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Study on the method of automatic measurement of flexible material processing path based on computer vision and wavelet

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ABSTRACT

Straightness, roundness, and primitive angle error of contour are important indicators of evaluating path precision during flexible material path processing. As processing path is composed of small arc or small line segment primitives, also the deformation of the flexible material during the processing path, making the captured image of processing path not clear, the edge of processing image over local uneven gray, the pixels of boundaries between the processing path image edge and background organizations not obvious. In order to extract the flexible material path contour effectively, mosaic method for flexible material processing path image is studied, next fast positioning strategy is introduced, and then we puts forward the search algorithm which taking processing path corner search as the cut-in-point, designing slope angle curve of starting and terminal point of each primitive and conducting slope angle curve for multiple scales wavelet transform by regarding DB(4) as wavelet operator based on wavelet edge modulus maxima extract principle. By judging whether one point of the curve appears at wavelet transform extremum, it can be determined whether the point is a corner one. In order to accelerate wavelet transform computing speed, FPGA IP core is 8-tap transpose is used to design the decomposition and reconfigurable of DB(4). The total time consumed by IP core wavelet decomposition increased only 2.802% compared to the PC computation time; path angle relative error is 8%, and the average measurement time is 198.22 ms.

1. Introduction

Flexible material path processing refers to the procedure of conducting kinds of complicated graphics processing in a workpiece which consists of multilayer soft material and emerging unsmooth stereo pattern on the surface [1,2]. Straightness, roundness and primitive angle error geometrical of processing contour are the important measurement parameters during flexible material path processing; these are also important indicators for evaluating the path processing precision and provide a basis for the processing of feedback compensation control [3]. However, the edge of flexible material processing path pattern is fuzzy and the corners are shaped, which makes the extraction of processing image feature information as the key issue in processing path measurement. At present, there are two main kinds of fuzzy edge detection algorithms: Pal fuzzy edge detection algorithm and multi-resolution image detection algorithm. Pal putted forward the Pal fuzzy edge detection algorithm in which the awaiting image is mapped into fuzzy membership matrix, and maximum and minimum operators are used to extract edge from the viewpoint that the uncertainty of the image is caused by the fuzziness, reference [4] putted forward the extended multi-scale fuzzy edge detection algorithm, making a merger of wavelet multi-scale and fuzzy theory and using competition rules to select the edge points.

In this paper, the processing path image has the following characteristics: as the deformation of flexible material path during the processing, a certain lag about elastic recovery of material will produce before and after processing, gray uneven will appear near the edges of capture image; the processing path is composed by small arc, line segment primitives, intemperance between edge and background is often not obvious. Thinking about the edge blur and diversity of geometry of flexible material processing path image, path detection based on multi-scale and rapid corner positioning are the key to realize path contour accurately measure. As the processing angle error can evaluate the processing effects of right angle, sharp angle and the comprehensive processing effect of line or arc are the composition of the angle. Due to space limitations, this paper focuses on the measurement of the path angle error [5].

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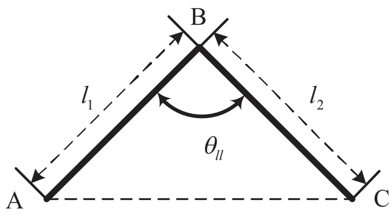

Fig. 1. Straight line–straight line.

2. The mathematical definition of processing path angle and wavelet image analysis

2.1. Geometric definition of processing path angle

Processing path is composed of small arc or small line segment primitives. Figs. 1–3 show straight line–straight line-angle, arc–arc-angle and straight line–arc-angle of processing path element angles. From the figures we can know that the angle between two line segments can be easily obtained. As for the angle between the arc and line segment (or arc), firstly we should calculate the arc tangent and then the angle between the tangent and line segment; therefore, the actual angle can be found through correctly extracting line segment and arc profile of processing path [6].

(1) Straight–straight-angle θ_{ll} in Fig. 1, AB and BC are fitting straight lines of l_1, l_2 which conduct profile extraction, $l_1 : a_1x+b_1y+c_1=0, l_2 : a_2x+b_2y+c_2=0$, θ_{ll} is the angle between the two straight lines, Formula (1) is the mathematical definition of θ_{ll}:

$$\theta_{ll} = \arccos\frac{|a_1a_2+b_1b_2|}{\sqrt{a_1^2+a_1^2}\cdot\sqrt{a_2^2+b_2^2}} \tag{1}$$

(2) Arc–arc-angle θ_{cc} in Fig. 2, arc–arc-angle θ_{cc} is formed by tangents l_1, l_2 of circle O_1, O_2; Formula (2) is the mathematical definition of θ_{cc}:

$$\begin{cases} l_1 : \left(x_0+\dfrac{a_1}{2}\right)x+\left(y_0+\dfrac{b_1}{2}\right)y+\dfrac{c_1}{2}x_0+\dfrac{d_1}{2}y_0+e_1=0 \\ l_2 : \left(x_0+\dfrac{a_2}{2}\right)x+\left(y_0+\dfrac{b_2}{2}\right)y+\dfrac{c_2}{2}x_0+\dfrac{d_2}{2}y_0+e_2=0 \end{cases}$$
$$\Rightarrow \theta_{cc} = \arccos\frac{|x_0^2+y_0^2+(a_1+a_2/2)x_0+(b_1+b_2/2)y_0+(c_1c_2+d_1d_2/4)|}{\sqrt{(x_0+(a_1/2))^2+(y_0+(b_1/2))^2}\cdot\sqrt{(x_0+(c_2/2))^2+(y_0+(c_2/2))^2}} \tag{2}$$

(3) Straight line–arc-angle al − c in Fig. 3, straight line–arc-angle θ_{lc} is formed by line path fitting straight line l_1 and the tangent l_2 of fitting arc R_1 of arc trajectory. The mathematical definition of θ_{lc}:

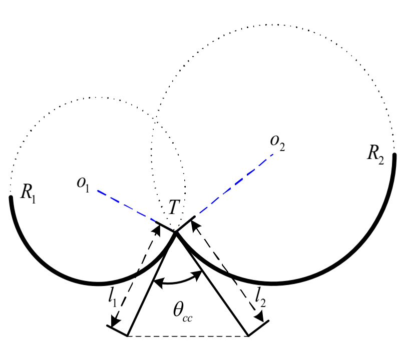

Fig. 2. Arc–arc.

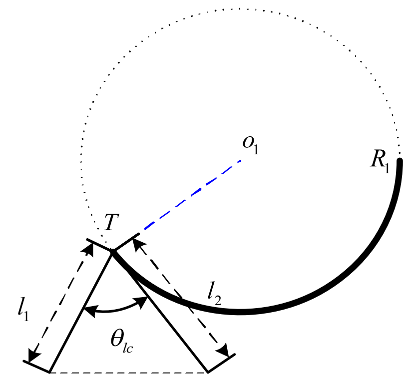

Fig. 3. Straight–arc.

$$\begin{cases} l_1 : a_1x+b_1y+c_1=0 \\ l_2 : \left(x_0+\dfrac{d_1}{2}\right)x+\left(y_0+\dfrac{e_1}{2}\right)y+\dfrac{d_1}{2}x_0+\dfrac{e_1}{2}y_0+f_1=0 \end{cases}$$

$$\theta_{lc} = \arccos\frac{|a_1x_0+b_1y_0+(d_1/2)A_1+(e_1/2)b_1|}{\sqrt{a_1^2+a_1^2}\cdot\sqrt{(x_0+(d_1/2))^2+(y_0+(e_1/2))^2}} \tag{3}$$

2.2. Mathematical definition of wavelet analysis of path image

If the flexible material path processing image is defined as $f(x_1, x_2)$ then $A_1f(x_1, x_2)$ reflects low-frequency components in both the horizontal direction (x_1) and the vertical direction (x_2) after conducting the two-dimensional wavelet transform for processing image, $d_1{}^{(1)}f(x_1, x_2)$ reflects the low-frequency components in direction x_1 and high-frequency components in direction x_2, $d_1{}^{(2)}f(x_1, x_2)$ reflects the high-frequency components in direction x_1 and the low-frequency components in direction x_2, $d_1{}^{(3)}f(x_1, x_2)$ reflects high-frequency in both directions x_1, x_2 [7]. L represents the low-pass filter having the impulse response, while H represents the high-pass filter having the impulse response; according to Mallat algorithm, wavelet decomposition or reconstruction of the flexible material path processing image $f(x_1, x_2)$ consists of several levels of high-pass filter H and low-pass filter L. H (Fig. 4), L can be built by using FIR filter, as shown in Fig. 5, when the filter coefficients are known [8–10].

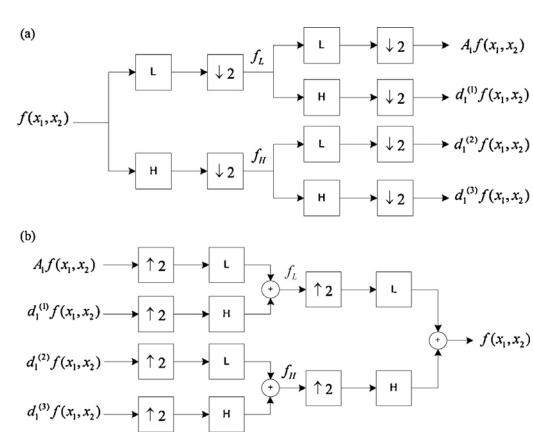

Fig. 4. Decomposition and reconstruction of $f(x_1, x_2)$.