Communication

Outlining the prostate boundary using the harmonics method

C. K. Kwoh[1] M. Y. Teo[2] W. S. Ng[2] S. N. Tan[2] L. M. Jones[2]
[1]School of Applied Science, Nanyang Technological University, Singapore 639798
[2]School of Mechanical & Production Engineering, Nanyang Technological University, Singapore 639798

Abstract—*In a computerised ultrasound image guidance for automated prostatectomy system, it is necessary to identify a smooth, continuous contour for the prostate (boundary) from the ultrasound image. The radial bas-relief (RBR) method, which has been reported previously, can extract a skeletonised image from an ultrasound image automatically. After this process the prostate boundary is clearly revealed. However, analysis of the image is far from complete, as there are many spurious branches that create too much ambiguity for the system to define the actual boundary. There are also sections missing from the prostate boundary. Therefore further post-processing is required to describe and define the prostate boundary. In the paper, the harmonics method is used to describe the prostate boundary. The harmonics method uses Fourier information for noise removal and encodes a smooth boundary. The results of using the harmonics method after application of the RBR method on ultrasound images are presented. Factors that affect the performance are also highlighted and discussed.*

Keywords—*Boundary estimation, Prostate, Ultrasound*

Med. Biol. Eng. Comput., 1998, **36**, 768–771

1 Introduction

AN ULTRASONIC image of a prostate from a living patient is taken to be analysed for benign prostate hyperplasia, the enlargement of the prostate brought about by the growth of tissues in the prostate, and for detection of prostatic carcinoma, when the growth is malignant (cancerous). In fact, prostatic carcinoma has become the most frequently diagnosed cancer in men (MCDOUGAL and SKERRETT, 1996), and the number of cases diagnosed each year is increasing at a very fast pace. Treatment for patients afflicted with either of these diseases is a complicated process that can result in some side-effects. Owing to the repetitive nature of the treatment and the requirement for high precision in carrying it out, it is suggested that treatments for both diseases be taken over by a robotic system (NG *et al.*, 1993). However, to achieve that, the precise location and boundary (volume) of the prostate must be identified.

A method called radial bas-relief (RBR) (LIU, 1997; LIU *et al.*, 1997) has been devised to analyse the image. Fig. 1*a* shows an original transrectal ultrasound image of a prostate, and Fig. 1*b* shows the prostate boundary extracted by RBR.

At this point, the prostate boundary is clearly revealed, with the skeletonised image representing the prostate boundary with single pixel lines. However, for this image to be used to detect the safety range in robotic surgery, a well-defined boundary, a closed loop contour line, is needed. Hence, this image is far from completion. First, the spurious branches, which must be removed, create too much ambiguity for the system to define the actual boundary. Secondly, there are also missing sectors, as parts of the prostate have missing boundary lines.

Correspondence should be addressed to Dr Chee-Keong Kwoh, email: asckkwoh@ntu.edu.sg

First received 3 December 1997 and in final form 7 April 1998

2 Harmonics method

In our work, we consider a transformation approach that takes into account information from the whole picture to come up with a few representative descriptors. This approach has the inherently simplified task of overcoming missing edges and gaps. Hence, overall consistency is more likely to result.

With this requirement, a Fourier series based algorithm (STAIB and DUNCAN, 1989; 1992; CHAKRABORTY *et al.*, 1994; SUN *et al.*, 1994) or its variance is a suitable candidate. Our method, called the harmonics method, has these characteristics. The harmonics method makes use of polar co-ordinate Fourier information of spatial domain data to generate a smooth fitting curve line for the data.

The exact Fourier transform pairs are

$$r(\theta) = \sum_{n=-\infty}^{\infty} c_n e^{in\theta}$$

$$c_n = \frac{1}{2\pi}\int_{-\pi}^{\pi} r(\theta)e^{-in\theta}d\theta \qquad (1)$$

where $n = 0, \pm 1, \pm 2, \ldots$.

This specific representation of the polar co-ordinate has a number of advantages. First, the rotation of the ellipse is presented as the phase shift in the transformed domain, and, hence, the shape information is invariant to rotation; if a normalised form is used, the shape information is also invariant to scaling. Secondly, both the decomposition and recon-

a b

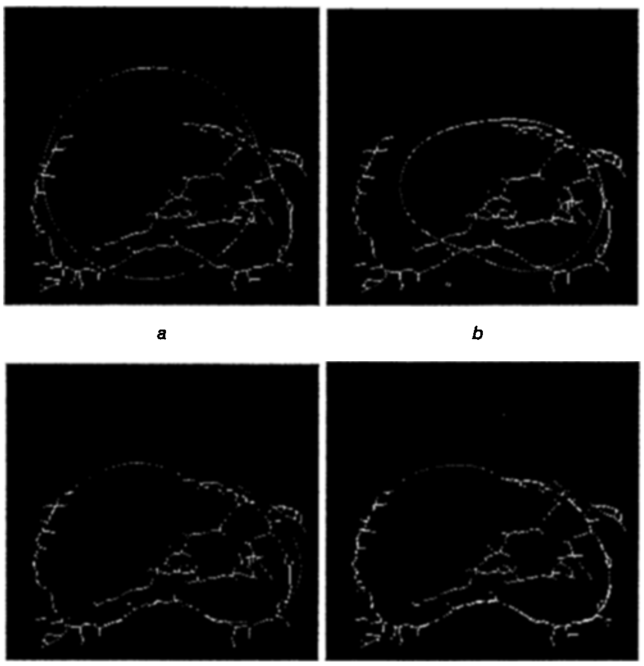
Fig. 1 *(a) Original transrectal ultrasound image of prostate (b) Prostate boundary extracted by RBR*

struction can be calculated efficiently using a fast Fourier transform. Thirdly, being Fourier descriptors, any truncation of the transformed coefficients will reconstruct back to a closed contour.

The various harmonics of the Fourier coefficients describing the various shapes are traced out by different rotating phasors. From Fig. 2, it can be seen that the first coefficient c_0 describes a circle. When more harmonics of the Fourier transformed coefficients are added to reconstruct the boundary, the constructed contour begins to fit closely to the prostate boundary. Eventually, as can be seen in Fig. 2*d*, the curve created by using four Fourier coefficients fits quite closely.

3 Steps of harmonics method

The main principle of the harmonics method is selection of the best number of Fourier coefficients to describe the contour and estimate the correct transformed coefficients from contour data points obtained from the RBR algorithm. To achieve this, an iteration process, which progressively removes spurious data points, must be used. The basic steps in this method are as follows:



a b

c d

Fig. 2 *Construction of boundary using (a) one coefficient c_0, (b) two coefficients c_0 c_1, (c) three coefficients c_0–c_2 and (d) four coefficients, c_0–c_3*

(*a*) interpolate the data into equally spaced data points (in our case, we used 512 of these)
(*b*) apply fast forward Fourier transformation on the data in polar co-ordinates
(*c*) select the number of harmonics
(*d*) apply inverse Fourier transformation
(*e*) interpolate to map back to data points for a closed contour
(*f*) compare with the previous set of data and delete points that are lying too far from the reconstructed contour
(*g*) repeat the method until no data point is removed in an iteration.

4 Application of harmonics method

The simplest way to apply the harmonics method is to assume that most of the data points extracted from the RBR are close to the organ boundary.

4.1 *Choosing the centre point*

The 'centre of prostate' in the image can be an arbitrary point, near the true centre, that is chosen to make the transformation more effective. It has some effect on the number of Fourier coefficients that are required to reconstruct a good contour and it also affects the deletion algorithm, which uses the radial magnitude for comparison.

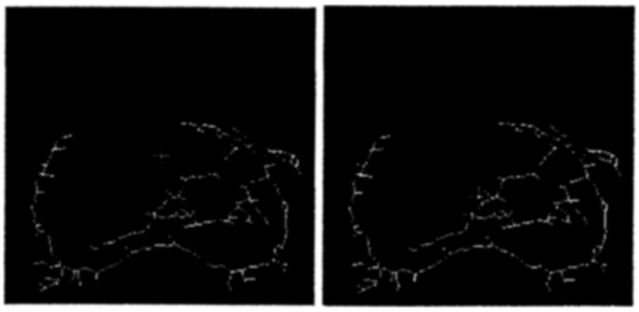
As can be seen from Fig. 3, the image centre does not coincide with the prostate centre. To minimise the above problem, the referenced centre is shifted to a position that is statistically estimated, using a series of prostate images, to be the centre of prostate (see Fig. 3*b*).

Once the reference centre is selected, the Cartesian co-ordinate boundary data can then be converted to polar co-ordinate data. Next, these polar co-ordinate data also must be sorted according to their angles and data points are sampled at regular angular spacing.

As the RBR method generates a prostate boundary with many spurious branches, there will be an undesired effect on the construction of the boundary using the Fourier coefficients if there is a concentration of points at one spurious branch. It will distort the Fourier coefficients, as the harmonics method works on the basis of the trend of data points. Thus, when there are many points, or a concentration of points, at some spurious branches, the boundary constructed using the harmonics method will be 'attracted' towards these branches. In this way, the reconstructed boundary will be a poor estimate of the true boundary.

In Fig. 4, owing to the concentration of spurious data points inside the lower right-hand side of the contour, the boundary lines created after the first iteration tend towards the centre. In addition to that, because there is a sector without boundary points at the far top left-hand corner, any path is equally probable. Hence, it is attracted to a single strayed data point in the top left-hand corner. Although the strayed points are not great in number (so few that the points are not easily visible), the interpolated data depended on it, and the Fourier coefficients were calculated from the interpolated data points. Hence, it distorted the re-constructed contour.

The way to remedy this problem lies in the process of tightening the iterative criteria for radial magnitude comparison for spurious data deletion.



a b

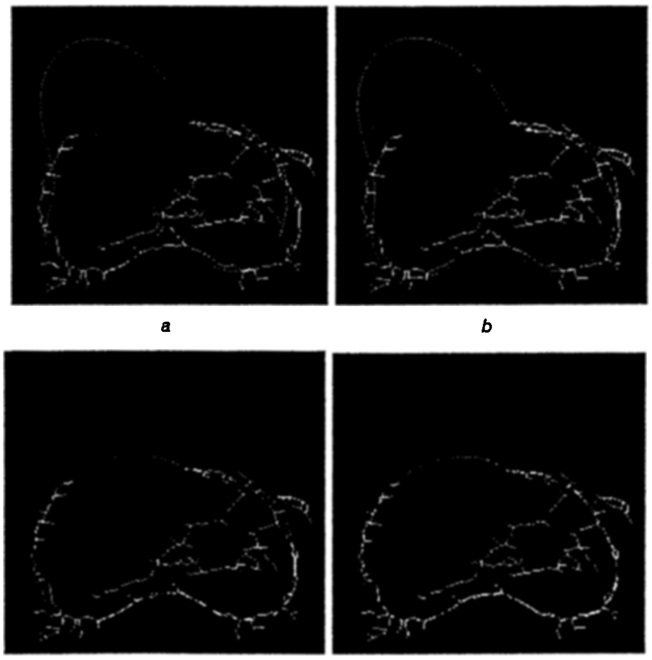
Fig. 3 *(a) Image centre (b) estimated 'prostate centre'*

Fig. 4 *Prostate boundary after first iteration*

4.2 *Comparison and deletion process*

The information used for comparison is the radial magnitude. In the comparison and deletion process, two limits are used, one positive and one negative. This method will trim away most of the spurious branches that do not fit the criteria.

In our work, radial magnitudes are measured in terms of calibrated units (c.u.) (BIOSCAN, 1992), which are scaling constants.



a b c d

Fig. 5 *(a) After second iteration; (b) after third iterations; (c) after fourth iteration; and (d) final image*

Using the truncated Fourier coefficients, a set of polar co-ordinate data is obtained through an inverse Fourier transform. These polar co-ordinate data are eventually converted back to Cartesian co-ordinates to obtain the reconstructed boundary. However, for radial comparison, the polar co-ordinate data are used.

The original set of polar co-ordinate data is compared with these newly generated data. Comparison is made by subtracting the radial magnitude of the original data from the radial magnitude of the reconstructed data. If the difference exceeds the positive or negative limits, the point is considered irrelevant to the prostate boundary and is discarded.

This is an iterative method. The data points that remain after the comparison step are entered into another round of harmonics sequences: apply forward FFT, delete higher harmonics, apply inverse FFT and, lastly, radial comparison. This procedure is repeated until there is no change in the number of data. This means that the contour created by the harmonics is very close to the contour represented by the remaining data points within the given tolerances, when most of the unwanted points have been deleted.

In the first few iterations, the negative limit was chosen to be 1.0 c.u., whereas the positive limit was set at 3.0 c.u. statistically. This was to allow more unwanted points that were concentrated at the centre to be filtered out, while those outside the reconstructed boundary were kept for curve fitting.

These limits are iteratively reduced until the value of 0.2 is reached. Subsequent iterations then use the same positive and negative limits for comparison until no point is deleted.

The process of fitting a curve to the prostate boundary at each iteration is illustrated in Figs. 5*a–d*.

5 Discussion and future work

The theoretical approach of our harmonics method is similar to that of STAIB and DUNCAN (1989, 1992). However, their method required two independent functions to describe a contour in Cartesian co-ordinates and many coefficients. In contrast, our representation is in polar co-ordinates with complex coefficients. This approach is more appropriate because the prostate is basically of elliptical form.

In this paper, we have fine-tuned the parameters for centre estimation and the limit used in the iterative process for ultrasound prostate images. These parameters are application specified and cannot be generalised to other organ images. Hence, further work must be done to derive procedures to select these parameters dynamically with built-in intelligence.

6 Conclusions

The radial bas-relief method and the harmonics method presented in this paper form a complete procedure to describe a closed prostate boundary from ultrasound images. The RBR method traces the boundary contour, whereas the harmonics method generates a smooth curve fit to describe the boundary fully.

The harmonics method has been shown to work well to describe the prostate boundary, provided that the RBR method extracts useful information from the ultrasound images. At each iteration, the harmonics method depended on the comparison limit setting, which must be adjusted to each application for different quality of skeletonised image generated by RBR.

References

BIOSCAN OPTIMAS (1992): 'User guide & technical reference, 5th Edition'. BioScan OPTIMAS, Washington

CHAKRABORTY, A., STAIB, L. H., and DUNCAN, J. S. (1994): 'An integrated approach to boundary finding in medical images'. Proc. IEEE Workshop on Biomedical image analysis, June 24–25, Seattle, Washington, pp. 13–22

LIU, Y.J., NG, W. S., TEO, M. Y., and LIM, H. C. (1997): 'Computerised prostate boundary estimation of ultrasound images using radial bas-relief method'. *Med. Biol. Eng. Comput.*, **35**,(5), pp. 445–454

LIU, Y. J. (1997): 'Computerised ultrasound image guidance for automated prostatectomy'. Master thesis, NTU, Singapore

MCDOUGAL, W. S., and SKERRETT, P. J. (1996): 'Prostate disease' (Times Books, New York)

NG, W.S., DAVIES, B. L., HIBBERD, R. D., and TIMONEY, A. G. (1993): 'Robotic surgery: a first-hand experience In transurethral resection of the prostate', *IEEE Eng. Med. Biol.*, March, pp. 120–125

STAIB, L. H., and DUNCAN, J. S. (1989): 'Parametrically deformable contour models'. *IEEE Proc.*, pp. 98–103

STAIB, L. H., and DUNCAN, J. S. (1992): 'Boundary finding with parametrically deformable models', *IEEE Trans. Pattern Anal. Mach. Intell.*, **14**, (11), pp. 1061–1075

SUN, Y. N., CHANG, J. C., and YAO, W. J. (1994): 'Three-dimensional reconstruction of kidney from ultrasound images'. Proc. IEEE Workshop on Biomedical image analysis, June 24–25, Seattle, Washington, pp. 43–49