Frontiers in Computing and Intelligent Systems
ISSN: 2832-6024 | Vol. 7, No. 2, 2024

Research of ESPI Stripe Skeleton Line Extraction Based on Improved Fast Parallel Algorithm

Yuancheng Zheng, Hongwei Ren *

School of Electrical Engineering, University of Jinan, Jinan, Shandong, China
*** Corresponding author:** Hongwei Ren (Email: 2301851314@qq.com)

Abstract: Stripe skeleton line method is one of the commonly used methods to extract the phase information of ESPI stripe maps, and the accuracy of the skeleton line extraction determines the accuracy of the stripe map phase information. In this paper, a fast parallel refinement algorithm for ESPI streak image is proposed for the commonly used ZS and OPTA fast parallel refinement algorithms, which improves the deletion template and retention template. It is experimentally verified that the algorithm can effectively reduce the burr bifurcation and fracture phenomenon of the refined image in ESPI skeleton line extraction, which has good practical value.

Keywords: ESPI; Skeleton Line Extraction; Refinement Algorithm.

1. Introduction

Electronic scattering interference (ESPI) is a modern optical measurement technology combining laser technology, image processing technology, scattering interference technology, etc. It has the characteristics of full-field, non-contact, high precision, etc., and is widely used in the deformation and displacement measurement of optical rough surfaces, and also attracts much attention in non-destructive testing, and its application fields are widening day by day[1]. The displacement or deformation of an object can be obtained by obtaining the phase information of the ESPI streak map. When applying this technique[2], the accurate extraction of phase is of great significance for the measurement of displacement, strain and vibration of the object.

The refinement of ESPI image plays an important role in the extraction of stripe information based on the stripe center method, and also plays a key role in the accurate interpretation of the electron scattering interference fringe pattern[3]. Therefore, improving the accuracy of electron scattering interference streak map refinement has been one of the research focuses.

The traditional refinement algorithms mainly include mathematical morphology refinement[4], ZS refinement[5], OPTA refinement[6] and Hilditch refinement[7], which are applied in many fields, among which the classical Hilditch refinement adopts serial processing, which is suitable for various shapes of electron scattering interference fringe maps, and is widely used, with the disadvantage of the presence of more burrs and breaks.

In summary, in order to improve the skeleton line extraction accuracy of ESPI streak map, an improved fast parallel refinement algorithm is proposed. The method first performs preprocessing operations such as filtering and binarization[8] on the image, and then refines the streak map through the improved retention template and deletion template. It can effectively reduce the burr and breakage phenomena existing in skeleton line extraction and improve the accuracy of skeleton lines.

2. ESPI Streak Map Preprocessing

In reality, the extracted ESPI stripline always inevitably exists various noises, which will disturb the accuracy of the stripline phase information extraction. Early commonly used denoising methods include median filtering[9] and mean filtering[10], etc. However, these filters tend to make the key information of the stripes while filtering out the noise, resulting in unsatisfactory skeleton line extraction. In this paper, the wavelet threshold denoising algorithm is adopted to reduce the noise of the stripe map[11], which can filter out the noise of the stripe map better. After the filtering process, the stripe map is binarized to get the ESPI stripe map binary image, which is ready for the subsequent skeleton line refinement process.

3. Classical Refinement Algorithm

There are two more classical algorithms for fast parallel class refinement algorithms, which are ZS fast parallel algorithm and OPTA fast parallel algorithm. Among them, the ZS fast parallel algorithm is based on two-step iteration, respectively, to judge all target points simultaneously; while the OPTA fast parallel algorithm uses one-step iteration to process all target points simultaneously by removing and retaining templates.

3.1. The ZS Refinement Algorithm

P_9	P_2	P_3
P_8	P_1	P_4
P_7	P_6	P_5

Fig 1. 8-neighborhood relationship of target point P_1

ZS refinement algorithm is a fast parallel refinement algorithm proposed by T.Y Zhang and C.Y Suen, whose basic idea is to first traverse to judge the 8-neighborhood around the target pixel point, then mark the target pixel point to be deleted by judging the logical operation conditions in two steps, and finally delete all marked points to be deleted at the same time [12]. It is assumed that the 8-neighborhood relationship of its target pixel is shown in Fig. 1.

The logical operation judgment condition of ZS refinement algorithm is the following two steps.

Step 1: Mark P1 as a pixel point to be deleted when the 8-neighborhood of the target pixel point P_1 satisfies the following conditions at the same time.

(1) $2 \leq N(P_1) \leq 6$
(2) $S(P_1)=1$
(3) $P_2P_4P_6=0$
(4) $P_2P_6P_8=0$

Where $N(P_1)$ denotes the number of non-zero pixel points; and $S(P_1)$ denotes the number of times the pixel value changes from 0 to 1 along the P_2P_3.... . the number of times the pixel value changes from 0 to 1 in the P_9 direction.

Step 2: When the 8-neighborhood of the target pixel point P1 satisfies the following conditions at the same time, then P1 is marked as the pixel point to be deleted. Among them, the first two conditions remain unchanged and only the last two conditions change.

(1) $2 \leq N(P_1) \leq 6$
(2) $S(P_1)=1$
(3) $P_2P_4P_8=0$
(4) $P_2P_6P_8=0$

The above two steps can be viewed as an iterative process, where all labeled pixel points to be deleted are deleted at the same time at the end of this iterative sequence. Then traverse all the pixel points of the target image and keep performing the above iterative computation until there are no pixel points in the target image that can be deleted.

The biggest advantage of the ZS refinement algorithm is the fast refinement speed and better topology preservation for inflection and intersection points, but the disadvantage is that in the refinement process, phenomena such as skeleton line burrs and bifurcation may remain.

3.2. OPTA Refinement Algorithm

Chin et al. proposed a parallel OPTA algorithm based on template matching, which firstly sets up eight deletion templates as well as two retention templates[13], as shown in Figs. 2 and 3, where x denotes either "0" or "1", "0" denotes background pixels, "1" denotes foreground pixels, and "1" denotes foreground pixels. The "0" denotes the background pixel and the "1" denotes the foreground pixel. The deletion template is used to delete the boundary pixels and the retention template is used to retain the points with special structure. Then the target pixel point P_0 and its nearby 10 neighboring pixels are selected as the neighborhood of P_0, as shown in Fig. 4, for each target point to determine whether its above neighborhood meets the two templates, first determine whether it meets the deletion template, if it does, then determine whether it meets the retention template, if it meets it, then the point is retained, otherwise it is deleted.

0	0	0
1	1	1
x	1	x

(a)

x	1	x
1	1	1
0	0	0

(b)

0	1	x
0	1	1
0	1	x

(c)

x	1	0
1	1	0
x	1	0

(d)

0	0	x
0	1	1
x	1	x

(a)

x	0	0
1	1	0
x	1	x

(b)

x	1	x
0	1	1
0	0	x

(c)

x	1	x
1	1	0
x	0	0

(d)

Fig 2. Deleting a template

x	x	x	x
0	1	1	0
x	x	x	x

x	0	x
x	1	x
x	1	x
x	0	x

Fig 3. Reservation template

P_1	P_2	P_3	
P_4	P_0	P_4	P_{10}
P_6	P_7	P_8	
	P_9		

Fig 4. Neighborhood extracted by OPTA algorithm

OPTA algorithm can refine the image and can retain the basic topology of the image, but due to the template setting is not reasonable enough, the refined image appears to be distorted large, broken, not smooth enough, which will bring great difficulties to the subsequent phase information extraction.

4. A Study of Fast Parallel Algorithms with Improved Combinatorial Templates

In this paper, further study of the OPTA series of algorithms reveals that the incomplete refinement is related to the retention of the templates, the skeleton is not smooth after refinement, there are many burrs, and the bad connectivity is related to the deletion of the templates, and although there are many combination templates in this series of algorithms, they do not generalize to all cases. The skeleton appears uneven in the combined template when the target point is deleted, which leads to small burrs during the iteration process. Therefore, this paper proposes new refinement algorithms to improve the deletion and templates, and constructs new retention templates using the automatic retention template generation algorithm. The new algorithm deletion template is shown in Fig 5. The new algorithmic retention template is shown in Fig 6.

x	1	0
0	P_0	0
0	0	x

(a)

x	0	0
1	P_0	0
0	1	x

(b)

x	1	x
0	P_0	1
0	0	0

(c)

x	1	0
0	P_0	0
0	0	1

(d)

Fig 5. Deletion template for the improved algorithm

Combining the de-redundancy template and retention template, the steps of the proposed improved refinement algorithm are generally described as follows:

Step 1: Traverse the target image, if pixel P0 satisfies the two steps of the ZS refinement algorithm, mark it as a deletable mark, and delete the pixel when it is finished;

Step 2: Judge the deletion mark, if there is a deletable mark, go to step 1, if not, jump to the next step;

Step 3: Traverse the image again to find the suspicious pixel point P0, whether it matches the 8 neighbors in the deletion template to match each other, if there is a match, mark it as a suspicious pixel and enter the suspicious pixel collection library;

0	0	0	0
0	P_0	0	1
0	x	1	0

(a)

0	0	1	1
0	1	P_0	0
1	0	0	0

(b)

0	0	1	0
0	P_0	0	1
0	1	1	0

(c)

0	1	1	x
0	P_0	x	1
0	0	1	0

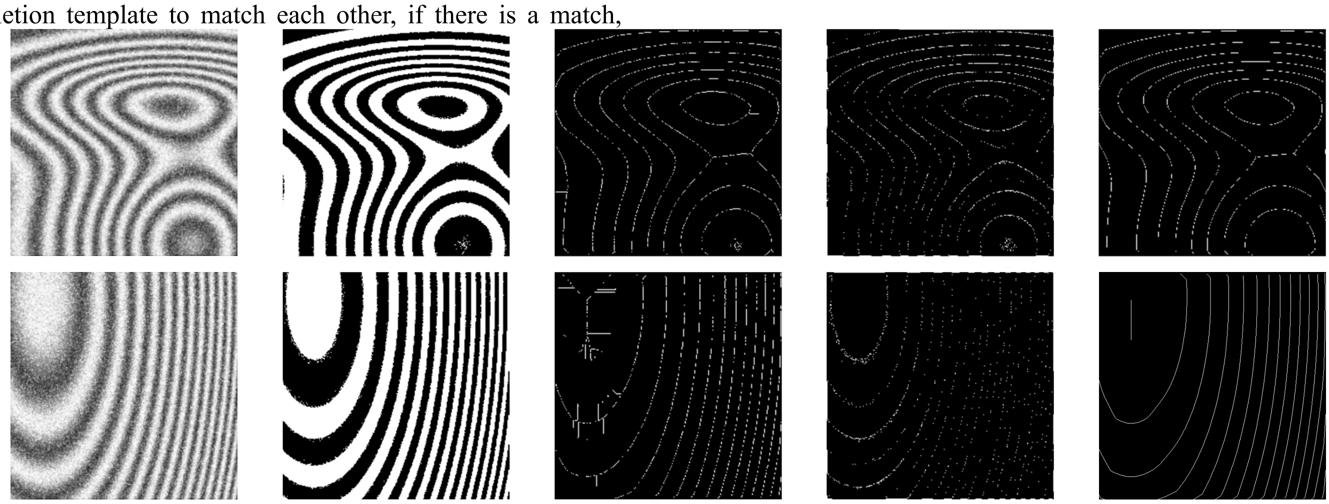
(d)

Fig 6. Retention template for the improved algorithm

Step 4: Further judge the marked suspicious pixel point P_0 in the suspicious pixel library, if the 11-neighborhood of the pixel P0 matches any one of the templates in the retention template pixels proposed above, the pixel point will be retained; otherwise, this pixel point is deleted. Until the judgment is finished, the whole refinement process is finished.

5. Experimental Results and Analysis

In this paper, two simulated ESPI images are used as experimental objects, and their binary images are obtained after filtering and binarization. ZS refinement, OPTA refinement and the improved fast parallel algorithm of this paper are applied to the binary images for refinement respectively, and the results are shown in Fig. 7.



(a) Original image (b) Binary image (c)ZS results (d) OPTA results (e) This paper

Fig 7. ESPI streak map skeleton line extraction results

After analyzing the experimental results, it can be seen that the skeleton lines obtained by the ZS refinement method have serious bifurcation and burr phenomena, and are not extracted accurately; the continuity of the streak skeleton lines extracted based on the OPTA refinement algorithm is very poor, and there are a lot of breaks; and the improved fast parallel algorithm proposed in this paper achieves very good results, reduces the burr and the phenomenon of skeleton line breaks, and has a strong superiority in extracting skeleton lines from high-noise and high-density streak maps. lines with strong superiority.

6. Summary

The skeleton line extraction of electron scattering interference fringe map is one of the most direct methods to obtain phase information. In this paper, on the basis of analyzing the ZS refinement and OPTA refinement algorithms, further considering the characteristics of the electron scattering interference streak map, an improved fast parallel algorithm is proposed, and the skeleton line is extracted by the method proposed in this paper for the ESPI streak map which contains a large amount of noise and a high density, and the extracted result is compared with the other methods, which shows that the skeleton line extracted by this paper's method has the characteristics of fewer streak breaks, The results show that the skeleton line extracted by this method has fewer stripe breaks, less burr bifurcation, and stronger noise resistance, and good results are achieved.

References

[1] Yang Lianxiang, Xie Xin, Zhu Lianqing, Wu Sijin, et al. Review of electronic speckle pattern interferometry (ESPI) for three dimensional displacement measurement. Chinese Journal of Mechanical Engineering, 2014, 27(1): 1-13.

[2] Yang Xia, Yu Qifeng, Fu Sihua. Determination of skeleton and sign map for phase obtaining from a single ESPI image. Optics communications, 2009, 282(12): 2301-2306.

[3] Cai Yuanxue, Ming Chengguo, Qin Yueting. Skeleton extraction based on the topology and Snakes model. Results in Physics, 2017, 7: 373-378.

[4] Niu Weilong, Chen Zan, Zhu Yihui, Sun Xiaoguang, Li Xuan. Track line recognition based on morphological thinning algorithm. Applied Sciences, 2022, 12(22): 11320.

[5] Ma Jun, Ren Xunhuan, Tsviatkou Viktar Yurevich, Kanapelka Valery Kanstantinavich. A novel fully parallel skeletonization algorithm. Pattern Analysis and Applications, 2022, 25(1): 169-188.

[6] Wang Ruizheng, Zhao Yiru, Ji Tianhao, Liu Liping. Fingerprint refinement model based on improved OPTA. Journal of Computers, 2020, 31(6): 274-283.

[7] Mariya Nazarkevych, Serhii Dmytruk, Volodymyr Hrytsyk, Olha Vozna, et al. Evaluation of the effectiveness of different image skeletonization methods in biometric security systems. International Journal of Sensors Wireless Communications and Control, 2021, 11(5): 542-552.

[8] Chen Lei, Tang Chen, Xu Min, Lei Zhenkun. Binarization for low-quality ESPI fringe patterns based on preprocessing and clustering. Applied Optics, 2021, 60(31): 9866-9874.

[9] Sagheer, Mohd Sameera V., George Sudhish N. A review on medical image denoising algorithms. Biomedical Signal Processing and Control, 2020, 61: 102036.

[10] Goyal Bhawna, Sun Guoxing, Li Yong, Li Weiqing, Su Zhiyong. Image denoising review: from classical to state-of-the-art approaches. Information fusion, 2020, 55: 220-244.

[11] Isabona Joseph, Agbotiname Lucky Imoize, Stephen Ojo. Image denoising based on enhanced wavelet global thresholding using intelligent signal processing algorithm. International Journal of Image, Graphics and Signal Processing, 2023, 15(5): 1-16.

[12] Shit Saifullahi Sadi, Bakar Syed Abd Rahman Syed Abu, Tahir Nura Musa, Bature Usman Isyaku, Liman Haliru. Efficient thinning algorithm for malaysian car plate character recognition. ELEKTRIKA-Journal of Electrical Engineering, 2021, 20(3): 15-25.

[13] Yuepeiyan, Qiu. Parallel algorithms for skeletonization of binary images. Diss. БГУИР, 2023.