Implementation of a Calligraphy Mechanical Arm Based on FPGA

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Abstract — Dimensional mechanical arm is an important development direction of mechanical arm, which plays a significant role in the industrial and agricultural production. The system is developed based on the platform DE2, which makes full use of FPGA hardware structure and Nios II flexible embedded processing capability. The mechanical arm motion is simplified through analysis of multi-dimension manipulator motion. The related control algorithm and hardware driver are implemented to copy Chinese calligraphy as well as accomplish Chinese calligraphy action as lifting and pressing, writing sketches and other functions. The experiment results proved the efficiency of the design.

Keywords — Mechanical arm, multi-dimensional, calligraphy, NIOS II, FPGA

I. INTRODUCTION

Nowadays little has done on the research of calligraphy demonstration by the mechanical arm. The control effect is more intuitive and attractive by studying the starting, bearing, rotating and folding of calligraphy. More could be done in multi-joint movements on the planar contour through the research of the multi dimension mechanical arm for calligraphy demonstrations. The design is focus on multi-axis motion localization algorithm and Chinese characters font structure. The former is realized by linear interpolation algorithm, the latter is made up of strokes order library, strokes library, location library. By searching the Chinese characters stroke order, stroke and stroke position to form a Chinese character.

The paper is organized as follows. The multi-axis motion localization algorithm is introduced in section 2. The database of Chinese characters font is described in section 3. The experiments realization is given in section 4. Finally, concluding remarks are drawn in the last section.

II. MULTI-AXIS MOTION LOCATION ALGORITHM

The structure of the mechanical arm can be divided into vertical type and horizontal mechanical type. The vertical type comprises four servos and one stepping motor, of which there are three servos driving the mechanical arm to do concertina movements in the vertical plane, whose structure is shown as Figure 1.The horizontal type has 3 stepping motors which drive the mechanical arm to do concertina movements on a horizontal plane, whose structure is shown as Figure 2.

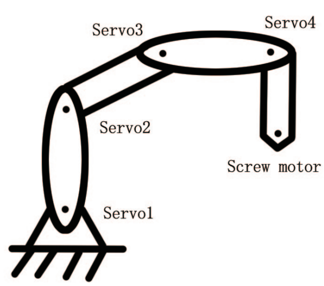


Figure 1. The front view of the vertical type

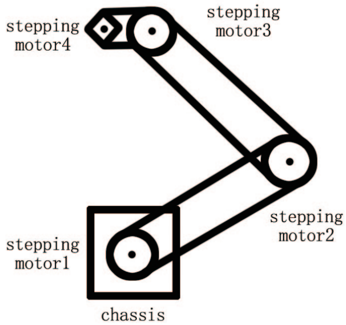


Figure 2. The vertical view of the horizontal type

A. The location algorithm of the vertical type

Among four servos, three of them are in the vertical plane and one in the horizontal plane. We use the polar coordinate system to transform from the X-Y coordinates to obtain simple formula. The structure is shown as Figure 3.

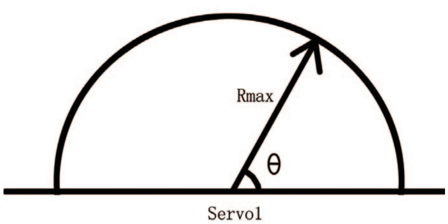


Figure 3. Location of polar coordinate

θ is the range of rotation of servo1. Rmax is the maximum extension of the mechanical arm. By changing the size of R, and angle θ, an arbitrary point in the semi-circular area can be reached. The size of R is determined by servo 2, 3, 4 which belong to the same plane. Because the writing brush is generally perpendicular to the paper, the brush is fixed in the servo 4. The structure is shown as Figure 4.

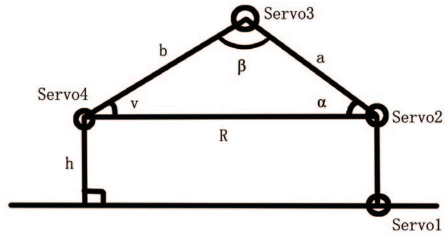


Figure 4 The structure of the vertical type

Servo 2, 3, 4 form a triangle, and the distance between servo1 and servo2 is the same as the distance between the brush and the paper, a, b, R are known, α, β, γ can be obtained as following.

$$\cos\alpha = \frac{R^2 + a^2 - b^2}{2aR} \tag{1}$$

$$\cos\beta = \frac{a^2 + b^2 - R^2}{2ab} \tag{2}$$

$$\cos\gamma = \frac{b^2 + R^2 - a^2}{2bR} \tag{3}$$

The results are:

$$\alpha = \arccos\left(\frac{R^2 + a^2 - b^2}{2aR}\right) \tag{4}$$

$$\beta = \arccos\left(\frac{a^2 + b^2 - R^2}{2ab}\right) \tag{5}$$

$$\gamma = \arccos\left(\frac{b^2 + R^2 - a^2}{2bR}\right) \tag{6}$$

The transform formulas from X-Y coordinates to polar coordinates are:

$$X^2 + Y^2 = R^2 \tag{7}$$

$$\theta = \arccos\left(\frac{X}{R}\right) \tag{8}$$

From the above, if the X-Y coordinates are given, then certain value of R and θ could be acquired, and finally the value of α, β, γ could be determined.

Since the movements of the mechanical arm is inside the semicircle, It is hard to complete vertical operation after locating at a certain point if only the four servos are driven, therefore, a stepping motor with a screw rod is fixed on servo 4 to solve the problem, as shown in Figure 5.

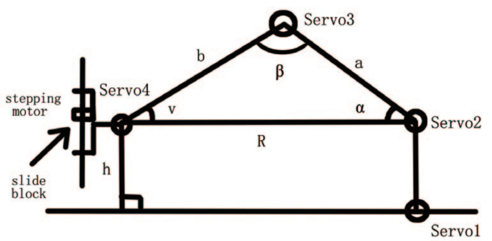


Figure 5. The vertical plane diagram of the mechanical arm with Z-axis

The stepping motor makes the slider up and down through the screw rod.

The servo is driven by the pulse width control, for a given periodic PWM signal, the servo is fixed at a specific angle and torque force is great. If there is large pulse width difference between the pulse trains, the mechanical arm would need large torque force to rotate, which would greatly shorten the expectation of the servo, and such motion does not conform to the smooth and soft of the brush writing. While the stepping motor is driven by the number of pulses, therefore, if the period of pulses is shorten down, the stepping motor's rotation speed will become faster, vise versa, the rotation speed will be slower.

The servos can be controlled by the following steps:

[1]. Loading value A into the register 1 and register 2.

[2]. Comparing the value between the register 1 and the register 2. If B>A then A++ until A=B, if B<A then A-- Until A=B.

[3]. Loading value A into the register 2.

[4]. Loading the new value B into the register 1.

[5]. Turn to (2).

The variation of the initial angle is determined by the value A. While the new value B>A, then A is accumulated until A=B, however if B<A, then A is decremented until A=B.

The mechanical arm has four servos, as a result after a servo rotates to a new angle, it couldn't move until the rest motors move to the desired angle, which can guarantee the lag or advanced action not appear among servos.

The step rotation speed can be controlled by 20ms cycle's delay. The shorter delay time, the faster a servo rotates a degree.

B. The location algorithm of the horizontal type

It is more consistent with the human's writing motion path by using the horizontal mechanical arm. The three stepping motors are positioned in the horizontal plane. The polar coordinates are described as Figure 6.

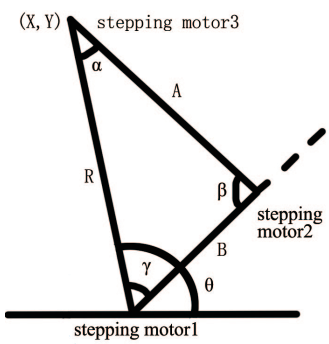


Figure 6. The structure of the horizontal type

The motion range of the stepping motor is larger than that of a servo and the precision of the former is higher too, therefore the coverage area of the horizontal type is larger than that of the vertical one. However, due to the limit of human motion, set $0<=\beta<=180°$, the stepping motor 1, 2, 3 form a triangle, other angles can be obtained by using the cosine theorem (as eq. (4), (5), (6)), thereby the mechanical arm could be controlled to move to a specific point.

The control of a stepper motor is different from that of a servo, which makes the initialization of the stepping motor be hardly controlled by a program, so the infrared sensors are installed on the mechanical arm joints as the aid of initializing location.

III. CHINESE CHARACTER FONT

Chinese characters font is composed of the stroke order, the stroke and the position table. The traditional way of describing Chinese characters is the lattice. Each Chinese character is formed by dozens or even hundreds of points. To construct a more than 2000 Chinese characters font will need large amount of data, which is a disadvantage for storage. The data redundancy can be greatly reduced as well as the efficiency of Chinese characters is greatly improved through the construction of the three tables.

Three tables are created as following:

A. The Stroke Order Table

Stroke order table records the order of each Chinese character. For example, the stroke order of the Chinese character “ 天 ” (day) is horizontal(一), horizontal(一), left-falling(丿), right-falling(㇏). If 1 stands for across stroke, 2 for left-falling stroke and 3 for right-falling stroke, then the stroke order of “ 天 ” is “1123”.

B. The Stroke Table

There are many kinds of strokes in Chinese characters, among them the most common used basic strokes are: dot, horizontal, vertical, left-falling, right-falling, rising, turning and hook, which are shown in Table1. If the style of calligraphy is the same, then the writing sketches of different Chinese characters are similar, so we can create a stroke table to record the basic strokes of a Chinese character stroke structure. When there is a need to write a Chinese character, the first to do is looking up the strokes in the basic stroke table, and then the mechanical arm will be controlled to move to the desired position and write down the corresponding amplified or lessened strokes.

TABLE I. The commonly used strokes in Chinese Characters

Strokes	Name	Strokes	Name
丶	dot	㇏	right-falling
一	horizontal	㇀	rising
丨	vertical	亅	hook
丿	left-falling	㇕	turning

C. The Position Table

The position table describes the location and the size of each stroke of a Chinese Character. The coordinates of the starting point and the end point of each stroke in a Chinese Character are recorded. Taking the Chinese character “ 天 ” as an example, its location record concludes the starting point coordinates and the end point coordinates of the first horizontal(一), the second horizontal(一), left-falling(丿), right-falling(㇏). The size of a stroke is controlled by the distance between the initial coordinates and the end coordinates. The proportional transform algorithm is introduced in the system. While the distance from the starting point to the end point is increasing, the stroke will getting bolder, otherwise if the distance from the starting point to the end point is decreasing, the stroke will getting thinner.

From the above, the contouring motion track of a Chinese character can be output. Linear interpolation algorithm is also used because the table records only several sampling points of the stroke. The remaining points of the stroke are supplied by applying the interpolation algorithm, which not only reduces the quantity of font data, but also improves the writing accuracy of the mechanical arm.

IV. EXPERIMENT AND RESULTS

The System is divided into three parts: MTL multi-touch LCD screen, FPGA-DE2 and the mechanical arm. The structure of the system is shown as Figure 7.

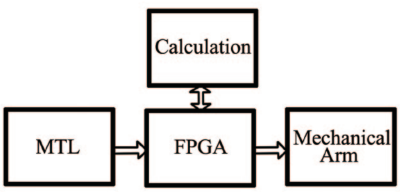


Figure 7. The structure of the system

The external data (Chinese characters) is acquired by multi point touch LCD screen which is specialized for the FPGA application with the full function of the capacitive touch screen supporting for multi-point touch and gesture recognition, then after the calculation of FPGA the mechanical arm will copy the corresponding character.

The system is implemented based on the platform of Altera FPGA-DE2. First of all, the processing ability and the calculation speed of FPGA is superior to that of the ARM, further more with the ability of parallel controlling, the multiple dimension control of the machine arm can be well completed. In addition, the Nios II embedded processor is used as the mechanical arm controller, which is the second generation of on-chip programmable processor with the Harvard structure and 32 bit instruction set. The modular structure makes it become more flexible. Compared with the traditional processors, the number and variety of peripherals could be increased or decreased during the design time while using Nios II system. The designer can use ALTERA development tools such as SOPC Builder to create software and hardware development platform, namely use SOPC Builder to create a CPU soft core and parameterized interface bus Avalon, and quickly integrate hardware system (including a processor, memory, peripheral interface and customized logic circuit) and general software into a single programmable chip. Besides, SOPC Builder also provides standard interfaces, so that the users can attach the peripheral circuit made by themselves to Nios II soft-core, which makes debugging more convenient for our system.

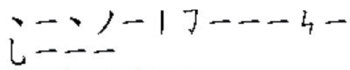
The following is a demonstration of the experiment.

The Chinese character “ 龍 ”(dragon) is used as a demo.

At first, look up the stroke order of “ 龍 ”:

The Chinese character: 龍

Strokes:



The number of strokes: 16

The standard Chinese character is shown as Figure 8.

Figure 8. Chinese calligraphy “ 龍 ”

The copy of the mechanical arm is shown as Figure 9.

Figure 9. The copy of mechanical arm

The similarity between the mechanical arm's copy and the standard calligraphy reaches 83%. The error is acceptable considering the artificial font has a certain degree of distortion, and the accuracy of the servos in the mechanical arm is not so high.

CONCLUSIONS

The principle of the servos and the stepping motors is discussed by applying the mechanical arm to write Chinese calligraphy. The location algorithm and model are introduced about two kinds of multi-dimensional mechanical arm. The screw motor is attached to the end of the mechanical arm which provides fine tuning in the vertical direction, thus greatly improves the mechanical arm's flexibility and initiative. The unique Chinese characters font structure makes the mechanical arm personified writing Chinese characters better. The mechanical arm writing brush calligraphy shows smooth and soft with the aid of the interpolation algorithm.

Multi dimensional location model and algorithm makes the mechanical arm adapt to the actual needs (writing Chinese characters) better. The development efficiency is greatly improved by combining the FPGA hardware structure and the flexible processing ability of Nios II.

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