where \( x_i \) and \( y_i \) are coordinates in \( \sum_R \), \( x_w \) and \( y_w \) are coordinates in the writing order coordinate system \( \sum_w \) as shown in Fig. 4b, \( H_{\text{char}} \) is the height of the character image pattern, \( (x_R + T_R/2, y_R - T_R/2) \) is the center of the writing area, and \( (X_{\text{char}}, Y_{\text{char}}) \) is the center of character in \( \sum_w \). Hereafter, if no specific declaration, the coordinates of the control points are those in \( \sum_R \).

3.4.1. \( S_1 \): Horizontal stroke. \( S_1 \) is not just a simple straight line. As shown in Fig. 10a, the character for ‘king’ contains three \( S_1 \)'s. In CCC, these three \( S_1 \)'s are written differently: (1) concave, (2) flat and (3) convex as in (a). In general, to generate the trajectory of the writing brush for this stroke, four control points \( P_1 \) to \( P_4 \) are necessary. In the case that the number of the control points is less than 4, auxiliary points can be generated according the coordinates of the control points. Auxiliary points \( B_1 \) and \( B_2 \) are generated from the coordinates of \( P_1 \), and \( E_1 \) to \( E_3 \) from those of \( P_4 \). The value of their coordinates are given in detail below.

(i) Writing the start of \( S_1 \)

Trajectory: \( B_1(x_1 - 2d_x, y_1 + d_y, z_d - d_{\min}) \rightarrow B_2(x_1 + 2d_x, y_1 - d_y, z_d - 1.1d) \rightarrow P_1(x_1, y_1, z_d - d) \).

Note that \( x_1 \) and \( y_1 \) are coordinates of the control point \( P_1 \) and the change of the \( z \)-coordinate is to make the tip of the writing brush take the shape as shown in Fig. 9c.

(ii) Movement of the writing brush

Trajectory: \( P_1 \rightarrow Q_0 \rightarrow Q_1 \rightarrow \cdots \rightarrow Q_M \rightarrow P_4 \).

Note that \( Q_j \) (\( j = 0, 1, \ldots, M \)) is the point on the B-spline curve determined by \( P_1 \) to \( P_4 \) and the width is \( z_d - d \).

(iii) Writing the end of \( S_1 \)

Trajectory: \( E_1(x_4 - d_x, y_4 + d_y, z_d - 0.8d) \rightarrow E_2(x_4 + 2d_x, y_4 - 2d_y, z_d - 1.1d) \rightarrow E_3(x_4 - 3d_x, y_4 - d_y, z_d - 0.8d) \).

Note that \( x_4 \) and \( y_4 \) are coordinates of the control point \( P_4 \) and the change of the \( z \)-coordinate is to make the end of the stroke take the shape as shown in Fig. 10b. Figure 10c shows the three variations of \( S_1 \) written by a robot hand.

3.4.2. \( S_2 \): Vertical stroke. Figure 11a shows four variations of \( S_2 \). The first one from the left is similar to the left falling stroke \( S_3 \). The control technique for it is the same with that of \( S_1 \) and will be discussed later. The second from the left is called an iron dot. The trajectories for points \( P_1 \) and \( P_2 \) are as follows:

(i) Writing the start of \( S_2 \)

Start: \( \text{tl} \)
Movements: \( \text{tn} \), \( n_y \), \( n_y \)
End: \( \text{br} \)

(ii) Writing the end of \( S_2 \)

Start: \( \text{br} \)
Movements: \( \text{tn} \), \( n_y \), \( n_y \)
End: \( \text{tl} \)

Note that \( x_5 \) to \( x_7 \) are the coordinates of the control points for the trajectory. Two auxiliary points, \( B_1 \) and \( B_2 \), are generated from them, twc \( B_1 \) and \( B_2 \) are

\[ 
\begin{align*}
{x_1} & \hspace{1cm} (a) \\
{x_3} & \hspace{1cm} \text{b)} \\
{x_5} & \hspace{1cm} \text{c)} \\
{x_7} & \hspace{1cm} (c)
\end{align*}
\]

Figure 10. (a) Sample character for ‘king’ including three \( S_1 \)'s. (b) Trajectory to write \( S_1 \). (c) Three \( S_1 \)'s written by the robot hand.

3.4.3. \( S_6 \): Ellipsoids. There are three types of dots, three calligraphers, aligned dot, dot, and inclined dot. For each group, three coordinate points, two digits, three control points, two control points, two control points, and two control points, except the \( x_5 \) and \( y_5 \) are the coordinates of the control points for the trajectory.

\[ 
\begin{align*}
\text{When } x_{91} \text{ to } x_{93} \text{ are the left side of the dot, and } x_{94} \text{ to } x_{96} \text{ are the right side.}
\end{align*}
\]

Figure 11. (a) Figure 11a shows four variations of \( S_2 \). The first one from the left is similar to the left falling stroke \( S_3 \). The control technique for it is the same with that of \( S_1 \) and will be discussed later. The second from the left is called an iron dot.
called an iron post, the third a hanging pin, and the fourth an elephant tooth. The trajectories for these three kinds of vertical strokes are determined by two control points \( P_1 \) and \( P_2 \). The following shows the trajectories of them.

(i) Writing the iron post

**Start:** the same with that of \( S_1 \).

**Movement of the writing brush:** \( P_1(x_1, y_1, z_4 - d) \rightarrow P_2(x_2, y_2, z_4 - d) \).

**End:** \( E_1(x_1 - d_x, y_1 + d_y, z_4 - 0.8d) \rightarrow E_2(x_2 + d_x, y_2 - 2d_y, z_4 - 1.1d) \).

(ii) Writing the hanging pin

**Start:** the same with that of \( S_1 \).

**Movement of the writing brush:** \( P_1(x_1, y_1, z_4 - d) \rightarrow E_1((nx_1 + mx_2)/(m + n), (ny_1 + my_2)/(m + n), z_4 - d) \rightarrow P_2(x_2, y_2, z_4 - d_{min}) \).

Note that \( m : n = P_1E_1 : E_1P_2 \) and is in the range from 6 : 1 to 10 : 1.

(iii) Writing the elephant tooth

**Start:** the same with that of \( S_1 \).

**Movement of the writing brush:** \( P_1(x_1, y_1, z_4 - d) \rightarrow P_2(x_2, y_2, z_4 - d) \rightarrow E_1(x_2 - d_x, y_2 - d_y, z_4 - d_{min}) \).

Figure 11b shows the three variations of \( S_2 \) written by a robot hand.

### 3.4.3. \( S_3 \): Dot stroke

The dot stroke is very complicated to write even for human calligraphers. Figure 12a shows four variations of \( S_3 \). They are called the right inclined dot, rising dot, vertical dot and right falling dot, from left. To express these dots, three control points \( P_1 \), \( P_2 \) and \( P_3 \) are necessary. To determine the trajectories for them, two auxiliary points \( R_1 \) and \( R_2 \) are inserted between \( P_1 \) and \( P_2 \) for these dots, except the vertical dot, according to:

\[
\begin{align*}
x_{R_k} &= \mp(y_2 - y_1) \times d_i / \|P_1P_2\| + (nx_1 + mx_2)/(m + n), \quad (8a) \\
y_{R_k} &= \mp(x_2 - x_1) \times d_i / \|P_1P_2\| + (ny_1 + my_2)/(m + n), \quad (8b)
\end{align*}
\]

where \( k = 1, 2 \). When \( k = 1 \), \( m : n \) is set to 1 : 2 and when \( k = 2 \), \( m : n = 2 : 1 \).

When \( x_{R_k} \) takes ‘−’ and \( y_{R_k} \) takes ‘+’ in the first item in (8), \( (x_{R_k}, y_{R_k}) \) lies in the left side of line \( P_1P_2 \) when moving from \( P_1 \) to \( P_2 \). Oppositely, \( (x_{R_k}, y_{R_k}) \) lies in the right side of line \( P_1P_2 \). For the right inclined dot and right falling dot, \( R_1 \) and \( R_2 \) are set on the left side of the line \( P_1P_2 \); for the rising dot, on the right side.

![Figure 11](image.png)

(a) Four variations of \( S_2 \). (b) Three \( S_2 \)'s written by the robot hand.
Writing the right inclined dot, rising dot and right falling dot

Start: $B_1(x_1 - d_v, y_1 + d_e, z_d - d_{\text{min}}) \rightarrow P_1(x_1, y_1, z_d - d_{\text{min}})$ and $B_1$ is the same as related in $S_1$.

Movement of the writing brush: $P_1 \rightarrow Q_0 \rightarrow Q_1 \rightarrow \cdots \rightarrow Q_M \rightarrow P_2$.

Note that $Q_j (j = 0, 1, \ldots, M)$ is the point on the B-spline curve determined by $P_1, R_1, R_2$ and $P_2$, and the width is controlled by:

$$z_j = z_d - \left( d_{\text{min}} + (d - d_{\text{min}}) \frac{k \delta}{M} \right).$$

End: $P_2(x_2, y_2, z_M) \rightarrow P_3(x_3, y_3, z_d - d_{\text{min}})$.

Writing the vertical dot

Start: $B_1(x_1 - d_v, y_1 + d_e, z_d - d_{\text{min}}) \rightarrow P_1(x_1, y_1, z_d - d_{\text{min}})$, where $B_1$ is the same as related in $S_1$.

Movement of the writing brush: $P_1(x_1, y_1, z_d - d_{\text{min}}) \rightarrow P_2(x_2, y_2, z_d - d) \rightarrow P_3(x_3, y_3, z_d - d)$.

End: $P_3(x_3, y_3, z_d - d) \rightarrow E_1(x_3 + d_v, y_2, z_d - d_{\text{min}})$, where $E_1$ is generated from $P_3$ and $P_3$.

Figure 12b shows the four variations of $S_0$ written by a robot hand.

3.4.4. $S_3$: Left falling stroke. The size of the left falling stroke changes from a very short one like a dot to a very long one, depending on the positions located in the different characters. For the short one, it can be expressed by two control points. Here, in general, at least four control points are necessary. If the number of control points is less than 4, auxiliary control points can be generated to make it be 4 according to (8) as in $S_0$. The trajectory is as follows.

Start: the same with that of $S_1$.

Movement of the writing brush: $P_1 \rightarrow Q_0 \rightarrow Q_1 \rightarrow \cdots \rightarrow Q_M \rightarrow P_4(x_4, y_4, z_d - d_{\text{min}})$.

Note that $Q_j (j = 0, 1, \ldots, M)$ is the point on the B-spline curve determined by $P_1$ to $P_4$ and the width is controlled according to (6). Figure 13b shows the two variations of $S_3$ written by a robot hand.

3.4.5. $S_4$: Right falling stroke. There are two variations for $S_4$, one is the same with the right falling dot as in $S_0$, another one is given in Fig. 14a. Here, we only discuss how to write the later one. To express this stroke, five control points are
Figure 13. (a) Left falling stroke $S_3$. (b) Two $S_3$s written by a robot hand.

Figure 14. (a) Right falling stroke $S_4$. (b) $S_4$ written by a robot hand.

Figure 15. (a) Rising stroke $S_5$. (b) $S_5$ written by a robot hand.

necessary as given in (a). If the number of the control points between $P_1$ and $P_4$ is less than 4, auxiliary control points can be inserted to make it be 4 according to (8) as in $S_0$. Below is the trajectory.

Start: $B_1(x_1 - d_x, y_1 + d_y, z_0 - d_{min}) \rightarrow P_1(x_1, y_1, z_0 - d_{min})$ and $B_1$ is the same as related in $S_1$.

Movement of the writing brush: $P_1 \rightarrow Q_0 \rightarrow Q_1 \rightarrow \cdots \rightarrow Q_M \rightarrow P_4$.

Note that $Q_j$ $(j = 0, 1, \ldots, M)$ is the point on the $B$-spline curve determined by $P_1$ to $P_4$ and the width is controlled according to (9).

End: $P_4(x_4, y_4, z_M) \rightarrow P_5(x_5, y_5, z_0 - d_{min})$.

Figure 14b shows a $S_4$ written by a robot hand.

3.4.6. $S_5$: Rising stroke. Two control points $P_1$ and $P_2$ are employed to express this stroke as shown in Fig. 15a.

Start: $B_1(x_1 - 2d_x, y_1 + d_y, z_0 - d_{min}) \rightarrow B_2(x_1 + 2d_x, y_1 - d_y, z_0 - 1.1d) \rightarrow P_1(x_1, y_1, z_0 - d)$.

Movement of the writing brush: $P_1(x_1, y_1, z_0 - d) \rightarrow P_2(x_2, y_2, z_0 - d_{min})$.

Figure 15b shows a $S_5$ written by a robot hand.

3.4.7. $S_6$: Vertical and hook stroke. Three control points $P_1$ to $P_3$ are employed to express this stroke as shown in Fig. 16a. $R_1$ is the auxiliary control point which is generated from $P_2$ to $P_3$.

Start: the same with that of $S_1$.
Movement of the writing brush: $P_1(x_1, y_1, z_d - d) \rightarrow P_2(x_2, y_2, z_d - d) \rightarrow R_1(x_2, y_3, z_d - 0.9d) \rightarrow P_3(x_3, y_1, z_d - d_{\text{min}})$.

Figure 16b shows a $S_5$ written by a robot hand.

3.4.8. $S_7$: Curved hook stroke; $S_8$: Inclined hook stroke; $S_9$: Lying hook stroke.

For these three strokes, at least five control points $P_1$ to $P_3$ are necessary as shown in Fig. 17a. If the number of control points between $P_1$ and $P_3$ is less than 4, auxiliary control points can be inserted to make it be 4 according to (8) as in $S_0$. The differences among these three strokes are how to write the starts and how to control the width of these strokes. The trajectories are given below.

Start: $B_1(x_1 - d_s, y_1 + d_s, z_d - d_{\text{min}}) \rightarrow P_1(x_1, y_1, z_d - d_{\text{min}})$, for $S_7$ and $S_9$, and $B_1$ is the same as related in $S_1$. For $S_8$, its start is the same with that of $S_1$.

Movement of the writing brush: $P_1 \rightarrow Q_0 \rightarrow Q_1 \rightarrow \cdots \rightarrow Q_M \rightarrow P_4$.

Note that $Q_j (j = 0, 1, \ldots, M)$ is the point on the $B$-spline curve determined by $P_1$ to $P_4$ and the width is controlled according to (6) for $S_7$ and $S_9$; for $S_8$, it is set at $z_d - d$.

End: $P_4(x_4, y_4, z_M) \rightarrow P_5(x_3, y_5, z_d - d_{\text{min}})$.

Figure 17 shows these three strokes written by a robot hand.

3.4.9. $S_{10}$: Vertical and turn-right stroke; $S_{11}$: Vertical, turn-right and hook stroke.

These two strokes are similar. $S_{11}$ is expressed by five control points $P_1$ to $P_5$ as shown in Fig. 18a, $S_{10}$ by four. For $S_{10}$, if we think an auxiliary control point exists, and is overlapping with $P_5$, the control techniques for these two strokes are the same. To generate a smooth trajectory from $P_2$ to $P_4$, another auxiliary control point $R_1$ is put in the right side of the line $P_2P_3$ according to (8), where $m : n$ is set at 1 : 1.

Start: the same with that of $S_1$.
3.4.10. $S_{12}$: Vertical and rising. This stroke can be considered as the combination of an elephant tooth in $S_2$ and the rising stroke $S_5$. Details are omitted here.

3.4.11. $S_{13}$: Horizontal and hook stroke; $S_{14}$: Horizontal and fold stroke. These two strokes can be expressed by five control points $P_1$ to $P_5$ as shown in Fig. 19. For the small $S_{13}$ or $S_{14}$, it can be expressed by three control points, i.e., $P_1$, $P_4$ and $P_5$. In that case two auxiliary control points are inserted between $P_1$ and $P_2$ in order to generate the trajectory for it. To write the fold at $P_3$, three auxiliary control points $R_1$, $R_2$ and $R_3$ are generated from $P_3$. The trajectory is as follows.

**Start:** the same with that of $S_1$.

**Movement of the writing brush:** $P_1 \to Q_0 \to Q_1 \to \cdots \to Q_M$. 

Note that $Q_j$ ($j = 0, 1, \ldots, M$) is the point on the B-spline curve determined by $P_2$, $R_1$, $P_3$ and $R_4$, and the width is set at $z_d - d$.

**End for $S_{13}$:** $R_1(x_4 - d, y_4, z_d - 0.9d) \to R_2(x_4 - d, y_4 + d, z_d - 0.8d) \to R_3(x_4 + 2d, y_4 - d, z_d - 1.1d) \to P_4(x_5, y_5, z_d - d) \to P_3(x_5, y_5, z_d - d)$.

**End for $S_{14}$:** $R_1(x_4 - d, y_4, z_d - 0.9d) \to R_2(x_4 - d, y_4 + d, z_d - 0.8d) \to R_3(x_4 + 2d, y_4 - d, z_d - 1.1d) \to P_4(x_5, y_5, z_d - d) \to P_3(x_5, y_5, z_d - d)$. 

Figure 18 shows a $S_{11}$ written by a robot hand. 

Figure 19. (a) Horizontal and hook stroke $S_{13}$. (b) Horizontal and fold stroke $S_{14}$. 

---

For $S_9$ written by a robot hand,

$$(x, y, z_d - d) \to$$
3.4.12. $S_{15}$: Horizontal, fold and hook. This stroke can be expressed by six control points $P_1$ to $P_6$ as shown in Fig. 20a. If the number of control points between $P_2$ and $P_3$ is less than 4, auxiliary control points are inserted according (8) as in $S_0$. To write the fold at $P_2$, three auxiliary control points $R_1$, $R_2$ and $R_3$ are generated from $P_2$. The trajectory is as follows.

Start: the same with that of $S_1$.

Movement of the writing brush: $P_1(x_1, y_1, z_d - d) \rightarrow R_1(x_2 - d_x, y_2, z_d - 0.9d) \rightarrow R_2(x_2 - d_x/2, y_2 + d_y/2, z_d - 0.8d) \rightarrow R_3(x_2 + 2d_x, y_2 - d_y, z_d - 1.1d) \rightarrow P_2(x_2, y_2, z_d - d) \rightarrow Q_0 \rightarrow Q_1 \rightarrow \cdots \rightarrow Q_M \rightarrow P_3$.

Note that $Q_j$ ($j = 0, 1, \ldots, M$) is the point on the B-spline curve determined by $P_2, \ldots, P_5$, and the width is set at $z_d - d$.

End: $P_5(x_5, y_5, z_M) \rightarrow P_6(x_6, y_6, z_d - d_{min})$.

Figure 20 shows two $S_{15}$'s written by a robot hand.

3.4.13. $S_{16}$: Horizontal, fold and left falling stroke. This stroke is expressed by five control points $P_1$ to $P_5$ as shown in Fig. 21a. If the number of control points between $P_2$ and $P_3$ is less than 4, auxiliary control points are inserted according (8) as in $S_0$. To write the fold at $P_2$, three auxiliary control points $R_1$, $R_2$ and $R_3$ are generated from $P_2$. The trajectory is as follows.

Start: the same with that of $S_1$.

Movement of the writing brush: $P_1(x_1, y_1, z_d - d) \rightarrow R_1(x_2 - d_x, y_2, z_d - 0.9d) \rightarrow R_2(x_2 - d_x/2, y_2 + d_y/2, z_d - 0.8d) \rightarrow R_3(x_2 + 2d_x, y_2 - d_y, z_d - 1.1d) \rightarrow P_2(x_2, y_2, z_d - d) \rightarrow Q_0 \rightarrow Q_1 \rightarrow \cdots \rightarrow Q_M \rightarrow P_3$.

![Figure 20](image-url) (a) Horizontal, fold and hook stroke $S_{15}$. (b) Two different $S_{15}$s written by a robot hand.

![Figure 21](image-url) (a) Horizontal, fold and left falling stroke $S_{16}$. (b) Two different $S_{16}$s written by a robot hand.
expressed by six control points between the points $d_1$, $d_2$, $d_3$ as in $S_0$.

\[ d_1, y_2, z_d - d_1, d_2, y_2 - d_2, z_d - d_2, d_3, y_2 - d_3, z_d - d_3 \]

\[ S_{15}'s \] determined

\[ S_{16}'s \] expressed by

case control points

\[ 1 \] in (8) as in $S_0$.

\[ d_1, y_2, z_d - d_1, d_2, y_2 - d_2, z_d - d_2, d_3, y_2 - d_3, z_d - d_3 \]

\[ \text{Width} \]

Note that $Q_j$ \((j = 0, 1, \ldots, M)\) is the point on the B-spline curve determined
by $P_2, \ldots, P_{5}$ and the width is controlled according to (6). Figure 21 shows two
\( S_{16}'s \) written by a robot hand.

3.4.14. $S_{17}$: Left falling and fold stroke. This stroke can be considered as the
combination of $S_3$ and $R_5$. Details are omitted here.

3.4.15. $S_{18}$: Left falling and dot stroke. This stroke is expressed by seven control
points $P_1$ to $P_7$ as given in Fig. 22a. The trajectory consists of two parts, one is from
$P_1$ to $P_4$ and the other from $P_4$ to $P_7$. If the number of control points for these two
parts is less than 4, auxiliary control points are inserted as in $S_0$. To write the end,
 auxiliary control points $E_1, E_2$ and $E_3$ are generated from $P_7$. The trajectory is
given below.

\textbf{Start:} the same with that of $S_1$.

\textbf{Movement of the writing brush from $P_1$ to $P_4$:}

\[ P_1(x_1, y_1, z_d - d) \rightarrow Q_0 \rightarrow Q_1 \rightarrow \cdots \rightarrow Q_M \rightarrow P_4(x_4, y_4, z_M). \]

Note that $Q_j$ \((j = 0, 1, \ldots, M)\) is the point on the B-spline curve determined
by $P_1, \ldots, P_4$ and the width is controlled according to (6).

\textbf{Movement of the writing brush from $P_4$ to $P_7$:}

\[ P_4(x_4, y_4, z_d - d) \rightarrow Q_0 \rightarrow Q_1 \rightarrow \cdots \rightarrow Q_M \rightarrow P_7(x_7, y_7, z_M). \]

Note that $Q_j$ \((j = 0, 1, \ldots, M)\) is the point on the B-spline curve determined
by $P_4, \ldots, P_7$ and the width is controlled according to (9).

\textbf{End:} $P_7(x_7, y_7, z_M) \rightarrow E_1(x_7 + 0.5d_x, y_7 + 0.7d_y, z_d - 0.8d) \rightarrow E_2(x_7 + d_x, y_7 + d_y, z_d - d_{min}) \rightarrow E_3(x_7, y_7 - d_y/2, z_d - d_{min})$.

Figure 22 shows a $S_{18}$ written by a robot hand.

3.4.16. Other strokes. Other strokes are given in Fig. 23. If we take $P_i$ as the
separation point, they are the combinations of two strokes whose trajectories are
related above. The separation is given below:

\[ S_{19} = S_2 + S_1, \quad S_{20} = S_1 + S_{12}, \quad S_{21} = S_1 + S_8, \]

\[ S_{22} = S_2 + S_{15}, \quad S_{23} = S_{14} + S_{16}, \quad S_{24} = S_{16} + S_7. \]

\[ S_{25} = S_{14} + S_{15}, \quad S_{26} = S_1 + S_{10}, \quad S_{27} = S_2 + S_{16}. \]
Figure 23. Strokes $S_{19}, \ldots, S_{27}$.

The trajectory at the fold point $P_1(x_l, y_l)$ is as follows, where $E_0, E_1, \ldots, E_3$ are auxiliary control points generated from $P_1$ and $E_0$ is the end point of the first half of the stroke:

- $S_{19}, S_{22}, S_{27}: E_0(x_l, y_l, z_d - d) \rightarrow E_1(x_l - 2d_x, y_l - d_y, z_d - d_{min}) \rightarrow E_1(x_l + 2d_x, y_l - d_y, z_d - 1.1d) \rightarrow P_1(x_l, y_l, z_d - d)$
- $S_{20}, S_{21}, S_{26}: E_0(x_l - d_x, y_l, z_d - d) \rightarrow E_1(x_l - d_x/2, y_l + d_y/2, z_d - d_{min}) \rightarrow E_1(x_l + 2d_x, y_l - d_y, z_d - 1.1d) \rightarrow P_1(x_l, y_l, z_d - d)$
- $S_{23}, S_{25}: E_0(x_l, y_l, z_d - d_{min}) \rightarrow E_1(x_l - 2d_x, y_l + d_y, z_d - d_{min}) \rightarrow E_1(x_l + 2d_x, y_l - d_y, z_d - 1.1d) \rightarrow P_1(x_l, y_l, z_d - d)$
- $S_{24}: E_0(x_l, y_l, z_d - d_{min}) \rightarrow E_1(x_l - d_x, y_l, z_d - d_{min}) \rightarrow P_1(x_l, y_l, z_d - d_{min})$.

4. EXPERIMENTAL RESULTS

The whole system is implemented on a Windows platform and the programming language is C++. The value of $T_{char}$ is set at 64 dots, and the threshold value for noise clump, $T_n$, at 6 dots. The size of the writing area $T_R$ is set at 200 mm. The searching range, $T_L$, to adjust the writing order points referring to the thinned image pattern is set at 8 dots. The number of divisions, $K$, between two control points is set at 5. The values of $d_{min}$ and $d_{max}$ are determined by the writing brush. For the present writing brush, HOUSENDOUT middle size, they are 12 and 30 mm, respectively. The width of the stroke, $d$, is set at 16 mm. Note that $d$ is the displacement of the robot hand along the $-Z$-axis from its default position. The ratio to the width of the stroke, i.e. $F_x$ and $F_y$, are set at 5. The value of the degree of inclination, $\delta$, is summarized in Table 2. The size of the characters written by the CCC robot is given by $T_R = T_{char} \times K_S$, where $K_S$ is the scale coefficient which is in the range of 0.5–1.0. When $K_S$ is set to 1.0, the robot writes the character in 200 mm × 200 mm area as shown in Fig. 6. Figure 24 shows some experimental results when $K_S$ is set at 0.8. Figure 24a shows a photo of the final size character for ‘minute’, robot hand and writing brush. Other results are summarized in Fig. 24b. The first column from left in (b) shows the input image patterns of characters for ‘king’, ‘water’, ‘wood’, ‘heart’, ‘woman’, ‘commonplace’, ‘no’, ‘moon’, ‘child’ and ‘force’, from top to bottom. The second column gives the writing order denoted by the control points. The third column lists the thinned image patterns used for adjusting the positions of the control points. The fourth column shows characters written by the CCC robot.

5. CONCLUSION

This paper inherits CCC data and angular, blunt, to this CCC robot and reston is also able to write the strokes.

Second, a dynamic pressure can write the stroke, all char of strokes by the con the trajectory brush. The robot to w

The total is about 3: constructed in block st.

For a character only inherit robot be at cursive an
Table 2.
Value of the coefficient of the degree of inclination

<table>
<thead>
<tr>
<th>Stroke code</th>
<th>$\delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_0$</td>
<td>2.2</td>
</tr>
<tr>
<td>right inclined dot</td>
<td>2.0</td>
</tr>
<tr>
<td>rising dot</td>
<td>2.4</td>
</tr>
<tr>
<td>right falling dot</td>
<td>2.7</td>
</tr>
<tr>
<td>$S_1$</td>
<td>0.7</td>
</tr>
<tr>
<td>$S_2$</td>
<td>2.0</td>
</tr>
<tr>
<td>$S_7$</td>
<td>2.0</td>
</tr>
<tr>
<td>$S_9$</td>
<td>2.0</td>
</tr>
<tr>
<td>$S_{16}$</td>
<td>0.3</td>
</tr>
<tr>
<td>$S_{18}$</td>
<td>0.3</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

This paper relates the trajectory generation of the writing brush for a robot arm to inherit CCC techniques. First, we related the preservation of CCC and constructed a CCC database. For a character, the calligraphy writings in different styles (ancient, angular, block, semi-cursive and cursive) by different calligraphers are all registered to this CCC database. At present, this CCC database contains 29 456 characters written by famous calligraphers in Chinese history. It is able to search CCC database and restore the calligraphy writing for a specific character in this CCC database. It is also able to add new calligraphy writings to this CCC database.

Second, we mainly relate the inheritance of CCC. As CCC is not a static, but a dynamic process of an activity concerning a lot of complicated factors such as pressure control to the writing brush, speed control of the writing brush, how to write the start and end of the stroke, how to write the turn and fold on the way of the stroke, etc., we proposed to inherit this dynamic process by a robot system.

All characters can be constructed by basic strokes. There are 28 different kinds of strokes to construct all of these characters. The skeleton of a stroke is decided by the control points existing in the stroke. The shape of a stroke is determined by the trajectory derived from the control points and the pressure applied to the writing brush. The control points for 28 strokes are given and the control techniques for a robot to write these strokes in block style are developed.

The total number of Chinese characters is more than 800 000 and that in daily use is about 3500 [9]. No matter how complicated the Chinese character is, it can be constructed by the strokes in Table 1. At present, the robot can write any character in block style.

For a character, it can be written in five different styles. At present the robot can only inherit the CCC techniques for block style writing. It is necessary to make the robot be able to inherit the CCC techniques for other styles (ancient, angular, semi-cursive and cursive). These are our future work objectives. The direct application
Figure 24. (a) Photo of a character for 'minute' written by the CCC robot, robot hand and writing brush, at scale 0.8. (b) The first column from the left shows the input image patterns; the second, the writing order by the control points; the third, thinned image patterns used for adjusting the positions of the control points; the fourth, characters written by the CCC robot.
of this system is the design and printing of signboards. However, the main purpose of this research is to preserve and develop the CCC culture. Nowadays, with the spread of computer word processors, such as Word, Ichitaro, etc., more and more people are using them and do not like to write characters even by pen or pencil, not to mention the writing brush. Therefore, the number of competent calligraphers is becoming smaller and smaller day by day. If this situation continues for several decades, the CCC culture may face the crisis of extinction. If the robot can master all the skills of a professional calligrapher, it can do creative jobs such as making new CCC artworks. Further, the robot can instruct people in the study of calligraphy. In this way, the robot can preserve, inherit and develop the CCC culture. This is the goal we are working toward.

REFERENCES


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