The Institution of Engineering and Technology

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Section	Group No.
UG	17

Empowering Robotic Calligraphy Through AI-Driven 3D Path Planning

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ABSTRACT

The art of Chinese calligraphy, celebrated for its intricate brushwork, presents unique challenges for robotic systems. This project introduces an innovative approach utilizing 3D Hermite curve-based path planning to enhance robotic manipulators' capabilities in performing traditional calligraphy. By leveraging large language models (LLMs) to generate text prompts, we convert these prompts into precise 3D Hermite spline trajectories that capture the fluidity of human brush strokes. The soft calligraphy brushes allow for writing at varying heights, resulting in strokes of different thicknesses, which our framework addresses by transforming 2D stroke-ordered vector graphics into 3D control points. This optimization considers variations in brush pressure and speed, ensuring that each stroke reflects traditional techniques. Experimental results demonstrate the system's ability to produce visually authentic calligraphy with high precision and artistic quality. This research underscores the transformative role of AI in creative fields, showcasing how 3D Hermite curves can bridge the gap between engineering and cultural artistry. By empowering individuals to explore new frontiers in human-robot collaboration, we aim to inspire innovative solutions in the evolving landscape of technology and art.

Keywords:
Robotic Calligraphy, Bézier Curve, Hermite Spline, Trajectory Generation, LLM

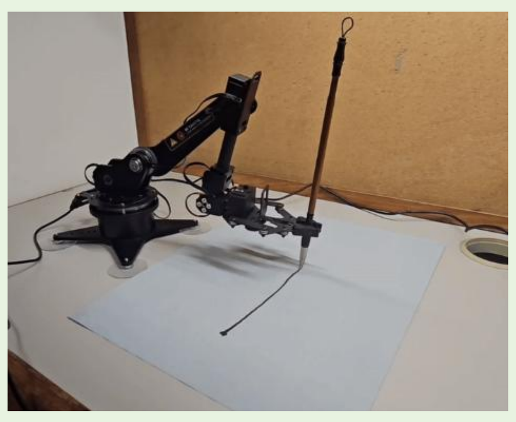
OBJECTIVES

- To utilize large language model (LLM) to generate 4 Chinese characters idioms text prompts based on user's input topic
- To develop and simulate a 3D Bézier curves path planning algorithm that generates smooth trajectories for the inputted Chinese characters
- To implement the Bézier curves path planning algorithm within the robot manipulator system for writing Chinese calligraphy, demonstrating the algorithm's precise and fluid movements.
- To demonstrate the advantages of using Bézier curves in robotic path planning compared to traditional methods, focusing on improvements in smoothness, speed, and accuracy.

Why 3D Path Planning when the paper is 2D?

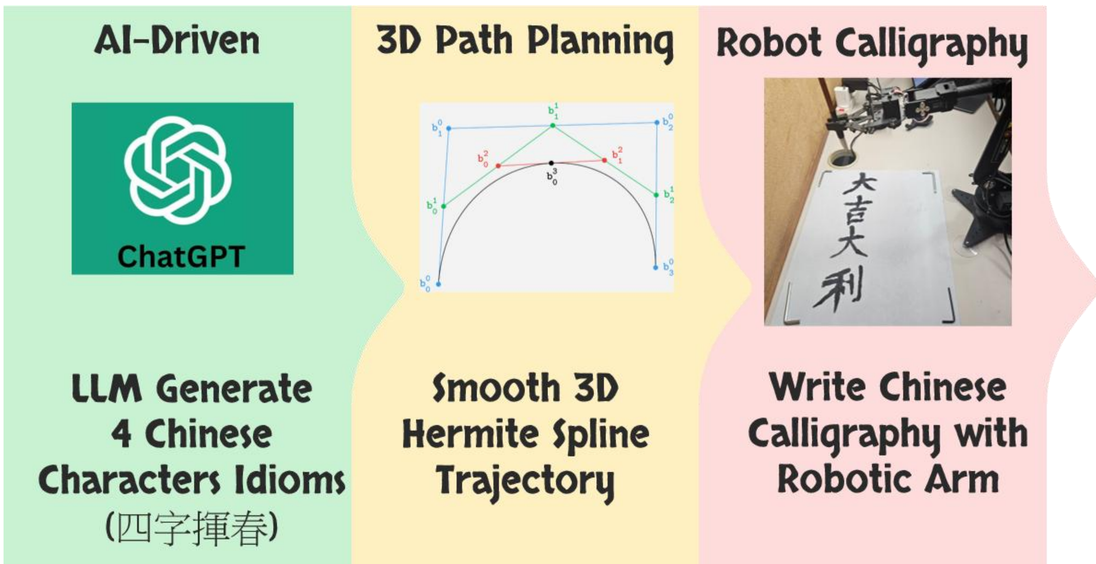
Because Height of Brush affects the Thickness of Lines

High Brush → Thin Line

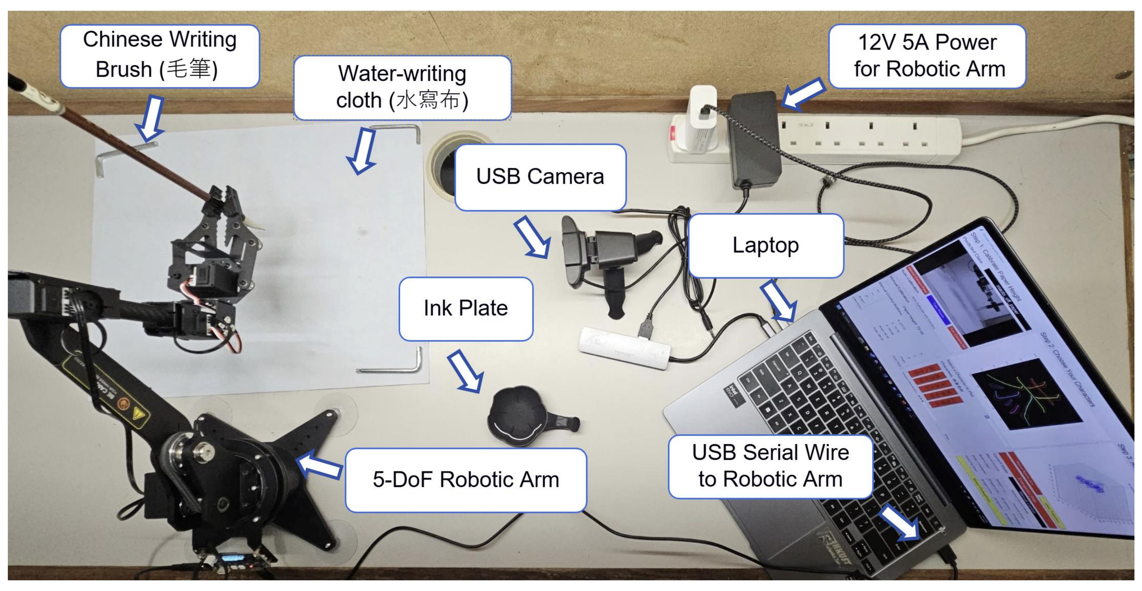


Low Brush → Thick Line

OVERVIEW

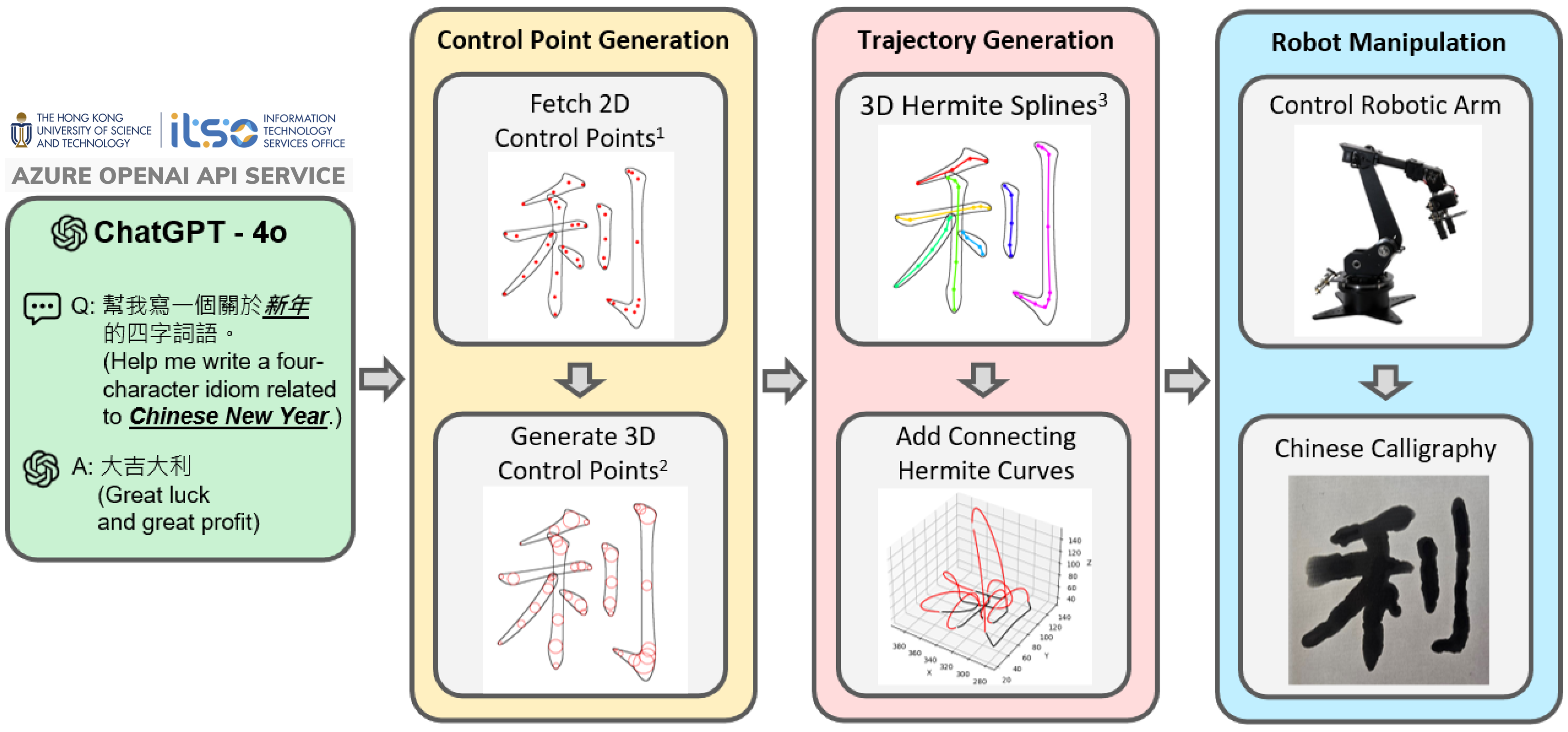


EXPERIMENT SETUP



5-DoF Robotic Arm: Waveshare RoArm-M1, USB serial wire JSON control
Chinese Writing Brush (毛筆): 0.9cm diameter
Water-writing Cloth (水寫布): turns black when wet, white when dry
USB Camera: 480p, to calibrate whether the brush touches the paper

WORKFLOW



[1] Chinese Character Dataset Fetched from https://github.com/skishore/makemeahanzi, Contains 9000+ common Chinese Characters

[2] Find the Largest Fitting Circles for each control point.
Size of circle → Line Thickness → Height of Brush

[3] Formula of Hermite Curve:

$$H(t) = \begin{bmatrix} t^3 & t^2 & t & 1 \end{bmatrix} \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} P_{0x} & P_{0y} & P_{0z} \\ P_{1x} & P_{1y} & P_{1z} \\ V_{0x} & V_{0y} & V_{0z} \\ V_{1x} & V_{1y} & V_{1z} \end{bmatrix}, \text{ where } V_i = \begin{cases} k(P_1 - P_0) & \text{if } i = 0 \\ k \cdot \min\left(|P_{i+1} - P_i|, |P_i - P_{i-1}|\right) \dfrac{P_{i+1} - P_{i-1}}{|P_{i+1} - P_{i-1}|} & \text{if } 1 \le i \le n-2 \\ k(P_{n-1} - P_{n-2}) & \text{if } i = n-1 \end{cases}$$

RESULTS

TABLE I: Examples of input prompts to LLM and the generated output.

Input:	幫我寫一個關於春節的四字詞語。 (Write a four-character idiom related to the Spring Festival.)
Output:	大吉大利 (Great luck and great profit.)
Input:	幫我寫一個關於清明節的四字詞語。 (Write a four-character idiom related to the Qingming Festival.)
Output:	春回大地 (Spring returns to the earth.)
Input:	幫我寫一個關於七夕的四字詞語。 (Write a four-character idiom related to the Qixi Festival.)
Output:	心心相印 (Hearts resonate with each other.)
Input:	幫我寫一個關於中秋節的四字詞語。 (Write a four-character idiom related to the Mid-Autumn Festival.)
Output:	佳人映月 (Beautiful person reflected in the moon)

Fig. 1: Simulated Trajectory of the 3D Path Planning

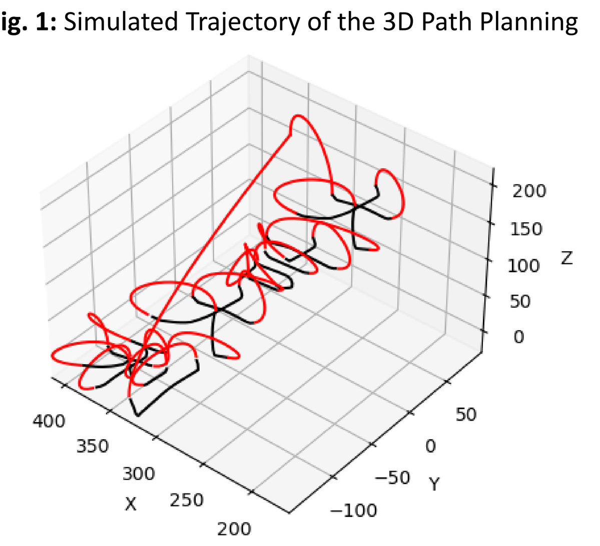
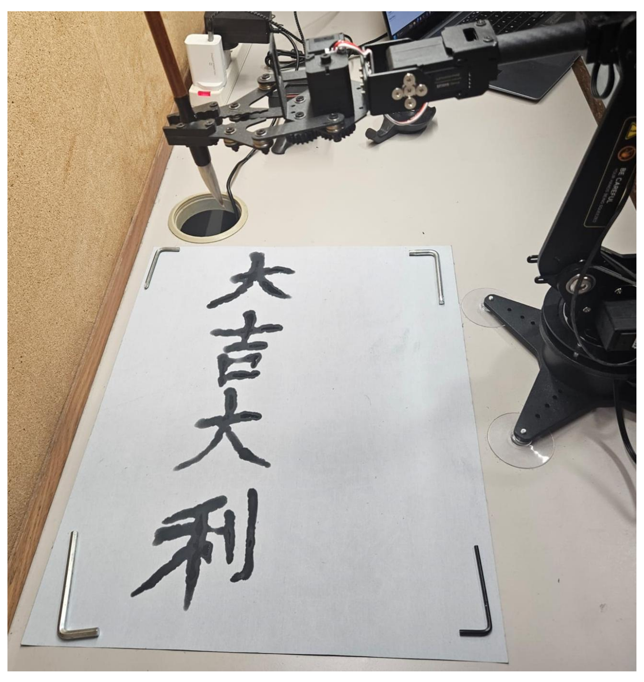


Fig. 2: Robot Calligraphy Results of 大吉大利



Scan QR Code to see Video Demo on YouTube: (https://youtu.be/PfwRGyaZ8r0)

Fig. 3: A List of Different Robot Calligraphy Results

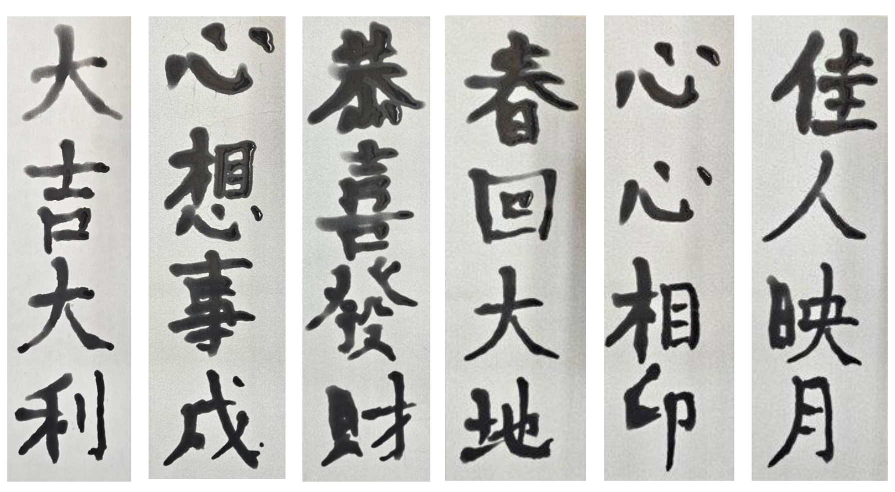
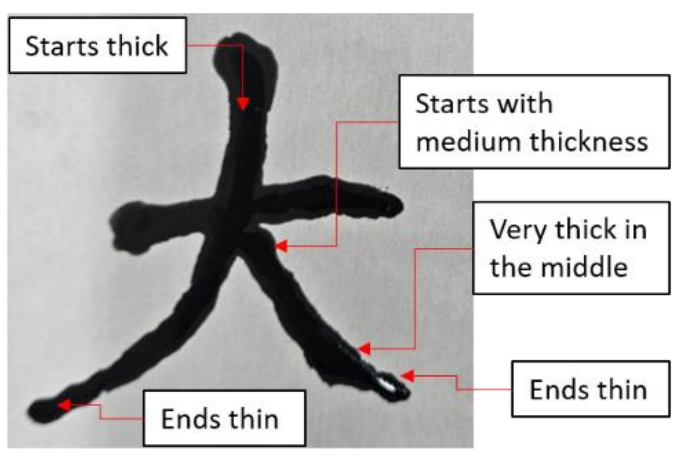


Fig. 4: 3D Path Planning results in more natural, different thickness strokes



CONCLUSION

In conclusion, this project showcases the potential of AI-driven 3D path planning to empower robotic manipulators in creating authentic Chinese calligraphy. The use of LLMs to generate text prompts, combined with the transformation of 2D strokes into 3D Hermite spline trajectories, allows the robot to mimic the nuances of human brushstrokes. This innovation was significantly enhanced by the easy and free access to GenAI APIs, such as those provided by HKUST, and other free, open-source online datasets. This accessibility enables students to explore complex topics, conduct in-depth research, and develop innovative solutions across disciplines. By leveraging these resources, students are further empowered to cultivate critical thinking, data curation skills, and collaboration. This positions them to drive the next wave of innovation, further empowering creativity and bridging technology and art for a more advanced world.