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Towards Robotic Calligraphy

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I. Introduction

Although thousands of Chinese characters exist, they can be constructed from a limited number of single strokes. In Chinese calligraphy these strokes are combined into a full character in a fluid way. Therefore Chinese calligraphy provides an interesting problem to study learning mechanisms such as how to automatically construct complex tasks (full characters) from previously learned simpler ones (single strokes) (Fig. 1). The goal of this project is that a robot should be able to decide which previously learned strokes or characters to use for drawing a newly presented character and to improve its drawing over several iterations.

Here a proof-of-concept prototype is introduced that shows the feasibility of learning single strokes. For the proof-of-concept prototype only the thickness of the stroke is learned and it is assumed that the thickness of the line is only depending on the distance between the brush and the paper, i.e. on the z-coordinate of the robot's end effector.

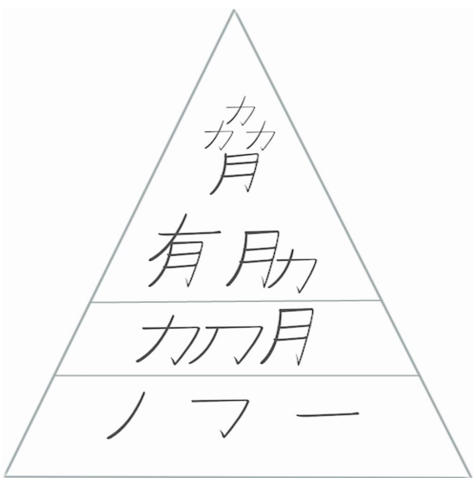

Fig. 1. The single strokes (bottom) form the basis for drawing simple characters (middle). In the end, complex characters can be constructed by combining and adapting previously learned strokes and characters (top).

Previous work on reproducing Chinese characters with a robot has mainly focused on one of two methods. Either the trajectories were extracted from an image of a Chinese character [1]–[3] or a brush model and its parameters were obtained from experiments [4], [5] and then used to find the trajectories for drawing the Chinese character [4], [6]. Little research has been done on improving the drawing by using experience from previous iterations. In [7] the researchers have used visual feedback to correct the xy-coordinates of the strokes, specifically the connection points of strokes. Here we focus on the thickness of strokes by learning the z-coordinate from visual feedback.

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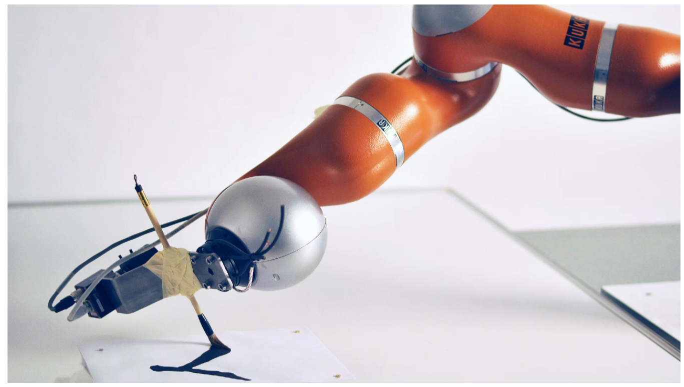


Fig. 2. The experimental setup consisting of the KUKA Light Weight Robot, a Prosilica GC 655C camera, and a brush.

II. Proof of Concept Prototype

Our experiments used a KUKA Light Weight Robot with an attached Prosilica GC 655C camera and a brush (Fig. 2).

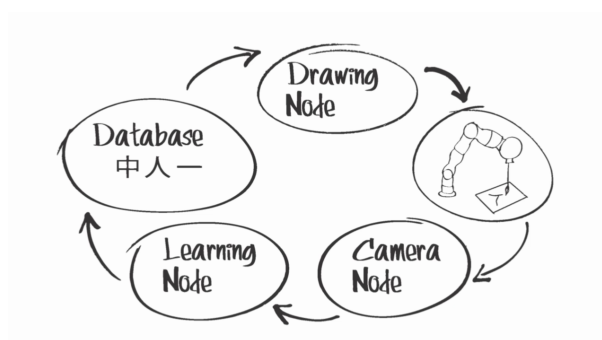
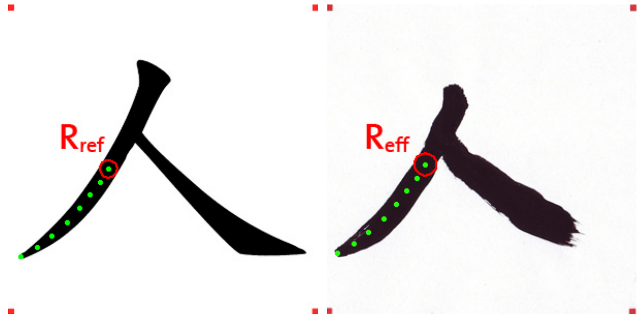


Fig. 3. Software architecture of the proof-of-concept prototype.

The software architecture is depicted in Fig. 3. The database contains a description on how to draw the strokes and on how to combine them into characters. The drawing node takes these descriptions and transforms them into trajectories that can then be executed by the robot. After drawing the character the robot positions the camera above the paper and the camera node detects the region of interest defined by the four red squares (Fig. 4). It also calculates the error between the reference character and the drawn character by projecting the positions that form the robot's



(a) Reference character (b) Drawn character

Fig. 4. Image analysis that is used by the learning node to improve the trajectory for drawing the character in the next iteration.

trajectory onto the paper plane and finding the biggest circle around them that does not contain white pixels (Fig. 4). In the learning node a P-type iterative learning controller (ILC) [8] is implemented that uses the following formula to adapt the z-coordinates of the positions that form the robot's trajectory: $z_{new} = z_{old} + k \cdot (R_{eff} - R_{ref})$ with $k \in \mathbb{R}^{+}$. The new trajectory information is then stored in the database for the next iteration.

III. Results and Discussion

The experimental results for a line that should be getting thinner towards the right end are shown in Fig. 5. The well-known tendency of P-type ILCs for overshooting can be seen in the third iteration. However, one of the main error sources was the bending of the brush after the first stroke (Fig. 7). After performing the first stroke (Fig. 5 (a)) the brush was bent to the left. Therefore, the strokes of the second and the third iteration (Fig. 5 (b)+(c)) start and end further left than the stroke of the first iteration. The bending of the brush is also an effect that is not accounted for in our model for adapting the z-coordinate.

(a) 1st iteration (b) 2nd iteration (c) 3rd iteration

Fig. 5. Three iterations of drawing a line that is getting thinner towards one end. The overshoot in the thickness of the line is due to the P-type ILC.

The experimental results for the Chinese character *ren* (human, person) are shown in Fig. 6. Also for this character an improvement can be seen.

IV. Conclusions and Future Work

We have implemented a database that contains some single strokes and simple Chinese characters and a method to create trajectories for a robot arm from their database representation. Our algorithms for analyzing the image enable us to find an error measure that can be used by a P-type ILC to

(a) Reference (b) 1st iteration (c) 2nd iteration

Fig. 6. The reference and two iterations for the Chinese character *ren* (human, person).

Fig. 7. The bending of the brush after one stroke was one of the main error sources and will be taken into account in future work.

improve the drawing in the next iteration. In our experiments we have applied this to a proof-of-concept prototype and could show that a robot arm could improve its writing of Chinese characters.

In the future, the ILC needs to be improved and extended to handle deviations in stroke positions. In addition the orientation and bending of the brush need to be taken into account. For the final goal of automatically constructing newly presented characters from previously learned strokes and characters, a concept for detecting such similarities is necessary.

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