









Fig.5 Process of removing useless strokes

## V. Experiments

To evaluate the proposed strategy for getting more precise results of segmentation, we have carried out experiments with NJUST603HW database. The database contains 623 binary images of handwritten courtesy amount string which are taken from the bank checks currently used in China. From all the images we extract 3783 sub-string images of isolated digits and 1591 sub-string images of touching digits which includes 911 images with single-point touching, 412 images with single-segment touching and 268 images with multiple-touching.

The performance of the classification scheme is run with 5374 total sub-string images and the result is shown in TABLE I. The developed scheme has 98.29% accuracy for classifying touching digits patterns.

The pattern-oriented segmentation and removing stroke performance is conducted on 1557 connected digits which touching patterns have been classified correctly and the result is listed in TABLE II. With the manual verification of the segmentation, 96.66% of digits were successively segmented.

TABLE I Result of Our Classification Scheme

	# Images	# Accuracy	Accuracy (%)
Isolated digits	3783	3725	98.47
Touching digits	1591	1557	97.86
Total	5374	5282	98.29

TABLE II Result of Pattern-Oriented Strategy for Segmentation

Touching pattern	# Touching digits	Segmentation accuracy (%)
Single point touching	891	97.08
Single segment touching	406	96.31
Multiple touching	260	95.78
Total	1557	96.66

TABLE III Result of our pattern-oriented segmentation

# Touching digits	Algorithm	Segmentation accuracy (%)	Recognition accuracy (%)
1591	DD	92.28	86.43
	FA	93.37	86.77
	DF	89.94	81.65
	Ours	95.60	88.18

Besides, TABLE III gives the performance comparison between ours and several successive algorithms described in other literatures: traditional Drop-fall algorithm (DF) [6], algorithm of distance difference from upper contour to lower contour (DD) [7] and foreground analysis algorithm (FA) [8]. By using our strategy 95.6% of touching digits were correctly segmented exceeding the other algorithms, and recognition accuracy is increased consequently. From Table 3, we can see that our algorithm works better than others.

## VI. Conclusion

In the strategy background region of touching digits is analyzed in order to identify the touching pattern. After separating touching digits, useless stroke is removed according to the touching pattern to get more precise results. The advantage of this strategy is the segmentation procedure can be implemented conveniently.

## VII. Acknowledgment

This paper was supported by Computer and Software Institute, Nanjing University of Information Science & Technology Foundation 20100340.

## References

- [1] Bul O., Polat F. and Alhaji R., "Multi-Agent Reinforcement Learning Using Function Approximation," IEEE-SMC,2000,Vol.30, No.4, pp.485-497.
- [2] K.K. Kim, J.H. Kim, and C.Y. Suen, "Segmentation-Based Recognition of Handwritten Touching Pairs of Digits Using Structural Features," Pattern Recognition Letters, 2002, Vol. 23, pp.13-24.
- [3] Chen Y.K., Wang J.F., "Segmentation of single- or multiple-touching handwritten numeral string using background and foreground analysis," IEEE Transaction on Pattern Analysis and Machine Intelligence, 2000, pp.1304-1317.
- [4] F. Kimura and M. Shridhar, "Segmentation-recognition algorithm for zip code field recognition," Mach. Vision Appl, Vol.5,No.3, pp.199-210, 1992.
- [5] U. Pal, A. Belaid, and Ch. Choisy, "Touching Numeral Segmentation Using Water Reservoir Concept," Pattern Recognition Letters, 2003,Vol. 24, pp. 261-272.
- [6] Congedo G., Dimauro G., and Impedovo S., "Segmentation of numeric strings," Proceeding of the Third International Conference on Document Analysis and Recognition, 14-16 Aug 1995, pp.1038-1041.
- [7] Fujisawa H, Nakano Y, and Kurino K, "Segmentation methods for character recognition: from segmentation to document structure analysis," Proceedings of the IEEE, 1992, Vol.80, No. 7, pp.1079-1092
- [8] Oliveira L S, "A new approach to segment handwritten digits," Seventh International Workshop on Frontiers in Handwritten Recognition (IWFHR-7), 2000,pp.578-582.