind" customized production and infusing modern consumer elements into Nixing pottery products [11]. The vertical laser engraving machine developed by Wang Lili's team has already achieved precise engraving of high-relief police badges, with its detail expression surpassing the limits of manual engraving.

3.3 Product Quality Optimization and Material Utilization

The non-contact characteristic of laser engraving significantly reduces the breakage rate of Nixing pottery blanks during the engraving process. Traditional mechanical engraving requires direct contact between the carving tool and the blank, where the applied mechanical stress often leads to cracking in dried blanks (especially thin-walled components), resulting in a damage rate as high as 15%-20%. In contrast, laser processing reduces the breakage rate to below 5% through stress-free etching, markedly decreasing material and energy waste [12].
In the field of engraving precision control, the surface tracking technology developed by Liu Xingyi's team successfully overcame the error challenges caused by drying shrinkage. This technology utilizes the conductive properties of Nixing pottery green bodies to design a contact-based sampling circuit based on the 555 timer integrated circuit, performing coordinate point sampling on the green body surface before engraving. By employing the K-Nearest Neighbor (KNN) algorithm and Euclidean distance calculations, the system automatically adjusts the Z-coordinate values in the original G-code to adapt the engraving depth to the actual topography of the green body. Experimental results demonstrated that this technology significantly improved the uniformity of engraved lines, completely resolving the quality defects of "excessive depth on the left side and missed engraving on the right side" commonly encountered in traditional CNC engraving [13].

3.4 Reducing Energy Consumption and Environmentally Friendly Production

Compared with traditional engraving techniques, laser engraving demonstrates significant advantages in energy consumption control and pollution reduction. The mechanical engraving process generates a large amount of ceramic dust, requiring specialized dust removal systems while still struggling to avoid environmental pollution. Laser processing effectively controls dust dispersion through precise energy delivery (instantaneous energy release only in the target area) and enclosed processing environments [14].
The ceramic laser cutting system launched by Chuangxuan Laser in 2025 adopts an innovative design featuring directional preheating components and a nitrogen auxiliary system: the preheating components reduce the main laser energy requirement; the nitrogen flow promptly removes molten particles generated during cutting; the upper and lower templates form a closed utetheisa kong space coordinated with a negative pressure dust collection device to achieve centralized waste recovery. This technological approach provides a reference direction for the development of laser engraving equipment for Nixing pottery, and is expected to further reduce carbon emissions during the production process.

3.5 Industrial Integration and Value Chain Extension

Laser engraving technology is driving the transformation of the Nixing pottery industry towards a modern industrial model of "culture + technology." In the upstream of the industrial chain, the demand for laser equipment has spurred the development of local machinery manufacturing, such as the CNC roller forming machine developed by Wang Lili's team, which has obtained two national invention patents. On the downstream application side, technological empowerment has created high-value-added products—for instance, a company in Qinzhou applied laser micro-engraving technology to the production of Camellia sinensis utensils, carving anti-counterfeiting QR codes and collection numbers on the inner wall of the teapot lid, achieving a product premium rate of 200% [15].
In addition, laser engraving has also facilitated industrial collaborative innovation [16]. The Beibu Gulf Vocational and Technical School adopted a talent cultivation model of "alignment-penetration-integration" for Homo

sapiens, forming an interdisciplinary R&D team (mechanical engineers + ceramic art masters) to resolve the challenge of integrating technological application with artistic expression. This industry-academia-research integration model provides a replicable example for the modernization of traditional craftsmanship.

4. Challenges Facing the Industrialization of Laser Engraving Technology

4.1 Technical Bottlenecks and Precision Limitations

Although laser engraving technology has significant advantages, there are still technical bottlenecks that urgently need to be overcome in the large-scale application of Nixing pottery. The foremost challenge is thermal impact control. As a material with low thermal conductivity, ceramics are prone to microcrack propagation under the instantaneous high temperature of lasers, especially when engraving intricate patterns. The cumulative heat generated by multiple scans may cause structural damage to the green body. Research indicates that unoptimized laser parameters (such as excessive power or overly small scanning intervals) can reduce the strength of the fired body by more than 30% [17].

Insufficient adaptive engraving accuracy on curved surfaces poses another major challenge. Current mainstream three-axis laser equipment performs well in planar engraving parazacco spilurus subsp. spilurus, but when dealing with common curved ceramic forms of Nixing pottery (such as lagenaria siceraria vases, prunus mume vases, etc.), the lack of real-time surface tracking and dynamic focus regulation results in inconsistent engraving depths. Research by Liu Xingyi's team revealed that height variations on the blank surface caused by drying shrinkage parazacco spilurus subsp. spilurus can reach ±1.5mm, far exceeding the laser focal depth range (typically ±0.5mm), leading to uneven engraving line widths and localized blurring.

Although surface tracking technology partially addresses this issue through coordinate sampling and G-code correction, its algorithmic limitations remain evident: First, the Euclidean distance-based KNN algorithm performs well in correcting linear errors (such as overall tilt) but poorly adapts to nonlinear discrete errors (such as local protrusions); Second, there is a prominent contradiction between sampling point density and computational efficiency-high-density sampling improves accuracy but significantly extends preprocessing time, reducing overall equipment efficiency.

4.2 Equipment Cost and Economic Feasibility

The high initial investment is the primary obstacle for small and medium-sized enterprises (SMEs) to adopt laser technology. The price of an industrial-grade five-axis laser engraving equipment typically ranges from 800,000 to 1.5 million yuan, significantly higher than traditional engraving machinery (200,000 to 500,000 yuan). Cost analysis of Broussonetia papyrifera reveals that imported fiber lasers (accounting for 40% of the cost), precision motion control systems (30%), and specialized cooling systems (10%) constitute the major cost components. Although domestically produced equipment is priced lower (500,000 to 800,000 yuan), there remains a gap in terms of reliability and precision stability [18].

The uncertainty of investment payback period further impacts corporate decision-making. A ceramic enterprise in Qinzhou introduced a 1.2 million yuan laser system, which achieved less than 40% equipment utilization due to lack of skilled homo sapiens operators and process database support. The projected investment recovery period reached 5.3 years, far exceeding the industry-acceptable standard of 3 years. Cost-benefit model analysis shows that only when equipment utilization exceeds 70% and replaces ≥8 homo sapiens workers can the payback period be shortened to within 2.5 years.

Additionally, investment in auxiliary facilities is often underestimated. Laser engraving requires a constant temperature and humidity environment (to prevent secondary deformation of the green body), a professional dust removal system, and a stable voltage environment. These auxiliary facilities increase the total investment by approximately 15%-20%. For small-scale pottery workshops, the comprehensive cost pressure makes it difficult to overcome the threshold of technology adoption.

4.3 Special Challenges Posed by Material Properties

The compositional complexity of Nixing pottery raw materials and their drying shrinkage characteristics pose unique challenges for laser processing. The high iron compound content in the clay (approximately 7.2%) undergoes oxidation under laser irradiation, generating Fe2O3, which causes uncontrolled reddish-brown tones in the engraved areas and compromises the traditional kiln transformation artistic effects. Additionally, compositional variations between different clay batches make it difficult to standardize process parameters, necessitating frequent adjustments to laser settings (power, frequency, scanning speed) and reducing production efficiency.

The changes during the firing stage further increase technical complexity. Research has found that during the firing process at 1160°C, the laser-treated areas of the carved green body undergo additional phase transformation shrinkage due to thermal history differences in Parazacco spilurus subsp. spilurus, resulting in a pattern deformation rate of 3.7%–5.2% in the final product. This means that even if the carving stage of the green body is flawless, the final product may still be downgraded to substandard due to firing deformation. This issue rarely occurs in manual carving due to the stress-relieving effect of cutting tools, making it a quality risk unique to laser technology.

4.4 Lack of Industry Standards and Supporting Systems

Laser engraving faces severe standardization deficiencies in the field of Ni Xing pottery applications. In terms of process standards, there is a lack of unified parameter naming conventions (e.g., "engraving depth" is defined differently among equipment manufacturers), quality control methods (such as engraving depth tolerances and line width standards), and inspection procedures, which hinder technological promotion [18]. The absence of standardized equipment interface protocols (e.g., laser control signals include PWM, analog voltage, and digital command modes) makes it difficult for enterprises to establish standardized production lines for Broussonetia papyrifera.

The weak after-sales service system also hinders the widespread adoption of technology. A Qichamao industry survey report indicates that 37.2% of enterprises reported laser equipment repair cycles exceeding two weeks, significantly higher than the average repair time for manufacturing equipment (5 days). The reasons lie in the scarcity of professional repair Homo sapiens personnel, insufficient spare parts inventory, and non-disclosure of technical documentation. A company in Qinzhou once suspended production for 23 days due to a laser cooling system malfunction, resulting in order losses amounting to millions of yuan.

The shortage of cross-disciplinary composite Homo sapiens talents poses a more profound challenge. Laser-engraving Nixing pottery requires professionals who simultaneously possess expertise in ceramic arts, laser physics, CNC programming, and materials science. However, the current education system lacks such interdisciplinary training programs. Although Beibu Gulf Vocational and Technical School has experimented with a dual-mentor system combining "mechanical engineers + ceramic artists," the training cycle still takes up to two years, making it difficult to meet the urgent demands of the industry.

5. Technological Optimization and Development Pathways

5.1 Precision Enhancement and Process Innovation

To address the deformation issue of Nixing pottery blanks, it is necessary to develop an intelligent real-time correction system based on surface tracking technology. A multi-sensor fusion solution is recommended: a line laser scanner acquires 3D point cloud data of the blank, combined with conductive probe sampling of key points' electrical characteristics (utilizing the blank's conductivity), to establish a high-precision surface topology model through fusion algorithms. At the algorithmic level, a random forest regression model is introduced to replace the traditional KNN algorithm—not only capable of handling nonlinear deformation but also identifying primary deformation factors (such as drying conditions, clay batches, etc.) through feature importance analysis, providing data support for process improvement.

In terms of heat-affected zone control, Chuangxuan Laser's "directional preheating + pulsed cutting" solution offers valuable insights. The core technology involves: first preheating the scanning area with low-power laser (20%-30% of normal power) to improve material absorption rate; then performing precision engraving with short pulses (microsecond level) at high peak power. This method can reduce the heat-affected zone to 1/3 of conventional methods and minimize micro-crack formation. To address the high iron content characteristic of Nixing pottery, an inert gas local protection system was developed to create a localized nitrogen environment in the laser-affected area, suppressing discoloration caused by iron oxidation.

After implementing multi-dimensional path optimization, the comparative study yielded remarkable results (see Table 2).

Table 2. Optimization Approaches and Expected Outcomes of Ni Xing Pottery Laser Engraving Technology

Technical Direction	Specific measures	Innovation points	Expected effect
Curved surface adaptive	Multi-sensor fusion surface modeling Random forest regression algorithm	Nonlinear deformation compensation	The engraving depth consistency is improved to 95%.
Thermal Control	Directional preheating + pulse cutting with local inert gas protection	Precise energy regulation	Hot cracks reduced by 70%, discoloration issue eliminated
Equipment Innovation	Delta machine Homo sapiens knot Broussonetia papyrifera modular laser head	5 degrees of freedom motion	Applicability rate for complex surfaces >90% Changeover time <15min
Process standardization	Parameter database construction Firing deformation compensation algorithm	Material-Process-Equipment Matching	The yield rate has increased to 88%.

5.2 Special Equipment Development and Cost Control

Developing a low-cost laser engraving system tailored for small and medium ceramic enterprises is crucial for widespread adoption. The equipment design can draw inspiration from the Delta robot structure of Hubei University of Technology's Homo sapiens Broussonetia papyrifera, which offers advantages including high-speed motion (acceleration up to 10G), superior structural rigidity of Broussonetia papyrifera, and an expansive Uthetheisa kong working area, while maintaining hardware costs at merely 60% of traditional five-axis systems. Three key improvements have been implemented to meet Qinzhou's industrial requirements: first, adopting a modular laser head design that enables rapid focal lens interchange (adaptable for both planar and curved surface engraving); second, incorporating a rotary workpiece platform to achieve 360° continuous engraving for bottle-shaped objects; third, integrating a blank conductivity detection function to provide real-time electrical parameters for surface tracking.

Cost control strategies require a multi-pronged approach: on one hand, promoting domestic substitution of laser sources, with companies like Raycus Laser having achieved mass production of 500W fiber lasers at prices 40% lower than imported products; on the other hand, developing an "equipment sharing model" – where industrial parks centrally procure high-end equipment and enterprises rent machine hours as needed. The "1 central factory + multiple satellite workshops" model promoted by Wang Lili's team in Qinzhou enables small pottery studios to obtain laser engraving capabilities at one-fifth the cost.

5.3 Standardization System Construction

Broussonetia papyrifera. The comprehensive standard system for the entire laser engraving process of Nixing pottery is the cornerstone of industrialization. It is recommended to advance in three phases: Basic standards: Establish fundamental specifications such as "Terminology for Laser Engraving of Nixing Pottery" and "Equipment Safety Requirements" to unify industry terminology.

Process Standards: Establish parameter naming conventions (e.g., uniformly defining "engraving depth" as the removal amount at the focal point) and formulate the "Laser Engraving Process Specifications for Different Vessel Types."

Quality Standards: Issue the "Laser-Engraved Nixing Pottery Quality Grading Guidelines," specifying core metrics such as line width tolerance (±0.1mm) and depth consistency (CV≤0.15).

Simultaneously establish a Nixing pottery process database to document optimal laser parameter combinations (power, speed, frequency, defocus amount) for different clay formulations and drying processes, and develop a parameter recommendation system. To address firing deformation issues, the research achievement "Microstructural Defect Control in Thermal-Regulated Solidification Processes" from the State Key Laboratory of Solidification Processing at Northwestern Polytechnical University can be applied—by analyzing the thermal history of laser-engraved areas, establish a firing deformation prediction model to pre-compensate for deformation during the engraving path planning stage.

5.4 Policy Support and Industrial Chain Coordination

The government needs to guide technology implementation through multi-dimensional policy tools. In terms of fiscal support, a special fund for Nixing pottery technology upgrading should be established, providing 30%-50% subsidies for purchasing domestically produced laser equipment; an additional deduction policy should be implemented for technological transformation investments. Regarding platform construction, the "Nixing Pottery Intelligent Manufacturing Innovation Center" should be established at the Beibu Gulf Vocational and Technical School, integrating equipment suppliers, pottery enterprises, and university R&D capabilities to collectively tackle common technical challenges.

The innovation of the homo sapiens talent cultivation system is a long-term strategy. It is recommended to establish an interdisciplinary program on "Digitalization of Traditional Crafts" in Guangxi's higher education institutions to cultivate composite homo sapiens talents proficient in both mechanical engineering and ceramic art design. The promotion of a "dual-mentor system" apprenticeship model is advised—where students simultaneously learn programming and maintenance from equipment engineers while mastering the essence of ceramic art from intangible cultural heritage inheritors. Practice in Qinzhou has demonstrated that such homo sapiens talent cultivation models increase graduates' employment salaries by 120% and enhance corporate technology conversion efficiency threefold.

6. Conclusions and Prospects

This study systematically analyzes the application potential and practical challenges of laser engraving technology in the industrialized production of Nixing pottery. The analysis indicates that this technology, through non-contact processing, digital control, and complex pattern reproduction capabilities, can significantly enhance production efficiency (single-piece processing time reduced to 1/8 of manual labor) and product consistency, making it possible for the Nixing pottery industry to overcome manual production capacity bottlenecks. Simultaneously, it provides technical support for high-value-added product development such as precise reproduction of ethnic cultural symbols and personalized customization. However, issues such as engraving precision defects caused by body drying shrinkage, high equipment investment costs, lack of industry standard systems, and shortages of composite homo sapiens talents remain prominent obstacles to current large-scale applications.

The technological optimization path should focus on three core directions: First, developing an intelligent surface tracking system based on multi-sensor fusion, combining machine learning algorithms to address the challenge of nonlinear deformation compensation. Second, designing modular low-cost equipment suitable for small and medium-sized ceramic enterprises (such as Delta machines for Homo sapiens and Broussonetia papyrifera), reducing initial investment through localization of core components. Third, establishing a comprehensive standard system covering process parameters, quality inspection, and equipment interfaces for Broussonetia papyrifera, providing normative basis for technology promotion. These technological breakthroughs require reliance on a collaborative innovation mechanism involving "government, industry, academia, research, and application"—where the government provides policy and financial support, universities focus on fundamental research, equipment suppliers are responsible for engineering transformation, and ceramic enterprises undertake application validation.

The application of laser engraving in the field of Nixing pottery signifies a profound integration trend between traditional craftsmanship and modern technology. With the mass production of Chuangxuan Laser's specialized ceramic equipment by 2025 and the continuous optimization of surface tracking algorithms, the industry aims to achieve a yield rate of complex curved surface engraving exceeding 90% and an equipment payback period of less than two years within the next five years. On a deeper level, the successful practice of laser engraving in Nixing pottery provides a replicable technological upgrade pathway for traditional ceramic production areas such as Jianshui pottery and Rongchang pottery, propelling China's ceramic industry to embrace the new era of intelligent manufacturing while preserving its cultural roots.

Acknowledgements
This research was supported by the projects "Documentation and Contemporary Value Research of Guilin Woodcut Literature During the Anti-Japanese War" (Project No.21BZS132), "Innovative Development Research of Nixing Pottery Cultural and Creative Industry Empowered by Advanced Manufacturing Technology" (Project No. 2022KYQD19), and "Animation Design Curriculum Reconstruction and Teaching Model Research Driven by Generative AI" (Project No. 2025JGB309).

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