AN IMPROVED THINNING ALGORITHM FOR FINGERPRINT RECOGNITION

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Abstract: Thinning is the important steps in pre-processing phase of fingerprint recognition. It explains the visual quality of skeleton with 1-pixel unit width. This paper presents the implementation work of famous thinning algorithms and enhances the Zhang-Suen algorithm in the facet of removal of pixel criteria for preserving the connectivity of pattern, remove noisy points, and for sensitivity of the binary image. The performances of the implemented algorithms are evaluated using Mean Square Error, Peak Signal Noise Ratio, and computational time measurement standard. The implementation is done on fingerprint databases FVC2000 and FingerDos using java platform.

Keywords: Fingerprint image thinning, Hilditch, Zhang-Suen, MSE, PSNR.

1. INTRODUCTION

Thinning process is useful for decreasing an object of the image for collecting the most useful information which is useful for further analysis and recognition process [1]. It is applied on binarized image and produces another binarized image as an output image [2-3] or it is called as skeleton. Thinning process used in many applications like OCR, document image analysis, fingerprint identification, biometric authentication using images of retina, signature authentication and so on [4].

The thinning process gives some benefits like:

- It decreases the width size of the ridge pattern up to a single pixel.
- Produces a thin line image of fingerprint image [5].
- Maintain connectivity between the pixels of an object [6].
- The computer can process the data faster and reduce the processing time.
- It reduces the usage of the memory because it generates only essential information and the size of the image becomes smaller [7-8].
- The thinned image can be used for the classification process of fingerprint recognition [9]
- The skeleton image contains information such as end points, bifurcation and connection points.
- It reduces undesirable features and undesirable noise.

Thinning is the main process for fingerprint recognition [10] because post-processing steps like minutiae extraction and core point detection is depended on thinning process. The binarized images are not used for extracting the minutiae because the ridges are wide in it. For that make the all ridges of the image thick up to 1 pixel. To find out the global and local features of the fingerprint image which are useful in classification, recognition and in matching [11, 41-43] process is become very easy from thinned image because it does not change the structure of ridge and valley.

2. RELATED WORK

Based on the literature review thinning algorithms either directly work on grayscale image without binarization [12-16] or maximum algorithms required binary image as an input images [8,17-25]. Three types of algorithm are worked for binary images: 1) sequential algorithms, 2) parallel algorithms, and 3) medial axis transform algorithms [8]. Sequential and parallel algorithms are iterative thinning algorithms while medial axis algorithms are non-iterative thinning algorithms.

The iterative thinning algorithms inspect each single pixel in binary image and remove the boundary pixel of the image unit pixel-width thinned image remains while in non-iterative thinning algorithm do not examine single pixels one by one, instead of that they produce some centerline of the pattern and then take a decision whether to remove that particular boundary pixel or not [26-27].

The non-iterative algorithms are efficient in computation time but are responsible for creating noisy skeleton while in iterative thinning algorithm the parallel thinning algorithms are frequently discussed because they are fast and efficient. The Zhang-Suen et al [28], Guo-Hall et al [29], Abdulla et al [30], R. W. Hall et al [31], etc. are the famous algorithm of thinning. The [32] implemented and compare this all four algorithms and prove that Zhang-suen’s algorithm gives the minimum computational time, while Guo-Hall’s algorithm constructs the best qualitative skeleton. In that paper proposed effective, faster and better preserves structure outcome on thinning using modified Zhang-Suen’s algorithm.
In [33] Guo Z et. al., and Zhang T.Y et. al., are implemented and prove that Zhang-Suen algorithm give the better result. In [34] proposed Hilditch algorithm to acquire more suitable skeletons obtained and give better results in Chinese characters and numbers as well as [35] and [36] implemented Hilditch algorithm for fingerprint images. The following sections discuss the famous iterative parallel thinning algorithms; Hilditch’s algorithm [37], Zhang-Suen’s algorithm [28] and proposed enhanced Zhang-Suen’s algorithm.

3. IMPLEMENTED WORK

First, implement Hilditch’s Algorithm [37]. It follow the below steps.
Hilditch's algorithm 3x3 windows is used. It involves performing various passes on the pattern. On every pass, it check the below four conditions if it satisfied then it change the pixel value from black to white.

- \[2 \leq N(p_1) \leq 6\]
- \[M(p_1)=1\]
- \[p_2 \cdot p_4 \cdot p_8 = 0 \text{ or } M(p_2)\neq 1\]
- \[p_2 \cdot p_4 \cdot p_6 = 0 \text{ or } M(p_4)\neq 1\]

Stop when nothing changes (no more pixels can be removed)

Here \(N(p_1)\) is number of non-zero neighbors of \(p_1\) and \(M(p_1)\) is number of 0,1 patterns in the sequence \(p_2 \cdot p_4 \cdot p_5 \cdot p_6 \cdot p_7 \cdot p_8 \cdot p_9 \cdot p_2\).

Then after implement Zhang-Suen algorithm [28]. This algorithm used 3X3 matrix as mask for binary image move down an entire image and go through the all pixels of the image. The below Fig. 1 show the 3X3 matrix.

![Fig. 1: 3*3 matrix](image)

This technique eliminates entire contour points of the image excluding those which reside to the skeleton [28]. The difficulty in maintaining the image connectivity with 3x3 operator is restricted in fully parallel thinning algorithms [29]. Up to the image is not reach at stable, and for maintaining the image connectivity many parallel algorithms divide the iteration in two sub iteration [28-31]. It follow the below steps.

- Here \(M(P_1)\) is the number of 0 to 1 transitions from \(P_2\) to \(P_9\) in a clockwise direction
- \(N(P_1)\) is the number of non-zero neighbors of \(P_1\) that is \(N(P_1) = P_2 + P_3 + P_4 + \ldots + P_8 + P_9\).
- Do until image is in steady state
- In the first sub-iteration, the contour point \(P_1\) is deleted from the digital pattern if it satisfies the following conditions:
  - \[2 \leq N(P_1) \leq 6\] or \(M(P_1)\) = 1 or \(P_2 \cdot P_4 \cdot P_6 = 0\) or \(P_4 \cdot P_6 \cdot P_8 = 0\)
  - In the second sub-iteration, the contour point \(P_1\) is deleted from the digital pattern if it satisfies the following conditions:
  - \[2 \leq N(P_1) \leq 6\] or \(M(P_1)\) = 1 or \(P_2 \cdot P_4 \cdot P_8 = 1\) or \(P_2 \cdot P_6 \cdot P_8 = 1\)

See in Appendix-I, that some new noisy points are created after implementing Zhang-Suen’s thinning algorithm. To remove this noisy point followed fix ridge algorithm after thinning process. This algorithm checks the each pixel of thinned image using 3X3 matrix like following Fig. 2.

![Fig. 2: 3*3 matrix implementation of fix ridge algorithm](image)

See in below e.g. If \(p\) is foreground and all its neighbors are background, then remove \(p\). If \(p\) is background and check its four neighbors, if there are more than 3 neighbors is foreground and then mark \(p\) is foreground.

The fix ridge operation applied two times for deleting the most of noisy point.

4. PERFORMANCE METRICS

There are three measurement standard are used to compare the performance of implemented algorithm.

1) PSNR and MSE value
2) Execution Time
3) Quality of an Image

1) PSNR and MSE value [38]

PSNR: PSNR is defined as peak signal-to-noise ratio between two images using following equation (6). The quality is measured among original and recreated image using it. The quality of recreated images is given by high PSNR and with low MSE value. MSE: MSE is defined as Mean square error which estimates the alteration among the original image and the thinned image. For example: Suppose two images are undistinguishable in all aspect then MSE among them is measuredas zero. First calculate the MSE value for calculating the PSNR value by using the below equation (5):

\[
MSE(x, y) = \frac{1}{N} \sum_{i=1}^{N} (x_i - y_i)^2
\]

Where, \(N\) is the total number of pixels in the input image.

The PSNR is computed using below equation:

\[
PSNR = 10 \log_{10} \frac{L^2}{MSE}
\]

Where, \(L\) is the number of discrete gray level.
2) Execution Time
The execution time is used to count the complete time for the whole process. The calculation is considered as the time between the first line and last line of code.

3) Quality of an image
The standard quality of an image is used to measure the spurious branches, noise, and thickness of an image.

5. EXPERIMENTAL RESULTS AND ANALYSIS
The implementation of thinning algorithms are done using java language and for the experiments the databases FVC 2000 DB1, DB2, DB3, DB4 released on the web [39], and FingerDOS database [40] are used. The details of the databases are given in below Table 1 and Table 2.

| Table 1. FVC2000 Database[39] |
|-----------------------------|
| **Set B** | **Sensor Type** | **Image Size** | **No. of Impression** | **Resolution** |
| DB1 | Low-cost Optical Sensor | 300x300 | 10x8 | 500 dpi |
| DB2 | Low-cost Capacitive Sensor | 256x364 | 10x8 | 500 dpi |
| DB3 | Optical Sensor | 448x478 | 10x8 | 500 dpi |
| DB4 | Synthetic Generator | 240x320 | 10x8 | about 500 dpi |

| Table 2. FingerDOS Database[40] |
|-----------------------------|
| **Sensor Type** | **Image Size** | **No. of Impression** | **Resolution** |
| optical sensor (SecuGeniD-USB SC) | 260 x 300 | 3600=60x6x10 i.e. No. of subjects=60 No. of fingers=6 (index, middle and thumb of right and left hand) No. of impression=10 | 500 PPI |

The below Table 3 show the comparison of thinning algorithm with the PSNR and MSE value. The following table shows that the performance of the current proposed technique is enhanced the result which having high PSNR and low MSE value. Thus, in terms of PSNR and in MSE value, it prove that the image produced by the proposed thinned algorithm generate the best value compare to other algorithms.

| Table 3. Performance Comparison of Thinning Algorithms using MSE & PSNR value |
|-----------------------------|
| **Images of FVC2000 and FingerDos Databases** | **Hilditch Algorithm** | **Zhang-Suen Algorithm** | **Enhanced Zhang-Suen Algorithm** |
| **MSE** | **PSNR** | **MSE** | **PSNR** | **MSE** | **PSNR** |
| FVC2000_DB1_B_101_1.tif | 19.254 | 28.455 | 16.173 | 31.322 | 13.852 | 33.944 |
| FVC2000_DB2_B_101_1.tif | 21.662 | 28.346 | 17.249 | 31.451 | 14.017 | 33.893 |
| FVC2000_DB3_B_101_1.tif | 19.364 | 29.584 | 16.795 | 31.531 | 13.795 | 33.962 |
| FVC2000_DB4_B_101_1.tif | 16.875 | 30.446 | 15.296 | 32.231 | 12.296 | 34.462 |
| LEFT_HAND_INDEX_FINGER_0101.bmp | 17.542 | 30.704 | 15.853 | 32.301 | 12.173 | 34.505 |
| LEFT_HAND_MIDDLE_FINGER_1201.bmp | 17.323 | 30.605 | 15.017 | 32.232 | 12.249 | 34.479 |
| LEFT_HAND_THUMB_3702.bmp | 16.454 | 31.128 | 15.256 | 32.243 | 12.256 | 34.476 |
| RIGHT_HAND_INDEX_FINGER_0401.bmp | 17.986 | 31.694 | 15.117 | 32.326 | 12.029 | 34.557 |
| RIGHT_HAND_MIDDLE_FINGER_1201.bmp | 17.576 | 30.587 | 15.029 | 32.243 | 12.117 | 34.526 |

The below Figure 4 and Figure 5 give clear idea using graphical representation of MSE and PSNR value comparison for three algorithms.
The following Table 4 show the comparison of algorithms based on execution time. It is clear that the execution time of Zhang-Suen’s compare to Hilditch’s algorithm take lower time but the proposed enhanced algorithm take little bit few more milliseconds to compute. But that can be neglect because the quality is important for the next minutiae extraction phase.

The below Table 5 in Appendix-I show that the quality of an images are improved using the proposed enhanced thinning algorithm. The mark on the images show that removal of spurious branches, noise, and thickness of an image.

6. CONCLUSION AND FUTURE WORK

This paper presents the role of thinning in fingerprint recognition. It shows the implementation of famous algorithm Hilditch and Zhang-Suen’s algorithm and also enhances the Zhang-Suen’s algorithm. The performance is evaluated on FVC2000 and FingerDos databases using MSE and PSNR measurement parameter. The experimental result prove that the enhanced Zhang-Suen’s algorithm is better than the existing Hilditch and Zhang-Suen’s algorithm in above all the mentioned aspect. In future, we try to work on post-processing phase like minutiae extraction, remove false point, core point detection and minutiae matching and try to enhance the accuracy level of fingerprint recognition.

7. REFERENCES

[1] M. Shimizu, H. Fukuda, and G. Nakamura. “Thinning Algorithm for Digital Figures of Characters”, Proceeding 4th IEEE Southwest Symposium on Image Analysis and Interpretation, 2000. Pp: 83-87.
[2] A. K. Jain, Fundamentals of Digital Image Processing, Prentice-Hall, 1986
[3] Lawrence O’Gorman and Rangachar Kasturi, Document Image Analysis, IEEE Computer Society Executive Briefings, 1997
[4] Housssem Chatbri, Keisuke Kameyama, Using scale space filtering to make thinning algorithms robust against noise in sketch images, Pattern Recognition Letters 42 (2014) 1–10
[5] E. Adeline, Enhancement of Parallel Thinning Algorithm for Handwritten Characters Using Neural Network, Master Thesis, Department of Computer Science, Faculty of
[6] Rinaldi, Munir. Pengolahan Citra Digital dengan Pendekatan Algoritmik. Bandung: Penerbit Informatika, 2004.

[7] Zhang, T. Y. dan Wang, P. S. P., “Analysis of Thinning Algorithms”, College of Computer Science Northeastern University Boston, MA 02115. 1992, pp.763-766.

[8] L. Lam, SW Lee, and CY.Suen, “Thinning Methodologies – A Comprehensive Survey”, IEEE Transaction on Pattern Analysis and Machine Intelligence. Vol. 14, No. 9, September 1992, pp. 869-885.

[9] Jang, BK, and Chin, RT., ‘Analysis of Thinning Algorithms Using Mathematical Morphology’, IEEE Transactions on Pattern Analysis and Machine Intelligence. Vol. 12, No. 6, 1990, pp. 541-551.

[10] Z. Guo and R. Hall, “Parallel thinning with two-subiteration algorithms,” Communications of the ACM, vol. 32, pp. 359–373, 1989.

[11] D. Maltoni and D.Maio, Handbook of Fingerprint Recognition, Springer, 2009.

[12] M.E. Hoffman, E.K. Wong, Scale-space approach to image thinning using the most prominent ridge line in the image pyramid data structure, in: Photonics West ’98 Electronic Imaging, International Society for Optics and Photonics, 1998, pp. 242–252.

[13] J. Cai, Robust filtering-based thinning algorithm for pattern recognition, Comput. J. 55 (7) (2012) 887–896.

[14] A. Witkin, Scale-space filtering: a new approach to multiscale description, International Conference on Acoustics, Speech, and Signal Processing (ICASSP), vol. 9, IEEE, 1984, pp. 150–153.

[15] T. Lindeberg, Scale-space theory: a basic tool for analyzing structures at different scales, J. appl. stat. 21 (1–2) (1994) 225–270.

[16] T. Sezgin, R. Davis, Scale-space based feature point detection for digital ink, in: ACM SIGGRAPH 2006 Courses, ACM, 2006, pp. 29–35.

[17] C. Arcelli, Pattern thinning by contour tracing, Comput. Graphics Image Process. 17 (2) (1981) 130–144.

[18] H. Chatbri, K. Kameyama, Sketch-based image retrieval by shape points description in support regions, in: International Conference on Systems, Signals and Image Processing (IWSSIP), 2013, pp. 19–22.

[19] H. Chatbri, K. Kameyama, Towards making thinning algorithms robust against noise in sketch images, in: International Conference on Pattern Recognition (ICPR), 2012, pp. 3030–3033.

[20] L. Huang, G. Wan, C. Liu, An improved parallel thinning algorithm, in: International Conference on Document Analysis and Recognition (ICDAR), IEEE, 2003, pp. 780–783.

[21] L. Lam, C.Y. Suen, Evaluation of thinning algorithms from an OCR viewpoint, in: International Conference on Document Analysis and Recognition (ICDAR), IEEE, 1993, pp. 287–290.

[22] Y. Chen, Y. Yu, Thinning approach for noisy digital patterns, Pattern Recognit. 29 (11) (1996) 1847–1862.

[23] R. Singh, V. Cherkassky, N. Papankolopoulos, Determining the skeletal description of sparse shapes, in: International Symposium on Computational Intelligence in Robotics and Automation (CIRA), IEEE, 1997, pp. 368–373.

[24] R. Palenichka, M. Zaremba, Multi-scale model-based skeletonization of object shapes using self-organizing maps, International Conference on Pattern Recognition (ICPR), vol. 1, IEEE, 2002, pp. 143–146.

[25] Y. Chen, Hidden deletable pixel detection using vector analysis in parallel thinning to obtain bias-reduced skeletons, Comput. Vision Image Underst. 71 (3) (1998) 294–311.

[26] W. Abu-Ain, B. Bataineh, T. Abu-Ain and K. Omar, “Skeletonization Algorithm for Binary Images”, Fourth International Conference on Electrical Engineering and Informatics (ICEEI) Elsevier, vol. 11, (2013), pp.704-709.

[27] G.V. Padole and S. B. Pokle, “New Iterative Algorithms for Thinning Binary Images”, IEEE Third International Conference on Emerging Trends in Engineering and Technology, vol. 7, (2010), pp. 166–171.

[28] T.Y. Zhang and C.Y. Suen, A Fast Parallel Algorithm for Thinning Digital Patterns, Communication of the ACM, Vol.27 No.3. pp 236, Mar 1984.

[29] Z. Guo and R. Hall, “Parallel thinning with two-subiteration algorithms”, Communications of the ACM, vol. 32, pp. 359–373, Mar 1989.

[30] W. Abdulla, A. Saleh, and A. Morad, “A preprocessing algorithm for handwritten character recognition,” Pattern Recognition Letters 7, pp.13–18, 1988.

[31] R. Hall, “Fast parallel thinning algorithms: Parallel speed and connectivity preservation,” Communications of the ACM, vol. 32, pp. 124–129, Jan 1989.

[32] Davit Kocharyan, “A Modified fingerprint image thinning algorithm”, American Journal of Software Engineering and Applications, 2013, PP: 1-6, (http://www.sciencedepublishinggroup.com/j/ajsea) doi: 10.11648/j.ajsea.20130201.11

[33] Gulshan Goyal and Ritika Luthra, “Performance Comparison of ZS and GH Skeletonization Algorithms”, International Journal of Computer Applications (0975 – 8897), Volume 121 – No.24, July 2015

[34] Jia Yu, Yaqin Li, “Improving Hilditch Thinning Algorithms for Text Image”, Conference on E-Learning, E-Business, Enterprise Information Systems, and E-Government, January 2010

[35] Atul Ganawale, J. A. Shaikh,”A Thinning Algorithm for Digital Figures of Characters” International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2312-7308, Volume 03, Issue 08, Aug-2014, Available @ http://www.ijret.org

[36] Mrs. Hemlata Patel, Pallavi Asrodia, “Fingerprint Matching Using Two Methods”, International Journal of Engineering Research and Applications , ISSN: 2248-9622, Vol. 2, Issue 3, May-Jun 2012, pp.857-860

[37] Hilditch, C.J., Linear Skeletons From Square Cupboards, in Machine Intelligence IV (B. Meltzer and D. Mitchieeds), University Press, Edinburgh, 1969. 403-420. 17, 2, 1970. 339.

[38] J. Kwon, “Improved Parallel Thinning Algorithm to Obtain Unit -Width Skeleton”.Journal of Multimedia & Its Applications (UMA), vol. 5, no. 2, (2013), pp. 1-14.

[39] D. Maio, D. Maltoni, R. Capelli, J. L. WaymanAnd A. K. Jain, “Fvc2000: Fingerprint Verification Competition”, IEEE Trans. Pattern Anal. Mach. Intell., Vol. 24, No. 3, Pp. 402-412, 2002.

[40] F. Francis-LothaiAnd D. B. L. Bong, “Fingeros: A Fingerprint Database Based On Optical Sensor,”Wseas Transactions On Information Science And Applications, Vol.12, No. 29, Pp. 297-304, 2015.

[41] Meghna B. Patel, Satyen M. Parikh, Ashok R. Patel, “Performance Improvement in Gradient based Algorithm for the Estimation of Fingerprint Orientation Fields”, International Journal of Computer Applications 167(2):12-18, June 2017.

[42] Ms. Meghna B. Patel, Dr. Satyen M. Parikh, Dr. Ashok R. Patel, Mr. Ronak R. Patel, “An Improved O’Gorman Filter for Fingerprint Image Enhancement” International Conference on Energy, Communication, Data Analytics and Soft Computing of
## Appendix-I
[Table 5. Quality Analysis of an Image]

| Original Image | Binarized Image | Hilditch Algorithm | Zhang-Suen Algorithm | Zhang-Suen with Fix Ridge Applied Once | Zhang-Suen with Fix Ridge Applied Twice |
|----------------|----------------|--------------------|----------------------|---------------------------------------|----------------------------------------|
| FVC2000        | ![image](image1) | ![image](image2)   | ![image](image3)    | ![image](image4)                      | ![image](image5)                      |
| DB1 (101_1.tif) | ![image](image6) | ![image](image7)   | ![image](image8)    | ![image](image9)                      | ![image](image10)                     |
| DB2 (101_1.tif) | ![image](image11) | ![image](image12) | ![image](image13)   | ![image](image14)                      | ![image](image15)                     |
| DB3 (101_1.tif) | ![image](image16) | ![image](image17) | ![image](image18)   | ![image](image19)                      | ![image](image20)                     |
| DB4 (101_1.tif) | ![image](image21) | ![image](image22) | ![image](image23)   | ![image](image24)                      | ![image](image25)                     |
| FingerDOS Database | ![image](image26) | ![image](image27) | ![image](image28)   | ![image](image29)                      | ![image](image30)                     |
| 0101.bmp (LEFT_HAND_INDEX_FINGER) | ![image](image31) | ![image](image32) | ![image](image33)   | ![image](image34)                      | ![image](image35)                     |
