MVA '96 IAPR Workshop on Machine Vision Applications, November. 12-14, 1996, Tokyo, Japan

Analysis of Bone Shape by Local Controlled Deformable Contour for Bone Maturity Estimation

Itqon*, Shun'ichi Kaneko**, Hidefumi Kobatake*, Fumio Otsuki***, Hideyuki Tanaka* and Mitsunori Murata****

*: Tokyo University of Agriculture and Technology
**: Hokkaido University
***: Tokyo Metropolitan University
****: Tokyo Women's Medical College

Abstract

A new method for shape analysis of X-ray images of human hand bones for estimation of bone maturity is proposed. To handle low contrast and non-uniformity of X-ray images, we design stable pre-processings to enhance images. The contour extraction method is based on local force control of a connected contour for deforming so as to fit it to an outline of a piece of bone. As a result with real images some effective parameters can be calculated based on the contour shapes detected by the algorithm.

1 Introductions

In the fields of paediatrics and growth diagnostics, estimation of human bone maturity (also referred to as bone age) is one of the important research subjects and some methods have been proposed so far [1]. They are, however, based on rather qualitative evaluation of hand or knee bones and not suitable for execution by computer so computer-aided diagnostics or automatic examination have not been thought feasible. In order to design an effective statistic for estimation of bone maturity, we have to find some parameters or features which have high correlation to relative growth of bones, such as change of the shapes and their composition. Contour shape and relative location of each component of bone are assumed to be extracted from X-ray pictures of hands and well correlated to bone age [3].

For shape snalysis, Snakes[4] is a model of active contour controlled by energy (i.e. scalar) calculation over the whole contour. It is interesting in the view of stable segmentation of a single object, but because of a scalar evaluation a segmented contour can not be so precise especially at portions with high curvature. Otherwise, a dynamic contour model based on explicit force calculation have been proposed, but it needs plural contours to extract a single object with some complicated shape [5].

We have proposed an estimation method based on shape analysis by X-ray pictures of hand bones, which consists of three major parts: contour extraction, parameter calculation and multivariate regression [2]. We adopt a deformable contour of a single loop controlled by local forces to segment an outline of hand bones. X-ray images of typical hand bones have complicated internal texture and so some simple techniques for segmentation can not be applied. Furthermore, the contour should be extracted to a certain accurate shape so that the following parameter calculation can be successful.

In this paper, we presents an algorithm of contour extraction or segmentation based on dynamic deformable contour and parameters designed for bone maturity estimation.

2 Outline of the System

The method is mainly for the automatic measurement system of bone maturity with X-ray pictures and have an initial stage and the five stages as follows:

[1] clipping,
[2] pre-processings,
[3] contour extraction,
[4] parameter calculation, and
[5] bone maturity estimation.

*:Address: 2-24-16, Nakamachi, Koganei, Tokyo 184, Japan, **: Kita-13, Nishi-8, Kitaku, Sapporo 060, Japan, E-mail: kanekos@hupe.hokudai.ac.jp, ***: 1-1, Minami-Osawa, Hachioji, Tokyo 192, Japan, ****: 2-1-10, Nishioku, Arakawaku, Tokyo 116, Japan

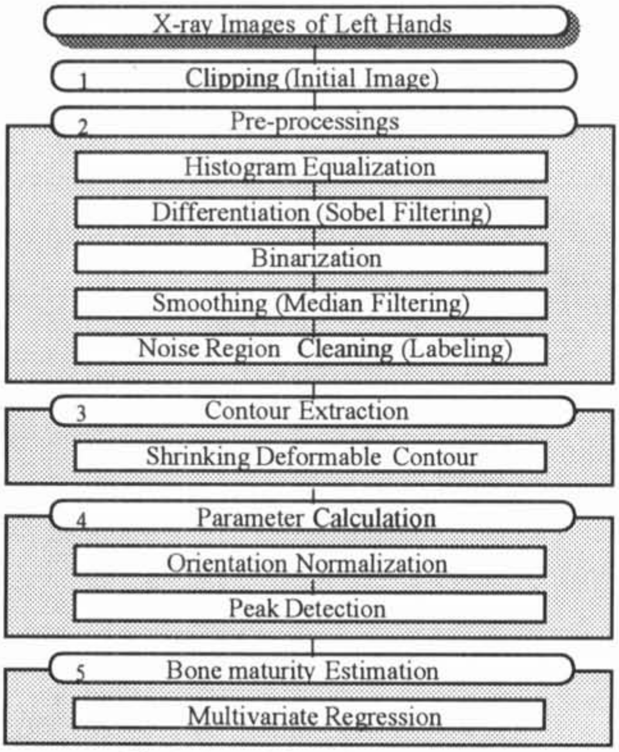
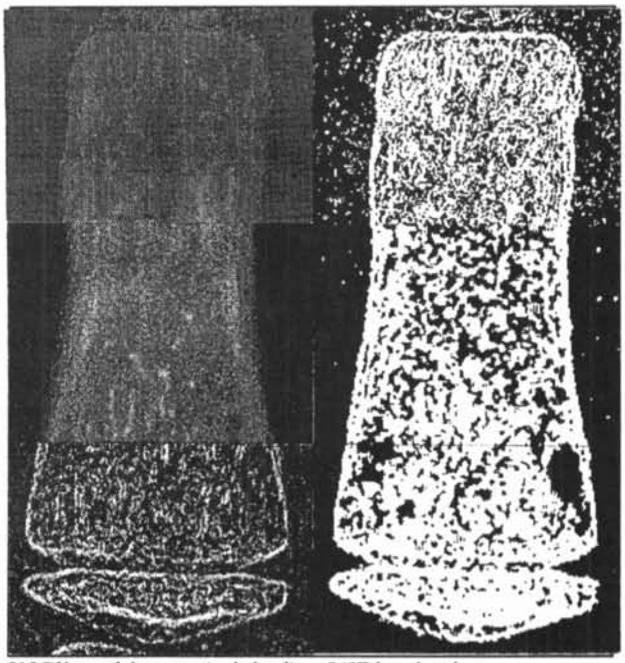


Fig.1 General flow of the method.



[1]Clipped image (original) [4]Binarization
[2]Histogram equalization [5]Median filtering
[3]Sobel filtering [6]Labeling

Fig.2 Examples of pre-processing
(the third proximal phalangis, male, maturity: 11.5)

A general flow of the method is shown in Fig.1. The first clipping stage is necessary for manually making initial images including epiphyses and metaphyses of the proximal and middle phalanges of the first and third fingers and the radius, which are more suitable for computer processing and have reasonable features. X-ray images are generally of low contrast and full of granular noise so we need the image enhancement stage following the first stage. This stage consist of simple image processing techniques such as histogram equalization, Sobel filtering, binarization, median filtering, labeling. Fig.2 shows real examples of pre-processings. It is not so easy to determine a threshold value for binarization and we have not had any procedure to obtain it, however, we have ascertained small variance of the value for similar X-ray images. The last two procedures are mainly for noise cleaning. We observe only small distortion of the object contour shape.

The third and fourth stages are main topics and should be described the following sections in detail. The final stage is not well considered so far because procedures to be executed at this stage are not more difficult than the others.

3 Contour Extraction

As shown in Fig.3, an initial contour set just inside the image frame (so it has a rectangle shape) is then shrinked toward the image center as investigating inside neighbor regions connected to the contour. The initial intervals are constant and position variant, i.e. the lower half has a fine interval between each node to fit prominent features with high curvature around a gap between a metaphysis and an epiphysis while the upper half has a coarser one enough to find smooth shape.

Fig.4 describes a scheme of the algorithm of contour extraction. Fig.4(a) shows a step of the iterative algorithm. V_i^k is a node to be moved and applied by a driving force whose magnitude is represented by the following equation:

$$F_t = F_i + F_c$$
$$= \text{sign}\,(i,k)\left\{a^2 + b^2\right\} + \frac{d^2}{\left\{1 - \cos\alpha_{\max}\right\}}$$

The internal force component F_i means restoring attractive forces applying V_i^k by V_{i-1}^k and V_{i+1}^k like in the case of an extended spring but they are assumed to be in proportion to the squared arc length. The constraining force F_c means a shrinking force oriented to the center of the contour, which is assumed to be in equilibrium at the position of V_{max} with the maximum bending angle α_{max}. The function sign(i,k) becomes +1 in the case of convex bent, i.e. the bending angle α is lower than 2π, or -1 otherwise. The orientation of the force is determined simply with the point V_{mid} and V_{max}. During a convex bent F_t points V_{mid} and then

V_{max} as a concave bent. The way of deriving the driving force is not a physical one but it is assumed to be a simplified version. The bending angle is constrained in the range of [α_{min}, α_{max}] [6]. Fig.4(b) shows "don't care point" in the neighborhood of V_i^k and (c) shows a scheme of node removal. Fig.5 is an example of detected contours.

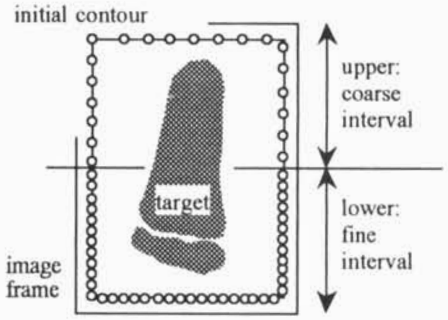
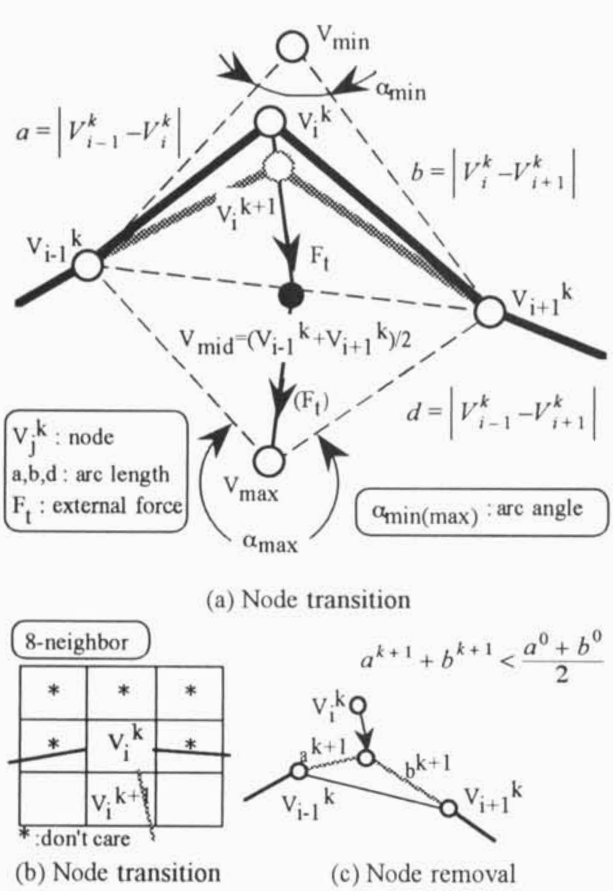


Fig.3 Initial contour.



(a) Node transition

(b) Node transition (8-neighbor version)

(c) Node removal

Fig.4 Shrinking.

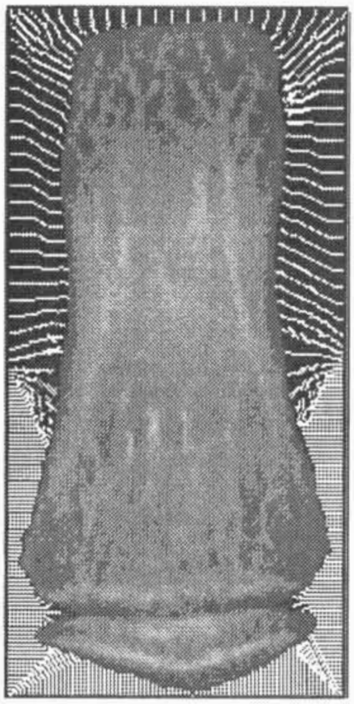


Fig.5 Example of contour extraction.
(the third middle phalangis, male, maturity: 10.0)

4 Parameter Calculation

In the fourth parameter calculation stage, the principal axis is firstly obtained by the principal component analysis with the detected contour points and then the contour is smoothed by a moving average filtering to detect peaks which can be used to define some parameters shown in Fig.6. The figure includes tentative candidates of parameters for bone maturity estimation because our discussion and evaluation for selecting effective parameters and a regression scheme is in progress.

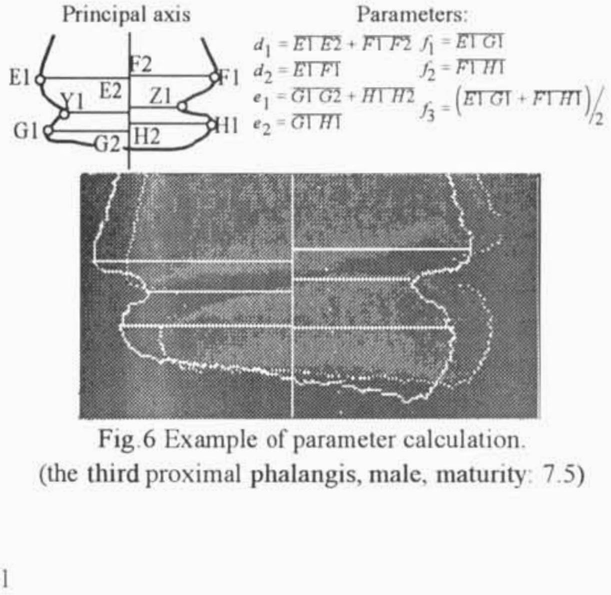
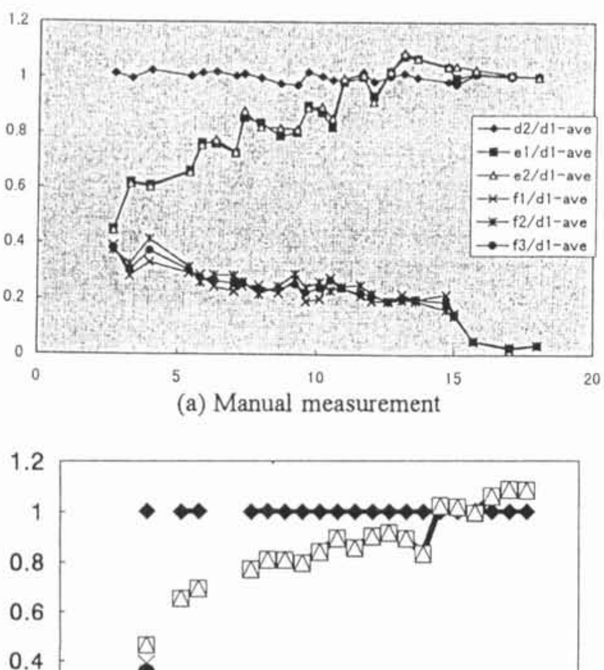


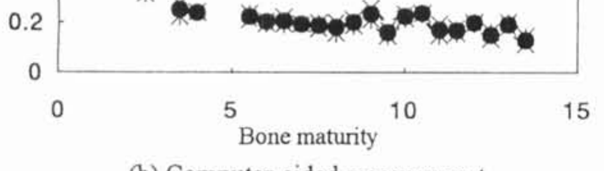
Fig.6 Example of parameter calculation.
(the third proximal phalangis, male, maturity: 7.5)

5 Bone Maturity Estimation

We are in progress of discussion for designing parameters and a regression scheme to estimate bone maturity. In order to use them in medical fields, it is requaired for them to keep high reliability and stability. Means of automatic evaluation should be prepared in computer diagnostic systems to aboid mistakes with outlying data. Some parameters have been designed and tested as shown in Fig.6. Fig.7 shows correlative relations between the parameters and bone maturity. The manural and computer-aided measurements are roughly similar to each other. We can find width parameters like e1 and e2 (normalized by d1) are of positive correlation to bone maturity while gap parameters like f1, f2 and f3 (normalized by d1) are of slightly negative correlation.



(a) Manual measurement



(b) Computer-aided measurement

Fig.7 Relation between parameters and bone maturity.

6 Conclusions

We have designed a new method for shape analysis for bone maturity estimation and experimental results show effectiveness of our method for real X-ray data. In the field of medical image processing, the method is expected to have real capacity for computer-aided diagnosis and inspection systems. Other parameters reflecting shapes, c.f. gap angles, should be designed and tested with real images.

These study have been in cooperation with the research group for development of the system of automatic bone maturity estimation under supervision of The Foundation for Growth Science in Japan.

References

[1] O. Nose, M. Murata, N. Matsuo and T. Tanaka, "Assessment of Skeletal Maturity and Prediction of Adult Height --TW2 Method -- (2nd Edition)" (Translation), HBJ Inc., 1993 (in Japanese).

[2] Itqon, S. Kaneko, T. Honda, F. Otsuki, H. Tanaka and M. Murata, "Analysis of Bone Shape from X-ray Images by Local Control of Dynamic Contour for Bone Age Estimation", Proc. of the 2nd Symposium for Sensing via Image Information (SII'96), pp.279-282, 1996 (in Japanese).

[3] E. Pietka, M.F. McNitt-Gray, M.L. Kuo and H. K. Huang, Computer-assisted phalangeal analysis in skeletal age assessment, IEEE Trans. on Medical Imaging, vol.10, pp.616-620, 1991.

[4] M. Kass, A. Witkin and D. Terzopoulos, "SNAKES: Active Contour Models", Proc. of the 1st ICCV'87, pp.259-268, 1987.

[5] M. Hild and T. Okamoto, "Balloon Operator for Extracting Regions Satisfying Shape and Orientation Constraints", Proc. of the 2nd ACCV'95, vol.2, pp.370-374, 1995.

[6] M. Hashimoto, H. Kinoshita and Y. Sakai, "An Object Extraction Method Using Sampled Active Contour", Trans. IEICE, vol.J77-D-II, no.11, pp.2171-2178, 1994 (in Japanese).