DEPTH DEPENDANCY OF FOURIER SPECTRA OF CATHETERS IN TURKEY BREAST

Anke Poelstra¹ and Heinrich Martin Overhoff¹

¹Medical Engineering Laboratory, Westphalian University of Applied Sciences, Gelsenkirchen, Germany

anke.poelstra@w-hs.de

Abstract: Catheter detection in B-mode ultrasound images is relevant for clinical interventions like brachytherapy planning. Previous investigations showed, that catheter spectra have band pass character. It was investigated, if the lower cut-off frequency of such spectra depends on the catheter's depth in turkey tissue. Typically, a decrease of cut-off frequency with depth could be observed in $N = 871$ A-line spectra.

Keywords: Ultrasound raw data, Fourier spectrum, catheter detection

Introduction

Certain stages of female breast carcinoma are treated by surgical lumpectomy and adjuvant radiation therapy to avoid local recurrences. High dose rate (HDR) brachytherapy allows dose concentration to the former tumor bed while sparing normal tissue. For this, catheters are implanted, through which radiation sources are placed temporarily in certain positions. Since the position of catheters determines the position of radiation sources, a well supervised catheter implantation is desirable. Whereas stereotactic mammography and CT allow to show post-implantation relations only, 3-D ultrasound is a promising alternative in order to show catheter positions.

For a clear visualization of catheters within an ultrasound volume a method is required to detect catheters automatically.

An image and raw data based method for the classification of windowed A-line samples into the classes 'tissue' and 'catheters' was developed [1]. In the raw data based part, Fourier amplitude spectra of signals originating from catheter reflections are analyzed. For this, an A-line excerpt s_i having its maximal amplitude at the i -th sample of the A-line is Fourier transformed after Hanning windowing (w_{han}). Its amplitude spectrum is

$$S_i = |\mathfrak{F}\{s_i \cdot w_{\text{han}}\}|. \quad (1)$$

These spectra have band pass character. It is hypothesized, that (H1) the cut-off frequency of an amplitude spectrum S_i decreases with increasing depth z .

Methods

Material

Polyphenylsulfon catheters were placed in different depths z of turkey breast. Via the ArtLab interface of a My-

Figure 1: Spectra of catheter signals in different depths $z(i)$.

Lab70 ultrasound system (Esaote Europe B.V., The Netherlands) raw data, i.e. A-lines of 30 image volumes are acquired. Turkey breast musculature was assumed to be an appropriate model for female breast tissue. The raw data have a sampling frequency of $f_s = 50$ MHz and with the depth index i and the speed of sound $c = 1540 \frac{\text{m}}{\text{s}}$ $z = i \frac{c}{2f_s}$ holds.

Method

$N = 871$ Fourier spectra $S_i(f)$ of catheter samples of the turkey breast ultrasound images were identified according to the procedure described above. To determine the depth dependence of the amplitude spectra $S_i(f)$, windowed A-lines s_i were only analyzed if they had been classified to represent catheter pixels by expert segmentation.

As is apparent from Fig. 1, the amplitude spectra of catheters in different depths z differ. As measure of the difference, the cut-off frequency f_c is determined which separates the stop band from the pass band (Fig. 2). For this, the cumulative sum y of each spectrum is determined according to

$$y(f) = \sum_{l=0}^f S_i(l). \quad (2)$$

Since a preceding analysis showed, that the transition zone between stop and pass band was 500 kHz, only this part is regarded and its cumulative spectrum $y(f)$ is approximated by a line. The transition zone $f_1^{\text{trans}} \leq f \leq f_u^{\text{trans}} = f_1^{\text{trans}} + 500 \text{ kHz}$ is modelled by

$$y(f) \approx \tilde{y}(f) = y_0 + m \cdot f, \quad (3)$$

(a) Low frequency part of the spectrum S_i of a catheter signal

(b) Cumulative spectrum y

Figure 2: Low frequency part of the spectrum of a catheter signal (2a) and its cumulative sum $y(f)$ (2b). The cumulative spectrum is partly approximated by a line.

where f_1^{trans} is defined by

$$\sum (y(f) - \tilde{y}(f))^2 = 0.2 \cdot 10^{-6}. \quad (4)$$

Accordingly, its cut-off frequency is defined by

$$f_c \approx -\frac{y_0}{m}. \quad (5)$$

Hypothesis H1 shall be verified, if the cut-off frequency f_c is depth-dependent

$$f_c \approx f_c(z) \quad (6)$$

due to a linear depth-dependency of slope m and intercept y_0 .

Results

By Eq. 2 and Eq. 4 the cumulated part of a spectrum $y(f)$ of an A-line excerpt s_i is parameterized by the triple $[i, y_0, m]$. After normalization of such triples, a principal component analysis of all N A-line excerpts,

$$\begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{bmatrix} \cdot \begin{bmatrix} \frac{i - \bar{i}}{\sigma_i} \\ \frac{y_0 - \bar{y}_0}{\sigma_{y_0}} \\ \frac{m - \bar{m}}{\sigma_m} \end{bmatrix} \quad (7)$$

was performed. The third principal component was vanishing, i.e.

$$w_3 = c_{31} \frac{i - \bar{i}}{\sigma_i} + c_{32} \frac{y_0 - \bar{y}_0}{\sigma_{y_0}} + c_{33} \frac{m - \bar{m}}{\sigma_m} \approx 0 \quad (8)$$

Table 1: Relative errors of models regarding or disregarding depth $z(i)$.

Model	based on $z(i)$	disregarding $z(i)$
Relative error	0.09	0.13

and thus, one of the parameters was identified to be obsolete. Intercept y_0 can be substituted by a linear depth-dependent model

$$\tilde{y}_0 = \alpha_0 + \alpha_i \cdot i + \alpha_m \cdot m. \quad (9)$$

Now, for Eq. 6 it can be derived

$$f_c = -\left(\frac{\alpha_0}{m} + \frac{\alpha_i}{m} \cdot i + \alpha_m\right) \quad (10)$$

with

$$\alpha_0 = \bar{y}_0 + \frac{c_{31}}{c_{32}} \frac{\sigma_{y_0}}{\sigma_i} \bar{i} + \frac{c_{33}}{c_{32}} \frac{\sigma_{y_0}}{\sigma_m} \bar{m} = -0.04 \quad (11)$$

$$\alpha_i = -\frac{c_{31}}{c_{32}} \frac{\sigma_{y_0}}{\sigma_i} = 1.54 \cdot 10^{-4} \quad (12)$$

$$\alpha_m = -\frac{c_{33}}{c_{32}} \frac{\sigma_{y_0}}{\sigma_m} = -3.87. \quad (13)$$

The quality of the model is quantified according to the relative error

$$E = \frac{\frac{1}{N} \sqrt{\sum^N (y_0^2 - \tilde{y}_0^2)}}{|\bar{y}_0|}. \quad (14)$$

For comparison, a model based on the parameter pair $[y_0, m]$ instead of the parameter triple is derived. The errors are given in Tab. 1.

Discussion

The spectra of $N = 871$ catheter A-lines have been analyzed with respect to the lower cut-off frequency f_c of their band pass character. From a linear model of the transition zone of its numerical integral, it could be shown, that f_c decreases with increasing catheter depth z (Eq. 6, $\alpha_d > 0, m > 0$). Based on Eq. 9, automatic catheter detection in A-line excerpts s_i could be possible. The error of the model regarding depth z reduces in comparison to the error of a model disregarding z .

Acknowledgement

This work was funded by the Federal State Northrhine-Westfalia in the Med in.NRW-program, grant no. GW01-078.

Bibliography

- [1] A. Poelstra and H. Overhoff, "Determination of the depth dependent fourier spectra of catheter reflections for automatic catheter detection," in *Ultrasonics Symposium (IUS), 2011 IEEE International*, pp. 284–287, 2011.