ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645
Indian Journal of Science and Technology, *Vol 8(35), DOI: 10.17485/ijst/2015/v8i35/86782, December 2015*

Skeletonisation Approaches for Determining Paths in an Image: A Review

V. Sangeetha*, V. Vaithiyanathan, R. Sivagami, K. Divyalakshmi, K. Joseph Abraham Sundar and M. Ifjaz Ahmed

School of Computing, SASTRA University, Thanjavur - 613402, Tamil Nadu, India; vvn@it.sastra.edu, sangeetha@sastra.ac.in, sivagamiramadass@sastra.ac.in, divyalakshmi@sastra.ac.in, joseph@sastra.ac.in, ifjazahmed@sastra.edu

Abstract

Skeletonisation is an effective way to provide an intact representation of an object's shape. This approach has great applications in the fields of motion planning, object representation, tracking, information retrieval, topology representation, sensor distribution and location, facility location, forestry application, building constructions etc. Skeletons naturally provide a pixel to boundary mapping through which the path between points can be found in a terrain map. Many approaches for determining the skeleton of a terrain exist. In this paper, the different methods for Skeletonisation are discussed. Initially the various categorizations of Skeletonisation is discussed which is further followed by application of those algorithms for path determining. Quantitative measures for validating the skeleton are also discussed. Finally, the applications of Skeletonisation in various domains are elaborated.

Keywords: Distance Map, Distance Transform, Skeletonisation, Thinning, Voronoi Diagram

1. Introduction

Numerous research is on the rise in the field of image processing. One such area is Skeletonisation. In the recent years, more focus is been put on this field due to its versatility in applications. The concept of skeleton begun initially from the Blum's Prairie Fire Analogy[1]. According to him, when a field containing grass is set fire, the fire propagates and meets exactly at the medial axis which is the skeleton of the area. It is inferred that skeleton is the set of quench points where the fire fronts meet. This classic definition led to many other definitions. Skeletonisation can be defined as the process of reducing the foreground regions to set of quench points called skeleton whereby most of the foreground pixels are thrown away but their connection to original boundary is preserved. Medial axis is the set points so that at least one is near to boundary. A formal definition for skeleton can be stated as loci of all centers of maximal hyper sphere inscribed. Skeleton can also be viewed as a result of Medial Axis Transform (MAT). A point is set to belong to a skeleton only if it has two closest boundaries. Skeletonisation has a greater range of applications and benefits[2]. Because of its ability to make out a compact representation of an object, it has greater affinity towards the fields of shape matching, shape recognition, object tracking, handwriting recognition. Skeletonisation will be able to represent a topological map in its most abstract and precise form. Thus, it has greater applications in the fields of path finding, path tracking, motion planning, sensor distribution, facility location. Skeletonisation has greater impact in medical field because of its shape description capability. The exact structure of blood vessels can be got after which the flow can be studied further. The skeleton structure is greatly bound by the presence of noise in the image. Common noises are the surface noise[3] and contour noise[3].

*Author for correspondence

Henceforth the raw skeleton got from the process must be processed to remove noise. Morphological operations like dilation and erosion are applied to remove noises. In the field of path planning, the process of Skeletonisation has the following stages[4]. Initially the binary mask is applied on the source image to extract skeleton. Binary mask is dependent on the structural element used in the operation. The Figure 1 shows the procedural structure of Skeletonisation for determining path.

The skeleton can be classified into two types as Surface skeleton and Curve skeleton. Surface skeleton[5] are two dimensional skeletons got from 3D images. This show the structure of skeleton with respect to surface. Basically it is a union of surfaces and curves. They are generic and the image can be reconstructed from them again. They are widely used in volumetric animation, surface smoothing, and registration. Curve skeleton[5], on the other hand are one dimensional skeleton for 2D images. They project the skeleton in terms of curves in its simple form. The curve corresponds to the centre of the object boundary. They can also be got as a result of dimension reduction from surface skeleton. They look like a stick figure where the details would be abstract. They are used in animations, morphing, and geometric processing. There also exists another method for classifying the skeleton according to the reference used. Automatic skeletons are those skeletons that do not have any input parameters. Semi automatic skeletons are those that require set of human validated parameters. There are two most important properties[6,7] for skeletons:

- Skeletons must preserve the topological structure.
- Skeletons must preserve the geometrical nature of the image.

Additional properties include hierarchical structure, robustness, uniformity, inclusion, clarity[8,9]. There are many different approaches for Skeletonisation. The rest of the paper discusses various approaches for Skeletonisation, validation of the skeleton and the applications of Skeletonisation.

2. Different Approaches for Skeletonisation

The approaches for Skeletonisation can be classified into three types.

- Approaches based on Geometric Continuities.
- Approaches based on object reduction.
- Approaches based on Curve propagation.

Also, there is another method for classification where the methods are classified as Parallel[7] and Sequential methods[7]. In parallel methods, both the process of distance computation and pixel reduction takes place simultaneously. In sequential methods, first the distance map of each pixel is formed. Then, the pixels are reduced accordingly. There is also a narrow categorization of approaches for Skeletonisation where the methods are categorized according to the constraints they face[8]. The figure below shows one such categorization.

The sections below elaborate the wider categorization of different approaches for Skeletonisation.

2.1 Approaches based on Geometric Continuities

Skeletonisation is achieved through geometric continuities by means of Voronoi diagrams[10] and Graph based approach[8,9]. According to Voronoi diagram, the image plane is portioned into zones, and each zone has one seed point or generating point. The other points are put into zones based on their distance to the seed point. Voronoi diagram follows incremental construction. Generally Voronoi diagram is the intersection of Voronoi diagram

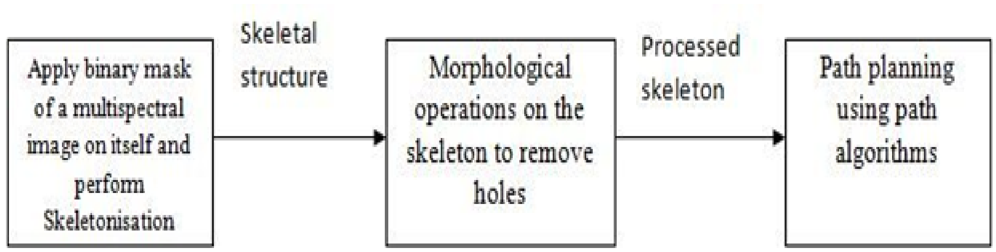


Figure 1. Procedural structure of Skeletonisation for determining path.

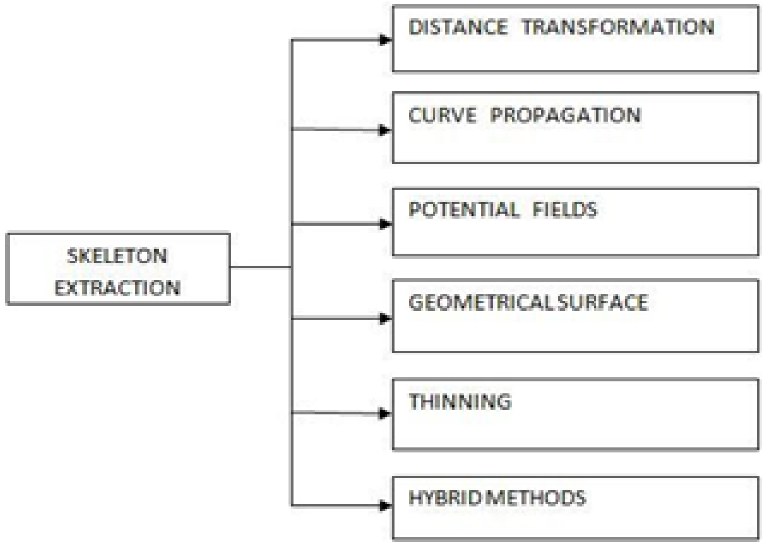


Figure 2. Narrow categorization of Skeletonisation algorithms.

of the boundary and the image[11]. In Voronoi diagrams, changes in the boundaries are not exactly represented in the inner skeletons. Thus it has less sensitivity towards change response. But Voronoi diagrams retain the topological and the geometrical nature of the image[12,13]. One of the major constrain in generating Voronoi diagram is calculating the distance between the geospatial features[14]. Voronoi diagram is greatly applied in fields like facility location, land planning, proximity analysis, building Geographic Information Systems. Another approach is Graph based approach for Skeletonisation. This approach follows collapsing and merging procedures where the zones are initially randomly portioned after which they are merged iteratively.

2.2 Approaches based on Object Reduction

Object reduction techniques are fairly called as thinning methods[15]. As the name implies, thinning methods aims at reducing the pixels directly. The pixels are rather deleted to get the final skeletal structure. The pixels are generally classified into three types. Line pixel[3], Border pixel[3], Euler Invariant pixel[3]. Border pixels are those that have at least one neighbor without Intensity value. Line pixels are those that are not located at the end of the line i.e., more than one pixel will have intensity value. Euler Invariant pixels are those pixels whose deletion will not cause any change in the Euler characteristic. Euler characteristic (χ) will describe the topological space's in a shape. The idea of thinning is that erode the above three pixels continuously until n further change occurs. The result of thinning will be single wide pixel skeleton[15]. The Figure 3 below shows the sample results of thinning of a sea shore area.

Thinning is advantageous because,

- It preserves the topology of the original image.
- It does not change the shape through origin.
- It produces a single pixel width skeletal structure.
- It produces the skeleton along the medial axis.

2.3 Approaches based on Curve Propagation (Distance Vector)

The formation of Distance map for the process of Skeletonisation is the most basic procedure. According to Curve propagation, the distance of a pixel from its nearest boundary is calculated and encoded in a map form called distance map. The Distance Transform (DT) forms the basic metrics for calculating the separation between points. From the distance map, the local maximal points are connected to form the skeleton. Curve propagation approaches have methods like, Active Region Contour[16], Shock Identification, Vector Field Identification[17], Potential Field model[18], Edge Strength model[15], Linear Diffusion[19]. Distance Transformation uses three metrics for evaluation. They are Euclidean distance metric[19], Chessboard distance metric[19], City block distance metric[19]. The Table 1 below summarizes the three metrics.

The notion of wave propagation led the way to Distance transform. In wave front propagation, the

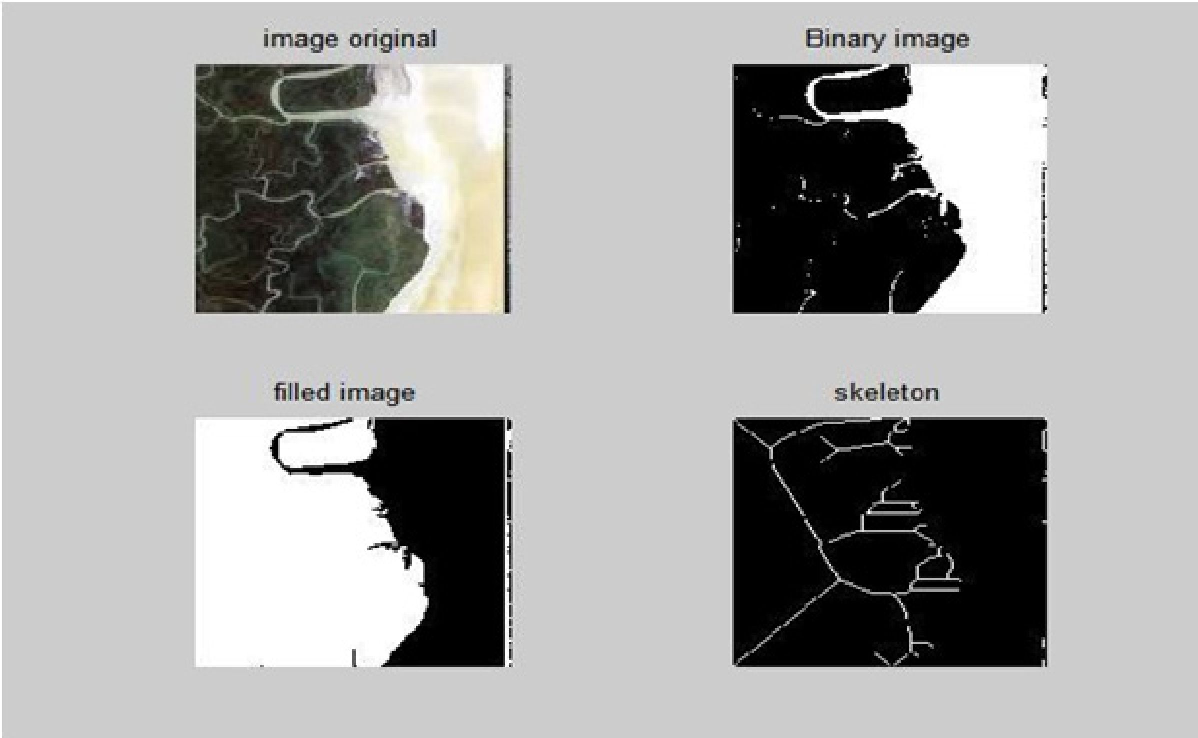
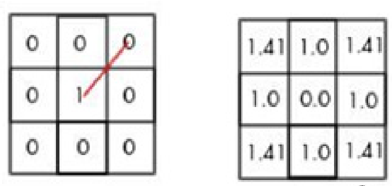
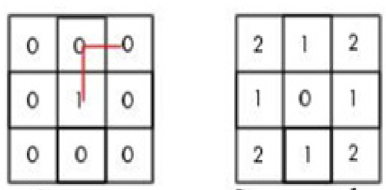
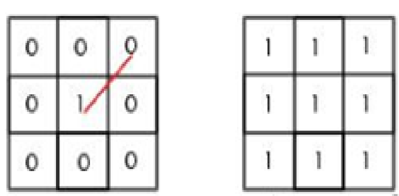


Figure 3. Sample Skeleton of seashore inward.

Table 1. Summarization of the three metrics of Distance Transform

Metric	Description	Illustration	Formula
Euclidean distance	Calculates the distance between two points in a straight line	 Image Distance Transform	$D_{Euclid} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$
City Block	Calculates the 4-neighborhood distance.	 Image Distance Transform	$D_{city} = \lvert x_2 - x_1 \rvert + \lvert y_2 - y_1 \rvert$
Chess Board	Calculates the 8 neighborhood distance	 Image Distance Transform	$D_{chess} = \max(\lvert x_2 - x_1 \rvert, \lvert y_2 - y_1 \rvert)$

wave propagates through the medium. The distance of the point at a particular position is taken. But this does not guarantee skeleton. As the wave propagates, cluster gets formed where the centers of cluster would be the local maxima. Thinning the cluster would result in skeleton structure. The presence of surface noises will cause parasite branches. Henceforth a detail search must be performed to identify the local maxima. This method of Skeletonisation ensures complete connectivity of the skeleton. The figure below shows some sample results of Skeletonisation through Distance Transform using all the three metrics. The differences in the structuring element[19] of the metrics results in slightly varying skeletal structures. Figure 4 shows the application of various distance measures on an image.

The Table 2 below summarizes all the approaches and compares them.

From the above table, it is inferred that, geometrical continuities approach yield good results. But they are not practically suitable for large topological spaces. Thus when curve propagation approaches and object reduction approaches are combined together, accurate skeleton structure can be got.

3. Quantitative Metrics for Validating Skeletons

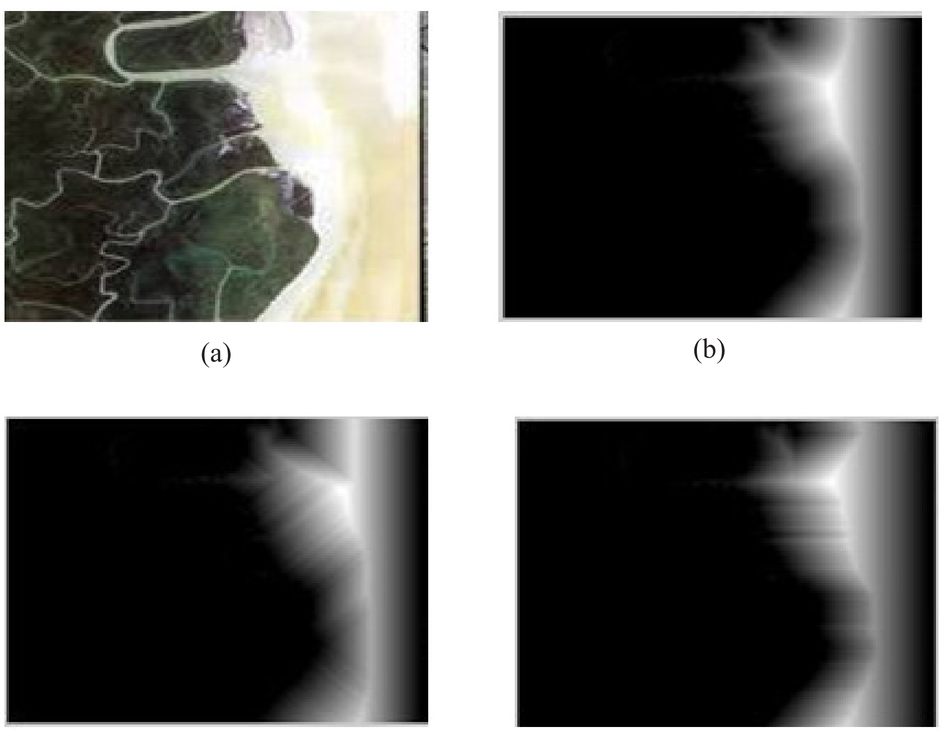
Every procedure performed in a process is not worthy unless validated. The results of Skeletonisation must be validated. There are three quantitative metrics for validating the skeleton. They are Thinness[20], Connectedness[20], and Localization Quality[20].

3.1 Thinness

Thinness is one of the most important qualities of skeleton. It is a constraint that the skeleton must be singe pixel

Table 2. Comparison of the three metrics of Distance Transform [19]

Method	Topological Structure	Geometrics of the region
Curve Propagation Approaches	Yes	No
Geometrical continuities approaches	Yes	Yes
Object reduction approaches	No	Yes



(a) (b) (c) (d)

Figure 4. (a) Original image. (b) Skeleton evaluated using Euclidean distance. (c) Skeleton evaluated using Chessboard distance. (d) Skeleton evaluated using City block distance.

wide. A simple formula for calculating the mean thickness of the skeleton is given below:

$$\mu_{dnp} = \frac{1}{T}\sum_{i=0}^{T} 2dnp - 1 \tag{1}$$

Where μ_{dnp} = mean thickness,
T = total number of local maxima distance values
Dnp=distance to the nearest skeletal pixel

3.2 Connectedness

A skeleton is so called only when it is connected in all aspects to all its pixels. A quantity called BettiNumber[20] quantifies the information about the number of connected spaces in a skeleton. B_0 specifies that there are no holes i.e., all spaces are connected. B_1 specifies the number of holes in 1D skeleton.

$$B_1 = p-q+M \tag{2}$$

Where B_1 = betti number of 1D skeleton
p = number of edges
q = number of nodes
M = number of connected components

3.3 Localization Quality

A skeleton is the central medial axis of an image space. Thus centerness is the most important criteria for a skeleton to be so. The points must be localized to its position. To crosscheck the localization, the skeleton can be compared against the hand-made ground truth skeleton[20].

4. Conclusion

A large number of research is been carried out in the field of Skeletonisation. Skeletonisation is one of the emerging areas of interest in the Image Processing domain. Because of its abstractness, Skeletonisation is been used in many areas of science like geography, biology, astronomy[21-24] etc. There are many different approaches under Skeletonisation which needs to be clarified further and can be experimented in many other fields[25]. The major challenge in devising algorithms is to preserve the characteristics of the image space both topologically and geometrically. Validation metrics for skeleton is another area which needs to be focused. There are many challenges like skeleton stretching, graph plotting with skeleton, skeleton merging in the operations with skeleton. In the future, Skeletonisation would definitely be a promising area of research with its challenges getting resolved.

5. Acknowledgement

This material is based on the research work financially supported by the Council of Scientific and Industrial Research (CSIR), the premier research and development organization in India, under the Senior Research Fellowship scheme. We sincerely thank the University Grants Commission, India for proving financial support through Maulana Azad National Fellowship of Grant for this research work. We also thank the SASTRA University for providing supportive infrastructure and resources required for the research.

6. References

1. Saha PK, Borgefors G, Baja GSD. A survey on skeletonization algorithms and their applications. Elseiver- Pattern Recognition Letters. 2015; 1–10.
2. Ashok M, Sreedevi J, Bai MR. An approach to noisy image skeletonization using morphological methods. International Journal of Scientific and Engineering Research. 2012 Sep; 3(9):1–8.
3. Chen Y, Drechsler K, Zhao W, Laura CO. A thinning-based liver vessel skeletonization method. International Conference on Internet Computing and Information Services. 2011 Sep 17-18. p. 152–5.
4. Zitkevicius E, Grigaitis D, Navakauskas D. On skeletonization of blood vessels in angiographic mri images of human brain. Information Technology and Control. 2007; 36(4).
5. Chapman BE, Berty HP, Schulthies SL. Automated generation of directed graphs from vascular segmentations. Elseiver, Journal of Biomedical Informatics. 2015 Aug; 56:395–405.
6. Ma L, Crawford MM, Yang X, Guo Y. Local-manifold-learning-based graph construction for semi supervised hyperspectral image classification. IEEE Transactions on Geoscience and Remote Sensing. 2015 May; 53(5):2832–44.
7. Sun TY, Huo CL, Tsai SJ, Liu CC. Optimal UAV flight path planning using skeletonization and particle swarm optimizer. IEEE world congress on computational Intelligence, Evolutionary Computing. 2008 Jun 1-6; 1183–88.
8. Chang H, Chen Z, Huang Q, Shi J, Li X. Graph-based learning for segmentation of 3D ultrasound images. Elseiver, Neurocomputing. 2015 Mar 5; 151(2):632–44.

9. Wang J, Yang X, Qin X, Ye X, Qin Q. An efficient approach for automatic rectangular building extraction from very high resolution optical satellite imagery. IEEE Geoscience and Remote Sensing Letters. 2015 Mar; 12(3):487–91.
10. Hu H, Liu X, Hu P. Voronoi diagram generation on the ellipsoidal earth. Elseiver-Computers and Geosciences. 2014 Dec; 73:81–7.
11. Amenta N, Choi S, Kolluri RK. The power crust, unions of balls, and the medialaxis transform. Comput Geom: Theory Appl. 2001 Jul; 19(2-3):127–53.
12. Brandt JW, Algazi VR. Continuous skeleton computation by Voronoi diagram. CVGIP: Imag Und.1992 May; 55(3):329–38.
13. Naf M, Szekely G, Kikinis R, Shenton ME, Kubler O. 3D Voronoi skeletons and their usage for the characterization and recognition of 3D organ shape. Comput Vis Image Und. 1997 May; 66(2):147–61.
14. Ogniewicz R, Ilg M. Voronoi skeletons: Theory and applications. Proceedings of the IEEE International Conference on Computer Vision and Pattern Recognition. 1992 Jun 15-18. p. 63–9.
15. Tari ZSG, Shah J, Pien H. Extraction of shape skeletons from gray scale images. Comput Vis Image Und. 1997 May; 66(2):133–46.
16. Leymarie F, Levine MD. Simulating the grass fire transform using an active contour model. IEEE Trans Pattern Anal Mach Intell.1992 Jan; 14(1):56–75.
17. Cornea ND, Silver D, Yuan X, Balasubramanian R. Computing hierarchical curve-skeletons of 3D objects. Vis Comput. 2005 Sep 14; 21(11):945–55.
18. Ahuja N, Chuang JH. Shape representation using a generalized potential field model. IEEE Trans Pattern Anal Mach Intell. 1997 Feb; 19(2):169–76.
19. Siddiqi K, Pizer SM. Medial Representations: Mathematics, Algorithms and Applications. Springer, 2008.
20. Gittoes W, Botterill T, Green R. Quantitative analysis of skeletonisation algorithms for modelling of branches. Proceedings of Image and Vision. 2011; 1–6.
21. Trier OD, Jain AK, Taxt T. Feature extraction methods for character recognition-A survey. Pattern Recognition. 1996 Apr; 29(4):641–62.
22. Ahmed M, Ward R. A rotation invariant rule-based thinning algorithm for character recognition. IEEE Trans Pattern Anal Mach Intell. 2002 Dec; 24(12):1672–78.
23. Arica N, Vural FTY. An overview of character recognition focused on off-line handwriting. IEEE Trans Syst Man Cybern Part C: Appl Rev. 2001 May; 31(2):216–33.
24. Thibault D, Gold CM. Terrain reconstruction from contours by skeleton construction. Geo Informatica. 2000 Dec; 4(4):349–73.
25. Fujiyoshi H, Lipton AJ, Kanade T. Real-time human motion analysis by image Skeletonisation. IEICE Trans Inf Syst. 2004 Jan 1; E87-D(1):113–20.