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A new active contour modeling method for processing-path extraction of flexible material

Yaohua Deng[a,b], Xiali Liu[a,*], Zhihang Zheng[a], Qiaofen Zhang[a,c], Liming Wu[a]

[a] Guangdong University of Technology, Guangzhou 510006, China
[b] Department of Mechanical Engineering, University of Michigan, Ann Arbor, MI 48109, USA
[c] Foshan Shike Intelligent Technology Co., Ltd., Foshan, China

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ABSTRACT

Due to properties of flexible material, uneven thickness, cutting speed, rapid changing feed direction and other factors in path processing of flexible material, the edge of processing path image become fuzzy, causing difficulty of improving edge detection precision. In this paper, after analyzing characteristics path contour of flexible material, taking gray-level integration of target area as a regional energy, and adding it to traditional Snake model which is widely used in edge extracting of complex geometric shapes, combining image edge with region information to build a new Region Snake (R-S) model, therefore by certain transformation, the description of total energy of contour can be replaced by force acting that moving on the contour. In new R-S model, matrix expression of discrete force balance equation of contour is obtained by discretization of finite difference method, then derivative terms are introduced and to get the calculation formula of processing path contour curve through Euler iteration method; finally by judging local extremum of covariance matrix of curve to realize corner detection. Three patterns with different shape characteristics were used to test the R-S model, Experimental results show that, the target contour curves of three patterns are completely extracted, the mean square errors of extracted curves are less than 0.35%, the detection rates of corners are greater than 90%, these prove that the R-S model proposed for flexible materials processing path contour extraction has high calculation accuracy and good stability, the method of corner detection is very suitable for flexible material processing path contour.

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 rendering uneven stereo pattern on the surface. Processing path angles, including straight–straight-angle, line–arc angle, and arc–arc-angle are the main form of flexible material processing path shape features [1]. However, due to the flexible material path processing is influenced by soft material, uneven thickness, cutting speed, rapid changing feed direction and other factors, the edge of the processing path pattern is fuzzy and the corner shape is different, thus corner feature information extraction of processing path image has become the focus and difficulty of processing trajectory visual measurement method of flexible parts [2].

Ten years ago, Pal and King has carried out complex shapes fuzzy edge extraction studies, they introduced fuzzy theory to edge detection and got a better edge detection, because of the ambiguity of image edge gradient [3,4]. Subsequently, the fuzzy image edge extraction has become a hot topic, the most representative is research of contour edge extraction of various geometric shapes based on Snake Model [5]. For example, Jang [6] studied lip contour extraction by the method of using the internal energy of Snake model to minimize the displacement deviation between neighborhood points, and using the external energy to prevent sudden bending contour. Kabolizade [7] studied color aerial image light detection and ranging data method based on Snake model for contour extraction for aerial buildings. Vard [8] studied Snake model based on self-correlation energy function to detect small objects under complex background.

Combined with the previous research [1,9] on flexible material processing trajectory measurement method, flexible materials processing trajectory angle area generally have long narrow depression area and high noise because of the characteristics of

* Corresponding author. Tel.: +86 15602231158.
E-mail address: liuxiali0128@foxmail.com (X. Liu).

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the processing. Using existing Snake model cannot get the correct contour and the corner information of the contour. In this paper, we propose a new active contour model (Region Snake, R-S) combing edge and region information for path contour extraction. And on the basis of this, we study the method of contour corner judgement by covariance matrix.

2. Mathematical model of active contour R-S extraction for flexible material processing path

The basic idea of Snake model is to transform the target contour extraction problem into finding a closed curve with minimal energy functional in the image under certain conditions. Taking gray-level integration of the target area as a regional energy, and adding it to the traditional Snake model to build a new Region Snake (R-S) mode, then target region information of image will be transformed into regional force by transform operator, and regional information will be introduced into the active contour extraction model by force balance equation, thus constructing active contour model (R-S) with the edge and region information.

If the size of two-dimensional image is $a \times b$, using x, y to represent coordinates of trajectory of flexible materials processing image, $I(x, y)$ represents trajectory image of flexible materials processing, s represents normalized arc of contour curve. As shown in Fig. 1, the solid red line R (the target area of the actual machining path) is the area surrounding by $v(s)$ on $I(x, y)$, then image containing area R:

$$I_R(x,y)=\begin{cases} I(x,y), & (x,y)\in R \\ 0, & (x,y)\notin R \end{cases},$$

$$v(s)=(x(s),\ y(s)),\quad s\in[0,1].$$

If area R is on the left side of $v(s)$ when moving along contour curve $v(s)$, the direction of contour curve is positive. When $v(s)$ located outside area R, contour curve will be led by regional force F_{reg} to contract inwardly to the boundary of target area.

And Δx, Δy are used to represent the variation between node (x, y) and former one on curve $v(s)$ along x and y directions. Introducing sign function sgn, define image transformation operator $H(I_R(x, y))$:

$$H(I_R(x,y))=\begin{cases} -sgn(\Delta x)I_R(b-x,y), & sgn(\Delta y)<0 \\ -sgn(\Delta y)I_R(x,a-y), & sgn(\Delta x)\geq 0 \\ sgn(\Delta x)I_R(x,y), & sgn(\Delta y)\geq 0 \\ sgn(\Delta y)I_R(x,y), & sgn(\Delta x)<0 \end{cases} \tag{1}$$

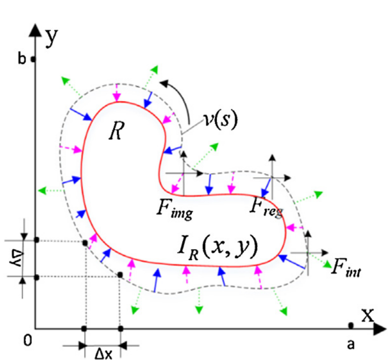

Fig. 1. Flexible material processing path contour curve energy diagram.

The image transformation operator H determines converge speed and direction of contour curve $v(s)$. When initial contour curve located outside the region, operator H generated guiding force toward inside contour curve, guiding contour curve to contract inwardly to boundary of target area. When initial contour curve located within the region, operator H generated guiding force toward outside contour curve, guiding contour curve to expand outwardly to boundary of target area.

If using E_{int}, E_{img}, E_{reg}, k_3 and k_4 to respectively represent internal energy of $v(s)$, image potential energy of $I_R(x, y)$, region energy of $I_R(x, y)$ and corresponding weights, so the total energy of contour curve is initially defined:

$$E_{snake}=\int_0^1 \left[E_{int}(v(s))+k_3E_{img}(v(s))\right] ds + k_4E_{reg} \tag{2}$$

where $E_{int}=1/2\left[k_1\left|\partial v(s)/\partial s\right|^2+k_2\left|\partial^2 v(s)/\partial s^2\right|^2\right]$, $E_{img}=-\left|\nabla(G_\sigma * I)\right|^2$, $E_{reg}=\iint_R H(I_R(x,\ y))dxdy$, ∇ represents gradient operation, G_σ represents Gaussian function with standard deviation σ, $*$ represents convolution operation.

And according to Green formula $\iint_D \left(\left(\partial Q/\partial x\right)-\left(\partial P/\partial y\right)\right) dxdy=\oint_L Pdx+Qdy$, which transforming double integral on plane area D into curve integral on boundary curve L. The regional integral of regional energy E_{reg} can be transformed into a curve integral, namely using $\hat{N}_R(x,y)=-\int_0^y H(I_R(x,t))dt$ to represent component on x-axis direction, $\hat{M}_R(x,y)=\int_0^x H(I_R(t,y))dt$ to represent component on y-axis direction. Then:

$$\begin{cases} P=\dfrac{1}{2}\hat{N}_R(x,y),\ Q=\dfrac{1}{2}\hat{M}_R(x,y)\Rightarrow\dfrac{\partial P}{\partial y}=-\dfrac{1}{2}H(I_R(x,y)), \\ \dfrac{\partial Q}{\partial x}=\dfrac{1}{2}H(I_R(x,y)) \\ E_{reg}=\iint_R H(I_R(x,y))dxdy\Rightarrow E_{reg} \\ \quad=\iint_R\left(\dfrac{1}{2}H(I_R(x,y))-\left(-\dfrac{1}{2}H(I_R(x,y))\right)\right)dxdy\Rightarrow \\ E_{reg}=\iint_R\left(\dfrac{\partial Q}{\partial x}-\dfrac{\partial P}{\partial y}\right)dxdy=\dfrac{1}{2}\oint \hat{N}_R(x,y)dx+\hat{M}_R(x,y)dy \end{cases}$$

Thus the total energy is further expressed as

$$E'_{snake}=\int_0^1\left[\frac{1}{2}\left(k_1\left|\frac{\partial v(s)}{\partial s}\right|^2+k_2\left|\frac{\partial^2 v(s)}{\partial s^2}\right|^2\right)(v(s))+k_3E_{img}(v(s))\right]ds + \frac{1}{2}k_4\oint \hat{N}_R(x,y)dx+\hat{M}_R(x,y)dy \tag{3}$$

We can see that formula (3) transforms total energy of contour to problems force working on contour motion. According to the basic idea of Snake model, contour extraction problem can be transformed into energy functional E'_{snake} minimum problem, namely achieve contour extraction by solving Euler equation of functional E'_{snake} [10]. In the literature [11]: Euler equation for functional $Q[y(x)]=\int_a^b F\left(x,y,y',\ldots,y^{(n)}\right)dx$ containing higher derivative of self-variable function is expressed as $F_y-\left(d/dx\right)\left(F_{y'}\right)+$