

Automatic Tea Ceremony Teapot Robotic Arm Design Based on TRIZ Principle

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Abstract. With the accelerated pace of modern society, there is a contradiction between the tedious steps of traditional tea ceremony and the convenient lifestyle. In order to solve this problem, this study applies the TRIZ theory to optimize the design of the fully automatic tea ceremony teapot robot arm. Through the "nine-screen method", the traditional tea-making process was comprehensively analyzed, the key steps were identified, and the cultural significance and technical requirements of each step were discussed in depth. Using the "technical contradiction matrix" and "physical contradiction" analysis, the potential contradictions in the tea-making process were revealed, and the "physical field model" was applied to construct the problem model and explore the possible solutions. The problem model was constructed by applying the "Physical Field Model", and possible solutions were explored. The study proposes a fully automated tea art teapot robotic arm design program that integrates several key technology modules such as heating and temperature control, plane movement, lid operation, and pouring and dispensing of tea. The program ensures the quality of tea soup and the experience of traditional tea ceremonies through the well-designed robotic arm structure and improves the efficiency of tea brewing at the same time. The structural safety of the design scheme is verified by stress analysis of the connecting plate of the robotic arm and the connecting plate of the teapot base. Finally, the feasibility and effectiveness of the proposed scheme are verified through kinematic analysis, prototype testing, and user experience evaluation. This study is of great practical significance for the modernization and transformation of the traditional tea ceremony and also provides a reference for the automation of other traditional crafts. With the continuous progress of technology, we expect more innovative products combining traditional culture and modern technology to appear in the future so that traditional art can be revitalized in modern society.

Keywords: TRIZ, automation, tea ceremony, teapot robot arm, mechanical design.

1. Introduction

Chinese tea culture, as a treasure in the treasury of oriental culture, not only contains deep historical tradition but is also the embodiment of art and philosophy in daily life [1]. The traditional tea ceremony, with its unique sense of ceremony and aesthetic value, elevates tea drinking to the level of spiritual culture [2]. In this process, brewing tea is the core link, every detail is full of elaboration. However, in the fast-paced life of modern society, the complexity and time consumption of traditional tea-making has gradually become a luxury. How to preserve the essence of traditional tea ceremony culture while adapting to the needs of modern life has become an urgent problem. In order to solve this contradiction, this paper applies TRIZ theory [3], which is a systematic approach to problem-solving and innovation. TRIZ theory extracts a series of tools and methods for solving technical and physical contradictions by analyzing a large number of invention patents [4].

In this paper, we first analyze the traditional tea-making process comprehensively by using the "Nine Screens Method" [5]. Subsequently, through the analysis of the "Technical Contradiction Matrix" [6] and "Physical Contradiction"[7], we reveal the potential contradictions in the process of tea making, such as the demand for uniform heating and rapid cooling of the tea cups in the blanching step, and the stability of the tea cups and the flexibility of the pouring action in the tea making step, etc. To address these contradictions, we constructed a problem model using the Object Field Model [8] and explored possible solutions by applying the principles of invention [9] in TRIZ. Through the in-depth analysis of the traditional tea ceremony brewing process and the application of TRIZ tools, this paper proposes an optimized design of a fully automatic tea ceremony teapot robot arm. The solution improves the efficiency of tea brewing and ensures the quality of tea soup and the experience of traditional tea ceremonies through careful design. Ultimately, the feasibility and effectiveness of the proposed scheme were verified through kinematic analysis, prototype testing, and user experience evaluation. This study is of great practical significance for the modernization and transformation of the traditional tea ceremony [10] and also provides a reference for the automation of other traditional processes [11].

The structure of this paper is as follows: firstly, we introduce the background of Chinese tea culture and traditional tea ceremony, and then we analyze the steps and challenges faced by traditional tea making; then, we detail the process of problem analysis and solution exploration by using TRIZ tools; finally, we propose the optimized design of the fully automated tea ceremony teapot robotic arm, and we discuss its application in the modernization transformation of the traditional tea ceremony and the direction of future research. Through the research in this paper, we expect to provide new ideas and methods for the inheritance and development of traditional tea art, so that this ancient art can be revitalized in modern society.

2. Analysis of the Steps of Traditional Tea Ceremony Tea Brewing

The traditional Chinese tea ceremony is a deeply cultural way of drinking tea, which is not only a process of preparing a beverage, but also a cultural art that combines philosophy, etiquette, and aesthetics. The art of making tea has been developed over thousands of years in Chinese history, forming a complete set of rituals and techniques. The core of this art is to enhance the sensory experience of drinking tea through delicate steps and rituals, while conveying the cultural values of respect, harmony, and tranquility. The traditional Chinese tea ceremony emphasizes the concept of unity and harmony between man and nature. Brewing tea is not just a simple act of drinking, but an art of life that cultivates one's body and mind and cultivates one's sentiment through brewing and tasting tea. In this process, every movement and every detail of the tea maker is full of respect and ceremony, reflecting the respect for tea and the sense of nature.

2.1 Cultural and Technical Requirements of Tea-Making Steps.

The process of making tea usually consists of four steps: blanching the vessel, adding tea leaves and water, brewing the tea, and pouring the tea into cups, each of which has its own unique cultural significance and technical requirements.

(1) Scalding: Scalding is the preparatory work before making tea, scalding the tea utensils, not only cleans the tea utensils but also provides a suitable temperature environment for the brewing of tea. In this step, the teapot is the main tool of ironing, its selection and use of the subsequent quality of tea has an important impact.

(2) Adding Tea Leaves and Water: Adding tea leaves and water is a key step in tea brewing, which requires the tea master to have a deep understanding and control of the type and quantity of tea leaves as well as the water temperature. Through the technique of "high rushing and low sprinkling", the tea leaves are fully unfolded in the teapot to prepare for the next brewing.

(3) Brewing tea: Brewing tea is the core of the whole tea ceremony, which requires the tea master to have precise control over the temperature of the water, the brewing time, and the ratio of tea leaves

to water, to ensure that the tea's color, aroma, and flavor are optimally displayed. In this step, the teapot's insulation performance and heating control are particularly important.

(4) Pouring tea into cups: Pouring tea into cups is the last step of the tea-making process and an important part of the tea ceremony. Through precise control of the speed and direction of the teapot water, the tea will be brewed evenly and poured into each cup, the process of "phoenix three nodding" is a reflection of the skills of the tea master and respect for the guests.

2.2 Nine-screen Method Analysis

In order to better understand the steps of the traditional tea ceremony and to provide directions for the optimization of the design, we use the "nine-screen method" in TRIZ to conduct a system analysis. The nine-screen method is a tool for comprehensively analyzing a system, as shown in Fig. 1, which reveals the inherent contradiction and potential improvement direction of the system by considering the performance of the system at different times and at different scales.

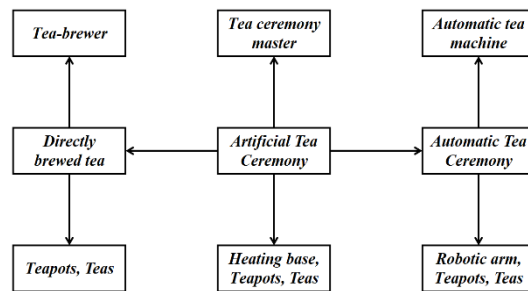


Fig. 1 Analysis of the nine-screen method

In our in-depth analysis of the tea-making process of the tea ceremony, we have adopted a multi-dimensional approach to gain a comprehensive understanding of this traditional skill. First, we traced the origins of the tea-making technique from a historical perspective, observing its evolution over time and its manifestations in modern society, which helped us to grasp the cultural and technical characteristics of the tea ceremony at different historical stages. In addition, we focus on the adaptability of the tea-making technique in different spatial environments, whether they are homes, teahouses or public places, and explore how the process of tea-making can be made to maintain its traditional essence while meeting the needs of different occasions. Further, we analyzed the internal mechanisms of each step of tea brewing in detail, including technical details such as the control of the water flow when blanching the vessel and the adjustment of the water temperature when brewing the tea, in order to identify the key technical requirements of the tea brewing process. At the same time, we also examined the interaction between the tea brewing steps and the external environment, such as the influence of the material of the tea utensils and the water quality on the quality of the brewed tea. On a more macro level, we examined the role of tea brewing in cultural and social events, analyzing how it serves as a cultural activity that facilitates social interaction and cultural transmission.

At the operational level, we delve into the specific techniques of the tea-making process, such as the turning of the wrist when shaking the incense, and the impact of these details on the final effect of the tea-making process. We also looked at the fluidity and coordination of the tea-making process as a whole and analyzed how the various steps can be organically combined to form a harmonious tea ceremony. In addition, we analyzed the conversion and utilization of energy during tea brewing and how effective energy management can enhance the efficiency and quality of tea brewing. Finally, we consider the information transfer during the tea brewing process, especially the non-verbal communication between the tea master and the guests, and how these messages shape the tea brewing process and the tea tasting experience. Through this comprehensive and detailed analysis, we are able to not only gain a deeper understanding of the traditional skill of tea ceremony brewing but also gain insights into its adaptation and evolution in the modern world, as well as its important role in cultural and social interactions.

3. Problem-solving with TRIZ Tools

3.1 Analysis and Resolution of Technical Contradictions.

Technical contradiction is a common problem in engineering design, which occurs when the improvement of one parameter leads to the deterioration of another. In our case, technical contradiction is mainly manifested in the following aspects:

(1) Technical contradictions in boiling water scalders

Increasing the water temperature to speed up the preheating rate in the boiling water scald step may result in damage to the material of the teacups. To solve this contradiction, we use the inventive principle "preaction" corresponding to the contradiction matrix. By designing a temperature control system, the system can automatically stop heating when the preset temperature is reached, thus avoiding damage to the teacups.

(2) Technical contradictions in pouring tea and separating cups

During the tea pouring and cup dispensing steps, increasing the pouring speed may reduce the precision and cultural experience of the tea broth to improve efficiency. We adopted the principle of "Dynamic Characterization" and designed a variable speed pouring mechanism that allows the user to adjust the pouring speed according to the type of tea and personal taste.

3.2 Physical Contradiction Analysis and Resolution

A physical contradiction is when the same parameter within a system has opposite demands under different conditions. In our case, the physical contradiction is between the need for stability and the mobility of the teapot. The physical contradiction of pouring tea and separating cups is that the teapot needs to be stable when pouring tea and flexible when moving to different positions. A switchable fix/release mechanism was designed using the time separation principle. In the pouring step, the teapot is stabilized and fixed on the robot arm to ensure precise pouring; in the moving step, the teapot is free to rotate and move to different positions.

4. Automatic Tea Ceremony Teapot Robot Arm Design

4.1 Key Structural Design

(1) Heating and temperature control system: The heating system of the robotic arm is designed with highly efficient heating elements, which can quickly raise the water temperature to a suitable temperature. As shown in Fig.2, the integrated temperature sensor monitors the water temperature in real time and accurately adjusts the heating power through the closed-loop control system to ensure the stability of the water temperature to meet the specific needs of different teas for water temperature.

Planar rotation mechanism: As shown in Fig. 3, the planar movement mechanism of the robotic arm adopts servo motor rotation to ensure that the robotic arm can realize precise position control during the process of adding water, adding tea leaves, and pouring the cups when pouring tea. The design of the mechanism takes into account the dynamic response and load changes to ensure smooth and reliable operation.

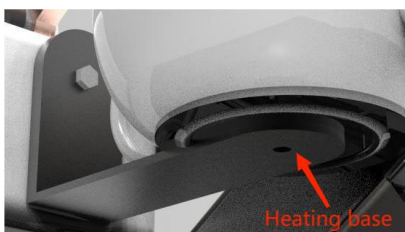


Fig. 2 Heating and temperature control system

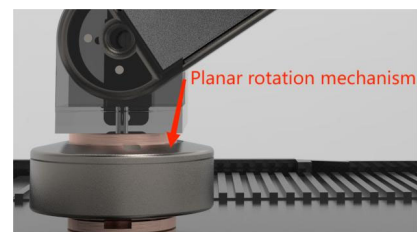


Fig. 3 Planar rotation mechanism

Pot lid lifting mechanism: As shown in Fig. 4, the pot lid operating mechanism is designed to be light and flexible, able to simulate the movement of human hands to lift and place the pot lid gently. The mechanism adopts pneumatic or electric actuators, and through precise control algorithms, it realizes the smooth opening and closing of the lid of the pot and avoids damage to the tea leaves.

Tea pouring mechanism: as shown in Fig. 5, the tea pouring mechanism is an innovative point in the design of the robotic arm, which can simulate the traditional "three nods of the phoenix" tea pouring action. The mechanism adopts a double-degree-of-freedom mechanical design, combined with the precise control of the servo motor, to realize the smooth movement of the teapot in the process of pouring tea and accurate positioning, to ensure that the tea soup is evenly distributed to each tea cup.

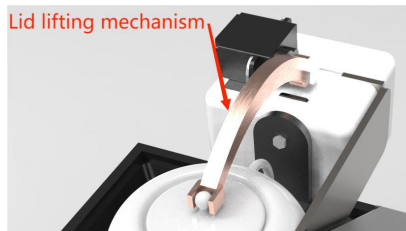


Fig. 4 Pot lid lifting mechanism

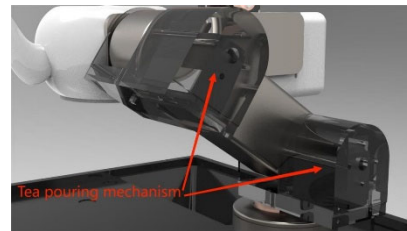


Fig. 5 Tea pouring mechanism

4.2 Functional Design.

(1) Automated iron

The automated blanching function of the robotic arm is realized by an integrated heating system and temperature control unit. This function not only automates the blanching process but also adjusts the heating time and temperature according to the material and size of the tea set to achieve the best blanching results.

(2) Precision tea brewing

The precise tea brewing function is realized by the temperature control system of the robotic arm and the precise water volume control unit. The robotic arm is able to accurately control the water temperature and time of tea brewing according to the preset program to ensure that the aroma and flavor of the tea leaves are fully released.

(3) Dynamic shaking incense

The dynamic shaking mechanism is designed to be able to realize the all-round rotation of the teapot. Simulating the artificial shaking action increases the contact area between the tea leaves and the hot water, promotes the release of the active ingredients in the tea leaves, and enhances the aroma of the tea broth.

(4) Pouring Tea in Cups

The design of the cup pouring mechanism takes into account the fluidity of the tea broth and the layout of the tea cups. By precisely controlling the pouring speed and direction, it ensures that the tea broth can be poured into each tea cup evenly and smoothly, and at the same time avoids spilling and wasting the tea broth.

4.3 Simulation Analysis

The structure of this product is relatively simple, the dangerous cross-section mainly exists in the mechanical arm connection plate, teapot base connection plate, therefore, the mechanical arm connection plate, and teapot base connection plate for stress analysis.

(1) Stress analysis of the connecting plate of the robotic arm, because the main movement of the connecting plate is fixed-axis rotation, so the analysis of force and moment. The material is alloy steel, applying 40 N and 5 N·m load, it can be seen that the yield force at this time is 2.75×10^7 N/m

2, and the material hazardous section is basically much lower than the value, so the structure is safe and stable. The finite element analysis is shown in Fig. 6.

(2) Stress analysis of the connection plate of the base of the teapot, because the main operation of the connection plate is fixed-axis rotation, the flip of the teapot, and the force and moment analysis of this part. The material is carbon steel, applying 5N and 10N-m load, it can be seen that the yield force is 1.8×10^8 N/m², and the material hazardous section is basically much lower than the value, so the structure is safe and stable. The finite element analysis is shown in Fig. 7.

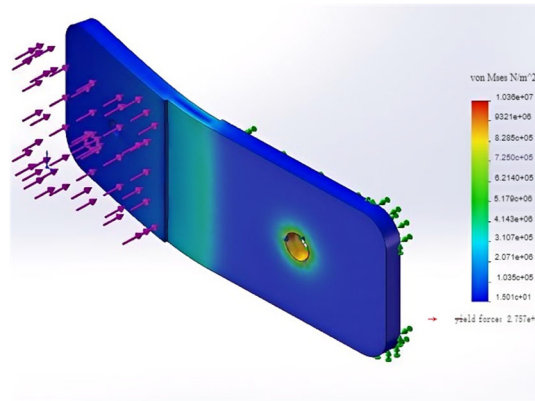


Fig. 6 Finite element analysis of robotic arm connecting plate (left)

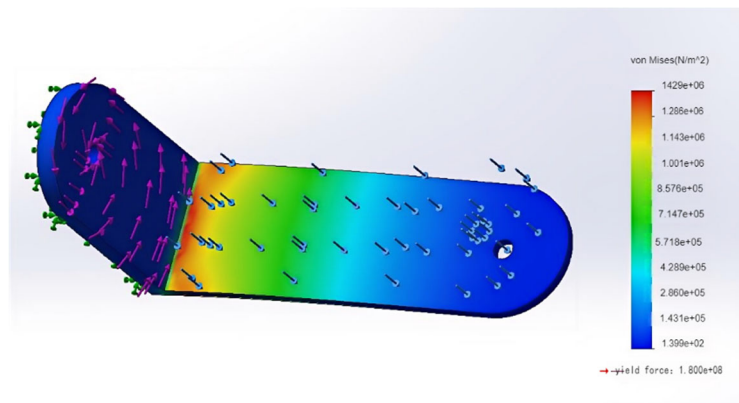


Fig. 7 Finite element analysis of the connecting plate of the teapot base (right)

5. Summary

This paper presents an innovative and optimized design of a fully automated tea ceremony teapot robot arm through the application of TRIZ theory. Through an in-depth analysis of the steps of traditional tea ceremony tea brewing, we identified the key technical requirements and used TRIZ tools to solve the technical and physical contradictions encountered in the automated tea brewing process. The final proposed design not only improves the efficiency of tea brewing but also ensures the quality of the tea broth and the experience of the traditional tea ceremony through the well-designed structure of the robotic arm. The design of the fully automated Tea Ceremony teapot robotic arm integrates several key technology modules such as heating and temperature control, plane movement, lid operation, and pouring and dispensing of tea. Each module has been carefully designed to simulate the manual operation in a traditional tea ceremony to achieve precise and consistent tea brewing results. With the modular design, the robotic arm is not only easy to operate but also easy to maintain and upgrade.

In addition, the design solution also takes into account the compactness and safety of the device, ensuring efficient operation in a limited space while providing adequate safety protection for the user and the robotic arm itself. The feasibility and effectiveness of the proposed solution is verified through actual kinematic analysis and prototype testing. The development of a fully automatic tea art

teapot robot arm is an innovative attempt to integrate traditional tea art with modern technology, which not only improves the quality of life, but also opens up a new path for the inheritance and innovation of traditional tea art. With the continuous progress of technology, we expect more innovative products combining traditional culture and modern technology to appear in the future so that traditional art can show new vitality and charm in modern society.

References

- [1] B. Hinsch, *The rise of tea culture in China : the invention of the individual*. Lanham: Rowman & Littlefield Publishers, 2018.
- [2] Y.-J. Shiah and D. Radin, "Metaphysics of the Tea Ceremony: A Randomized Trial Investigating the Roles of Intention and Belief on Mood While Drinking Tea," *EXPLORE*, vol. 9, no. 6, pp. 355–360, Nov. 2013.
- [3] D. Mann, "An Introduction to TRIZ: The Theory of Inventive Problem Solving," *Creativity and Innovation Management*, vol. 10, no. 2, pp. 123–125, Jun. 2001.
- [4] K. Gadd and J. Wiley, *TRIZ for engineers : enabling inventive problem solving*. Chichester, Uk: John Wiley & Sons Ltd, 2011.
- [5] Wang Shigang, Z. Jie, Wang Xifeng, and Wang Fengjuan, "Thinking Method of Product Form Design of Bionics Based on Nine Screens," *Advances in intelligent systems research/Advances in Intelligent Systems Research*, Jan. 2015.
- [6] H. P. Dave, "TRIZ: 40 principles and their ranking by contradiction matrix," Apr. 2017.
- [7] Naser Ghannad, Roland De Guio, and P. Parrend, "Feature Selection-Based Approach for Generalized Physical Contradiction Recognition," *IFIP advances in information and communication technology*, pp. 321–339, Jan. 2020.
- [8] L. Chybowski, "Use of Triz SU-Field Models in the Process of Improving the Injector of an Internal Combustion Engine," *Multidisciplinary Aspects of Production Engineering*, vol. 1, no. 1, pp. 257–268, Sep. 2018.
- [9] G Altshuller and L Shulyak, *40 principles : TRIZ keys to technical innovation*. Worcester, Mass.: Technical Innovation Center, 1998.
- [10] T. C. <1995> Bilardello, "The Current Trends of the Contemporary Chinese Tea Industry and their Development through Taiwanese Influence and Historical Reforms," *dspace.unive.it*, Apr. 2021.
- [11] S.-L. Jämsä-Jounela, "Future trends in process automation," *Annual Reviews in Control*, vol. 31, no. 2, pp. 211–220, Jan. 2007.