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Brush Footprint Acquisition and Preliminary Analysis for Chinese Calligraphy using a Robot Drawing Platform

Ka Wah Lo, Ka Wai Kwok, Sheung Man Wong, and Yeung Yam, *Senior Member, IEEE*

Department of Automation and Computer-Aided Engineering
The Chinese University of Hong Kong
Hong Kong
kwlo, kwkwok, smwong, yyam @acae.cuhk.edu.hk

Abstract – A robot drawing platform supporting four degrees of freedom (x, y, z and z-rotation) of a brush-pen motion for studying Chinese painting and calligraphy has been operational in our laboratory. This paper describes the real-time capturing and data analysis of the brush footprint using the new hardware and software capabilities in the platform. They include a transparent drawing plate and an underneath camera system, together with projective rectification and video segmentation algorithms. Preliminary result of the footprint analysis and non-parametric modeling, and their applications to well-known Chinese calligraphy are demonstrated.

I. INTRODUCTION

Robot drawing has evolved to become an integrated study of robots, computer vision, artificial intelligence, simulation and human skill acquisition since the appearance of the first robot painter Aaron [1]-[2] some year ago. In recent years, numerous works on robot drawing and simulation of Chinese calligraphies and drawings have also started to appear [3]-[8]. Unlike some western style painting, the spiritual depiction in Chinese brush painting is to large extent expressed by the brush stroke rather than the outward appearance of the painted subjected. Of the works published, Xu. et al. [5] and Lee [6] specifically studied the modeling aspects of computer generated artistic Chinese calligraphy in simulation, Wong et al. [7] on a virtual brush stroke model, and Kazuyuki H. et al. [8] on virtual calligraphy system. The work so far, however, did not deal with the actual production of Chinese artistry. In this regards, the robot platform we have constructed in our laboratory is aimed at the actual generation and replication of Chinese calligraphies and drawings.

In Chinese black ink painting, the traditional bristles are usually made from the soft hair of animals. If the brushes do not have the proper elasticity and shape, the brushes cannot provide stroke line with adequate quality. Since the depth exerted on the brush increase during painting, the elastic brush is deformed and its bristles spread out such that their contact area widens to maintain a constant total volume. As a result, the brush paints a thicker stroke on the paper. However, all these qualities are not easy to measure for real brush as they vary with different bristles materials used, number of hairs and size of the bristle bundle.

In this paper, we report on the study we conducted on real-time capturing and data analysis of a brush footprint using newly developed facilities in our robot platform. They include, on the hardware side, the installation of a transparent drawing plate and an underneath camera system. On the software side, video projective rectification and segmentation functions are incorporated. Upon preliminary result of the footprint analysis and non-parameterization modelling, the appropriate painting depth can be determined. The painting trajectory is then generated together with Constrained Delaunay Triangulation (CDT) algorithm, the actual execution of some Chinese calligraphic characters are demonstrated and shown in Fig.1

Fig.1. Would-be brush stroke achieved by taking the union of the captured footprint

The present paper is organized in six sections. The next section describes the robot drawing platform and the newly added hardware for footprint capture. Section III shows the footprint capture process and subsequent data analysis. Section IV proposes a simple non-parameterization footprint model, which is applied in Section V to generate the brush stroke for replication of Chinese calligraphy characters. Finally, conclusions and future works are presented in Section VI.

Fig.2. Hardware Design of the Drawing Robot

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II. Robot Drawing Platform

A robot platform has been constructed in our laboratory aimed at studying the actual generation and reproduction of Chinese calligraphies and paintings. Preliminary capabilities of the platform are reported in [9] and [10]. The robot is designed to support five degrees of freedom (DOF) for emulating the hand and wrist movement in the process of Chinese calligraphy artistry. Four DOFs are presently operational and are used for the study in this work.

Fig.2 shows the drawing platform constructed in our laboratory. The top part of the platform consists of a *x-y-z* axis translational mechanism, and a robot gripper with a z-axis rotation degree of freedom, yielding a total of 4 DOFs for the pen movement for now. A fifth DOF, which is the titling of the brush pen, will be added latter. The platform utilized industrial grade components to achieve the high precision and repeatability needed for the fine execution of brush strokes. The x and y-translation are executed by two AC servomotors each with an angular torque of 0.51Nm and a length of travel of 1m. The corresponding accuracy is ±0.001mm. The z-axis AC motor has an angular torque of 0.08 Nm, and a vertical support load of 50N to provide the needed support for the specially designed robot gripper. The z-axis stroke length is 0.1m and the accuracy is ±0.03mm. For the z-axis rotation, an AC servomotor with maximum angular velocity of 3000 rpm and an angular torque of 0.095Nm is used. The z-axis rotation provide clockwise and counter-clockwise movement from 0°- 300° and the accuracy is ±0.1°.

Fig.3. Conceptual idea and hardware for footprint acquisition

The DOFs of the drawing platform are all independently commanded, doing away with the kinematics problems associated with many other robot-based drawing systems. The issued commands (*x*, *y*, *z* and *z*-rotation) are executed through a PID type controller. The eventual goal of the platform will be on the acquisition, learning, and execution of human techniques in Chinese brush pen painting and calligraphy. To be successful, a good understanding of the workings of the Chinese paint brush, or the footprints that it makes as a function of the robot commands, is vital. The present work is a pursuit in this direction.

The basic idea of the present work is shown in Fig.3. As the brush moves on the transparent glass plate upon certain command, robot, its footprint is captured by a video camera system placed below the plate looking upwards. The captured footprints are then correlated with the input commands for a non-parametric characterization. Fig.4(a) shows the actual transparent setup and the installed camera system underneath. The system uses a Sony EVI-D30/D31 Pan/Tilt/Zoom Colour Video camera with a resolution of 640×480 pixels and the ability to capture 20-30 frames per second. For present purpose, those video frames will be indexed with the corresponding time instant and brush motion commands. The transparent plate in our case is actually in the form of a container. At times, blue liquid is put in the container to enhance the effect of the footprint capturing, as the case shown in Fig.4(b). The blue colour liquid acts as the background of the video captured, providing a good contrast to the yellow brush tuft of the footprint.

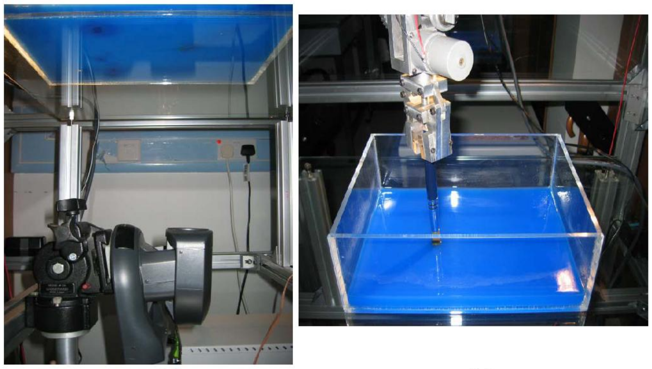

(a) (b)

Fig.4. Actual hardware for footprint acquisition: (a) Video camera, (b) the transparent drawing setup

The captured video needs to be transformed into a full plane view as if observed from directly below the transparent plate. This Projective Rectification process [11] aims to remove the projective distortion in the perspective video image. This process allows the captured image to be rectified in a full plane view with proper scaling so that the rectified image has the same pixel resolution as the original stroke image and subsequent stroke quality measurements can hence be based on the same pixel unit before the two can be compared. The strict requirement of having the camera system looking up at 90° may also be relaxed.

III. FOOTPRINT ACQUISITION AND DATA ANALYSIS

For this work, we performed a number of horizontal brushstroke experiments under different drawing conditions. The depth along the z-axis was set from 0mm to -8.5mm, and the pen velocity from 7.5mm/s to 30mm/s. The instantaneous footprints of each stroke are captured in video film file during the process. Each video frame is indexed with the corresponding time instant and robot encoder readings. Appropriate setting of colour, contrast and brightness are adjusted to ease this footprint segmentation process.

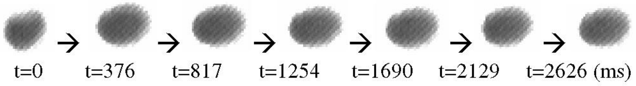
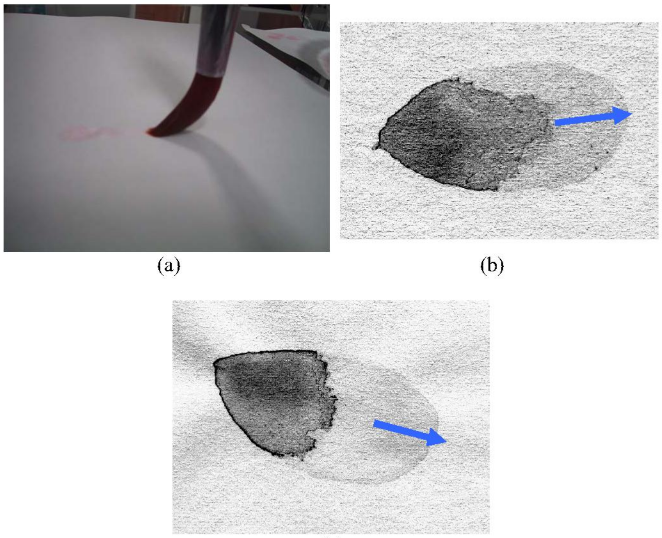


Fig.5. Captured footprint with time indexing for *z*=-3mm

Fig.5 shows the sampled footprint of one of the executed strokes with time indexing. The z-axis depth in the case is -3 mm. We can actually take the union of these footprints along the video frames to yield the would-be-executed brush stroke, as shown in Fig.1.

As the start, the running brush will form a contact with the paper as shown in Fig.6(a). The portion of hair depositing ink on paper such that the bristles slipt and spread laterally to produce a wider elliptic footprint which is shown in Fig.6(b). With a running brush rotated about z-axis slowly by CW30°, the footprint actually maintains more or less the same shape except that it is also rotated by the same amount. This is shown in Fig.6(c).


(a) (b)

(c)

Fig.6. (a) Pen brush position after starting , (b) The corresponding actual ink footprint on the real paper, (c) Actual footprint profile upon CW z-axis rotation of 30°

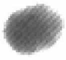
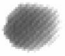
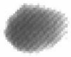
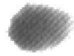
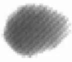
Depth (mm)	Z = -1	Z = -2	Z = -3	Z = -4	Z = -5	Z = -6
V=7.5 (mm/s)						
V=10 (mm/s)						

Table 1. Steady state footprint profile for different depth and velocities

As one concrete example, with a z-axis value of -3mm and a linear velocity of 7.5mm/s, it would take roughly 376ms to settle the footprint become almost as ellipse. Moreover, as the resulting stroke would be the union of all footprints, the actual shape of the footprint would be less important as compared to the width of the footprint in the direction of the traversal of the brush pen. Table 1 shows the steady state profiles acquired for different depths along the z-axis direction and linear velocities. It can be observed that the shape of the footprint remain almost the same but the size of the footprint increases significantly with increased depth.

IV. NON-PARAMETERIZATION FOOTPRINT CHARACTERIZATION

This approach uses an experimental raw data which had been repeated many times in the drawing platform. The real footprint stroke area is then modeled in term of major axis and minor axis. Such characterization is useful for determining the z-axis command and orientation of the pen to yield an appropriate stroke thickness in Chinese calligraphy. Also, this thickness is not sensitivity to the different linear velocity setting. To yield a simple non-parameterization footprint characterization of the footprints for different commanded z-depth and velocities, we make two assumptions. These two assumptions may seem to be over-simplified, but they suffice as a first attempt to obtain a baseline characterization of a complicated process.

We assume that

(1) Using a constant small number of pixel value with respect to the various depth of z-axis for both starting and ending brush stroke, and
(2) The steady state footprints are approximated as ellipses.

As can be seen from the next section, results from applications are quite satisfactory. Specifically, we model the “footprint”, U_t, of the brush at any instance of time, t as a 3-tuple:

$$U_t = (a_t, b_t, w_t)$$

where a_t is the major axis and b_t the minor axis of the ellipse, and w_t is the z-axis rotation of the ellipse. The subscript t indicated that they can be evolving as function of time. While assumptions (1) and (2) above ensure that (a_t, b_t, w_t) are not changing with respect to time for given z-axis depth value and pen velocity, the depth and linear velocity themselves may be varying with time, in which case (a_t, b_t, w_t) as well.

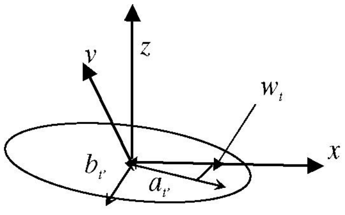


Fig.7. Illustration of w_t, a_t and b_t

Fig.7 shows the assumed footprint which is a rotated ellipse, and the physical meaning of the parameters (a_t, b_t, w_t). The question is how this rotated ellipse will change with different depths and velocities of the brush pen. For calligraphy stroke replication, we will set w_t such the orientation follows the tangential slope of the running trajectory in (x,y) coordinates.

In what follow we will derive some non-parameterization relation between various footprint variables (a_t, b_t, w_t) and the z-depth values and linear velocity. In this case, we have data ranging from 0mm to -8.5mm at intervals 0.5mm for the depth and from 7.5mm/s to 19mm/s at intervals 1mm/s for the velocity. Fig.8 shows the corresponding pixel area of the footprint against the depth z and velocities v. Each grid point represents the results from one horizontal stroke for certain z

and *v*. The area measured reflects the brush surface exerting on the paper. When the brush is exerted toward on the paper, the bristles spread out such that their contact (footprint) area widens to maintain a constant total volume. To ensure the repeatability and the accuracy of the data are good enough, each trajectory stroke are repeated executing three times, the mean experimental data value are collected for analysis here.

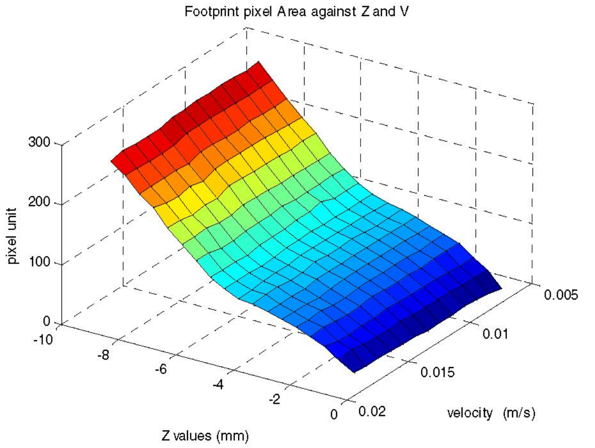


Fig.8. 3D diagram of footprint pixel area against z-axis values and velocities

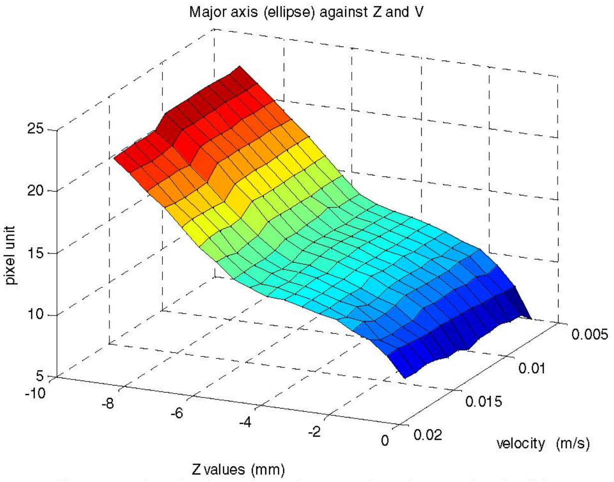


Fig.9. 3D diagram of major length against z-axis values and velocities

Fig.9 and Fig.10 show, respectively, the major and minor axis of the assumed elliptical footprint against the depth values and linear velocities. Here, the major axis length a_t and minor axis length b_t are computed by taking the second-moments of the approximate ellipse. They are essential parameters to determining the assumed footprints of the brush stroke.

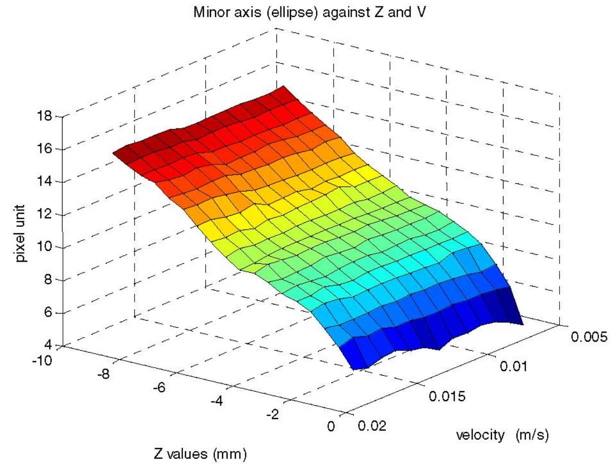


Fig.10. 3D diagram of minor length against z-axis values and velocities

By observing the characterization of Fig.8 to Fig.10, they indicate that the area, major and minor axis of the approximate elliptic profile increase as the z-axis depth values increase. The linear velocity, however, does not have much effect. To be consistent, the steady velocity during execution is set at 7.5mm/s in the execution. Specifically, Fig.11 shows the variables a_t and b_t as function of z-axis value which the corresponding velocity is 7.5 mm/s.

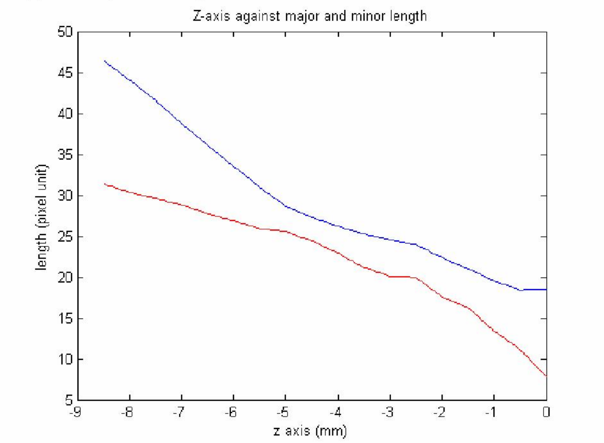
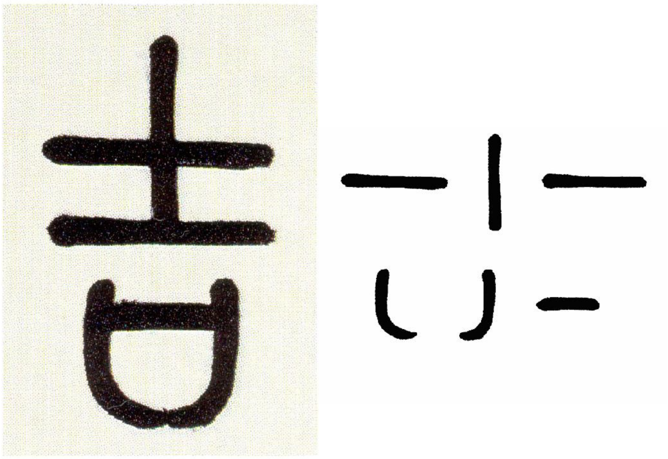


Fig.11. Relationship of the parameters a_t and b_t vs z-axis values

V. APPLICATIONS OF FOOTPRINT ANALYSIS IN CALLIGRAPHY REPLICATION

For our present calligraphy case, the resulting skeleton would follow or less the middle of the stroke segment, giving rise to the trajectories in stroke painting. Thinning Algorithm [12] is one of the most common pre-processing steps for such feature extraction on many pattern recognition systems. It results in one-pixel-wide skeleton of the image foreground. However, for some thick and high resolution stroke images, it usually generates spurious skeletons such as splitting some forked line segment at the stroke terminals. These defects will usually result in the failure of painting trajectory estimation.



(a) (b)

Fig.12. (a) Original calligraphy character “吉” with lucky meaning (source:[15]), (b) the character divided into six strokes separately

In what follows, we propose another morphological transform called the Chordal Axis Transform (CAT) [13]-[14] that can achieve the skeleton from a discretized shape (polygon). Firstly, we will make the boundary of each stroke divided into equally edge unit length. The optimal edge unit length on each stroke boundary can be determined based on the Constrained Delaunay Triangulation (CDT) of polygons. In order to have a best fitting edge unit length, the iterative search algorithm with predefined initial edge unit length will be used. In this case the initial value is used 30 pixels. The selection criteria which is using the maximum fitting coverage triangle area with less overlapping area of the inner stroke will be used to shorter the edge unit length. Once obtained the best triangle size, then the shorter edge unit length will be found.

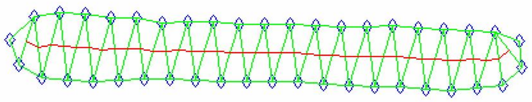
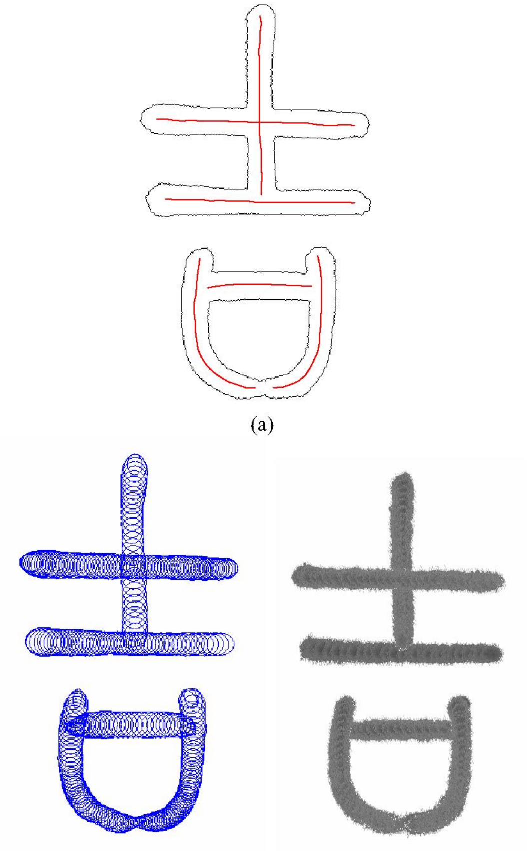


Fig.13. CDT result of first stroke in character “吉” and its median axis is indicated

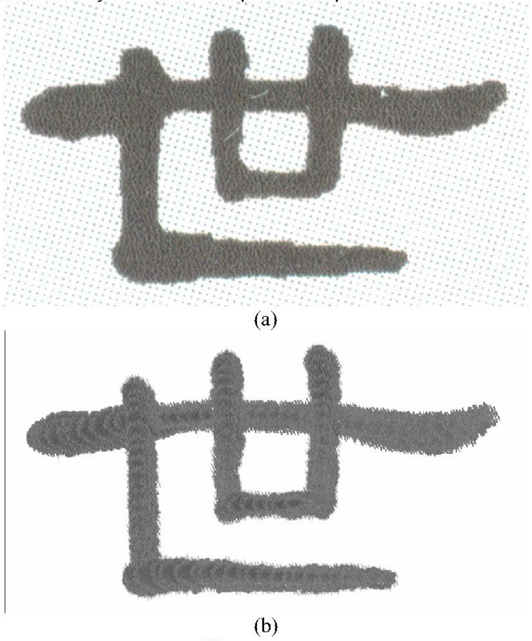
The first study is on the Seal character “篆書” which is the earliest form of the writing. The character “吉” is shown in Fig.12(a) and we divided it into six strokes manually as depicted in Fig.12(b). Those boundary unit lengths are evaluated in 21-25 pixels for different strokes. Upon the resulting triangulation from CDT, the CAT is then used to obtain the main frame path axis for the stroke as shown in Fig.13. Thus, the (x, y) trajectory is formed by lining up the mid-point of each chordal axis inside the stroke as depicted in Fig.14(a). On the other hands, the stroke thickness control will make use of the experimental data in Fig.8, Fig.9 and Fig.10. By fitting the maximum inscribed elliptical footprint along the trajectories as depicted in Fig.14(b), the required z-axis commands can then be determined. The painting depth z together with (x, y) trajectories are then implemented in the robot execution on the transparent setup.



(a)

(b) (c)

Fig.14. (a) (x, y) painting trajectories inside six strokes estimated by CAT, (b) elliptic footprints centered at trajectories are simulated, (c) the resulting character formed by the union of captured footprints.



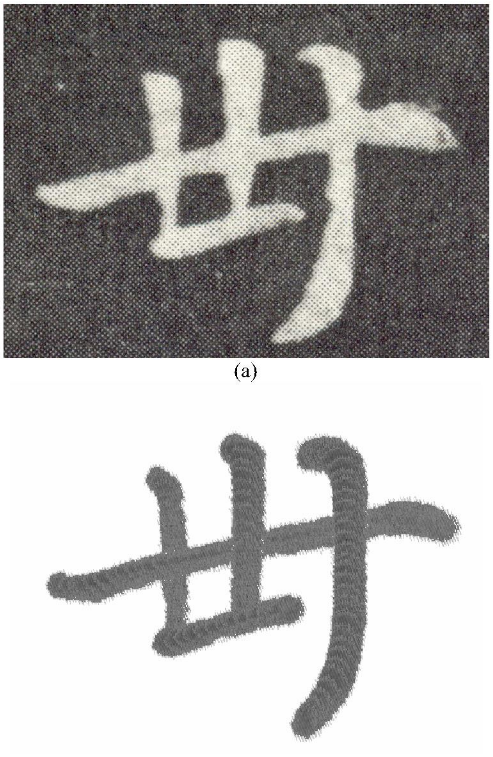
(a)

(b)

Fig.15. (a) Original character “世” (source:[16]), (b) the resulting character formed by the union of captured footprints

Fig.14(c) shows the unions of the instantaneous captured footprints forming the calligraphy character. The results as shown are quite satisfactory. In this case, we note that the strokes forming the character are quite uniform in width. It is envisioned that the execution will be done on the real paper with the additional ink diffusion model rather than on the transparent setup.

Another example allowing more variation in the strokes is presented. Fig.15(a) and (b) shows the example and comparison of another character “世” in an ancient style of calligraphy popular in the Han Dynasty “漢朝” . These results are promising given the simple nature of the footprint analysis at hand. For further demonstration, Fig.16(a) and (b) shows the same character “世” but in another font style by the Chinese famous ancient calligrapher Wang Xianzhi “王羲之”.



(a)

(b)

Fig.16. (a) Original character “世” by Wang Xianzhi “王羲之” (source: [17], (b) Corresponding character formed by the union of captured footprints

VI. CONCLUSIONS

A robot drawing platform aimed at studying Chinese calligraphy and painting is used for the real time capturing of paint brush footprints. New hardware which include a transparent drawing plate with an underneath camera system is installed. Projective rectification and video segmentation capabilities are also added. The present results shows that corresponding footprints can be roughly approximated as elliptical, with the major and minor axes more dependent on the z-axis depth of the brush, rather than the linear velocities. Application to robot execution of a few Chinese characters yields quite satisfactory comparison to the original ones. Except some limitation on some font style shown on Fig.16(b), the starting and ending stroke are still not quite sharper enough when compared to the original. Brush stroke execution plays a vital role in Chinese artistry. Future works will include improving the starting and ending stroke performance, dynamic modelling and parameter identification of a detailed brush stroke characterization.

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