Adaptive Filtering of Fibre-optic Fetoscopic Images for Fetal Surgery

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INTRODUCTION

Intrauterine interventions currently rely on the use of a fetoscope as the main intraoperative imaging modality [1]. Fetal surgery could benefit from computational processing of fetoscopic images, such as image mosaicking. However, images from fibre-optic fetoscopes contain a "honeycomb" pattern due the camera oversampling the irregular fibre bundle image guide. This honeycomb pattern distracts the clinician and will adversely affect any subsequent image computing algorithm; thus, a crucial first step in the image-processing pipeline is the removal of the honeycomb pattern.

Previously published methods for the removal of the honeycomb structure include adaptive spectral masking [2] and spatial interpolation methods [3-5]. We chose the spectral masking filter approach because, as opposed to spatial interpolation, it can cope with defocused images where individual fibres cannot readily be distinguished in the honeycomb pattern, and because, once the method is validated, spatial filtering can be readily optimised by GPU implementation. To filter out the honeycomb structure without over-blurring the image, it is important to estimate the optimal cut-off frequency f_c for the filter mask. The optimal f_c depends on the fibre intercore distance and also on the camera focus and zoom levels, which may change during the procedure. We test three different approaches for estimating the optimal f_c from fetoscopic images: (1) by direct measurement of the intercore distance; (2) by estimating the fibre density; or (3) by estimating the honeycomb frequency spectrum. Here we demonstrate that the honeycomb pattern can be robustly filtered using the f_c estimated from any of the three approaches.

MATERIALS AND METHODS

Data. Test images were obtained using a fibre-optic fetoscope and an imaging system (Karl Storz, Germany). The test images include a set of *in vivo* images obtained during an intrauterine procedure.

Estimating f_c from the intercore fibre distance. The locations of the fibres were identified by finding the regional maxima in the image. Then the median distance between adjacent fibres d_{ic} was used to determine f_c as: $f_c = 0.4/d_{ic}$.

Estimating f_c from the fibre density. The imaged fibre density was estimated by measuring the area of the imaged bundle and using the number of fibres in the bundle, n_{fibre}, supplied by the manufacturer. Then the average distance between adjacent fibres d_{ic} was calculated by relying on a hexagonal circle packing assumption as: $d_{ic} = \sqrt{(2 * area)/(n_{fibre} * \sqrt{3})}$. As in the first approach, f_c was then set as: $f_c = 0.4/d_{ic}$.

Estimating f_c in the frequency domain. The FFT of the fetoscopic image was computed and its log amplitude was used to estimate the frequency of the honeycomb pattern. The honeycomb frequency f_{comb} was detected by integrating the log amplitude of the FFT over rings of varying radius, and finding the non-zero radius with the largest average amplitude (Fig. 1). f_c was then determined as: $f_c = 0.4 * f_{comb}$.

Spectral mask filtering. Using the f_c estimated with either spatial or frequency method, fetoscopic images were filtered by applying a smoothed spectral mask in the frequency domain. A circle mask of radius f_c was smoothed with a Gaussian filter to avoid ringing artefacts (std. dev. = 10) and multiplied with the FFT of the image (Fig. 1d). The filtered image was then recovered by taking the inverse FFT of the masked spectrum, and then examined for the removal of the honeycomb pattern.

RESULTS

The optimal f_c was estimated using all three approaches, and the resulting values were within 15.68±2.96% (mean ± std. dev., n=28 images) of one another. The estimates from the first and the third approach differed by 11.04±2.51%. No one method was systematically overestimated or underestimated the f_c.

Images of the USAF-1951 test pattern at different zoom and focus levels were filtered with the spectral mask

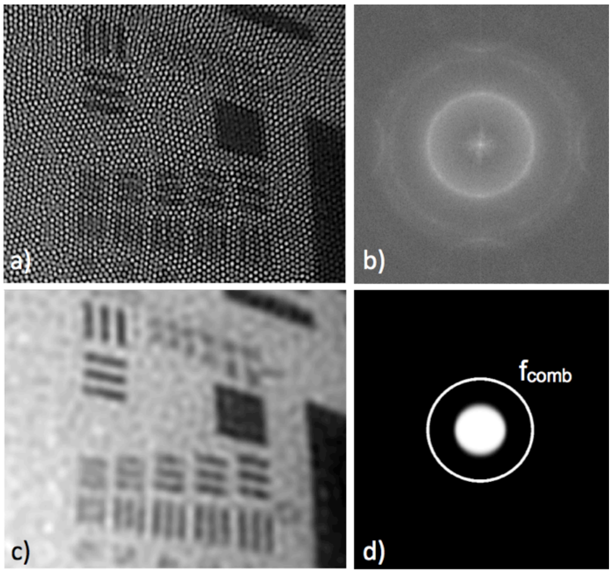

Fig. 1 a) Magnified fetoscopic image of the USAF-1951 test pattern showing the honeycomb pattern, b) Fourier power spectrum of the whole fetoscopic image (logarithmic grey scale), c) Filtered image using estimated f_c = 0.068, d) Ring used for the detection of f_{comb} (inset) and the smoothed mask used for spectral filtering.

using the f_c estimated in the frequency domain, which was generally the median value of the three estimates.

All filtered images had the honeycomb pattern removed while not over-blurring the small structures in the image (Fig. 1).

In vivo images filtered using the estimated f_c also had their honeycomb patterns removed while preserving the finer anatomical details in the image (Fig. 2).

Finally, a comparison between the adaptive spectral filtering and the Gaussian filtering shows that the Gaussian filtering slightly over-blurs the image, while the spectral filtering maintains the edges (Fig. 3).

DISCUSSION

Our results suggest that the honeycomb pattern can be robustly removed from fetoscopic images at different focus and zoom levels by estimating the optimal cut-off frequency and applying a filter. The cut-off frequency for the filter mask could be estimated using any of the three proposed approaches. Future work will focus on speed optimisation by re-estimating f_c only when a change in zoom or focus is detected, and designing a fast filter as done in [6] but with spectral characteristics that are closer to an ideal circular band-pass filter without the ringing artefacts.

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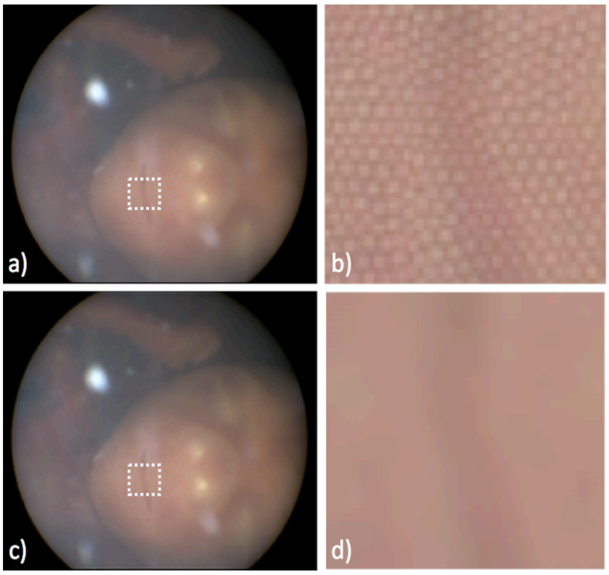

Fig. 2 a) *In vivo* fetoscopic image (dashed rectangle: ROI), b) Magnified ROI showing the honeycomb pattern, c) Filtered fetoscopic image using estimated f_c = 0.064, d) Magnified ROI of the filtered image.

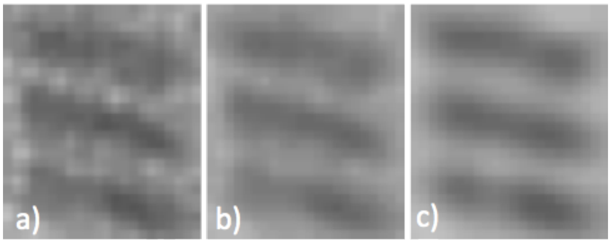

Fig. 3 a) Filtered image using a Gaussian filter with $\sigma = 0.4*d_{ic}$, b) The same as in a) but with $\sigma = 0.5*d_{ic}$, c) Filtered image using the estimated f_c as in Fig. 1c.

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