TRANSFORM ORIENTED TECHNOLOGY FOR QUANTITATIVE ANALYSIS OF FETAL MOVEMENTS IN ULTRASOUND IMAGE SEQUENCES

Leonid Yaroslavsky and Ben-Zion Shaick
Dept. of Interdisciplinary Studies, Faculty of Engineering, Tel Aviv University
Tel Aviv, 69978, Israel
Tel: +972 3 640-7366; fax: 972-3-641-0189
e-mail: yaro@eng.tau.ac.il

ABSTRACT

An image processing technology for featal organ tracking in ultrasound image sequences is presented. The technology includes a variety of algorithms for image calibration, noise suppression, target locations, signal interpolation and image geometrical transformation and is based on an extensive use of nonlinear signal processing in the domain of orthogonal transforms such as DFT and DCT.

1 INTRODUCTION

With technological refinement of diagnostic ultrasound, a shift has occurred in fetal study from an emphasis on anatomical components to an investigation of the complex neurobehaviour and physiology of the fetus. One of the most significant advances provided by ultrasound is the potential it offers to examine the spatial and temporal characteristics of the movement of foetuses in their natural environment. The study of the spatial and temporal characteristics of fetal movement could significantly improve our understanding of neonatal sensorimotor functioning and the evolution of congenital motor disabilities ([1]).

In investigation of fetal movements the following organs are usually involved: trunk, arms, head, neck, breast, heart, eyes and mouth. Movement characteristics such as the force quality are important aspects of normal fetal movement strategies and may prove useful in early detection of fetal distress or pathology ([1]). Today, no medical devices are available that can give an accurate and automatic movement measures of separate different organs. Medical devices that are available can only give indication of global well being and movement of different organs can not be separated and measured. The most accurate and detailed information can be gathered by the use of a real-time ultrasound imaging systems. Physicians who are specialists in ultrasound monitoring can view the fetal motion and determine status of its neurological development. However, in most of the visual examination tests, the precise value of the movement kinematics parameters of fetal organs can not be obtained, rather they are described qualitatively by terms such as fast, slow, forceful, etc. Only recently, attempts were made to quantitatively measure the fetal angular velocity of the shoulder joint using real-time US images. These attempts were carried out through the use of special measuring equipment that is handled manually. Such a measuring process requires significant efforts and time due to the numerous amounts of frames of the images in the ultrasound video sequences.

The developed system is aimed at automation of this process. The system (Fig. 1) complements the routine system used to record a videocassette of US fetal movie with a PC based image processing experimental system for analysis of the recorded video sequence. The system applies to organs such as arms and head that exhibit rotation and shifting movements. For these organs, the system measures the kinematics parameters of shifting, rotation and angular velocity. The importance of these kinematics parameters is that they help to assess the force quality of the movements.

The innovation and advantage of our work is that it offers the doctors a semiautomatic measuring device that permits them to select and mark the fetal organs whose movements are then automatically measured. To the best of our knowledge, this is a first attempt to provide a computerized solution of the problem. Tracking and measuring the movement of fetal organs in ultrasound images requires solving the following problems:

- Image calibration and noise suppression;
- Target object localization and tracking in cluttered background;
- Fast and accurate image geometrical transformation to allow for image variations that may occur in the process of movement and imaging.

The main sources of noise that may cause the target tracking failures are:

- Periodic noise due to imperfections of the VCR system;
- Speckle noise generated by the US imaging system.

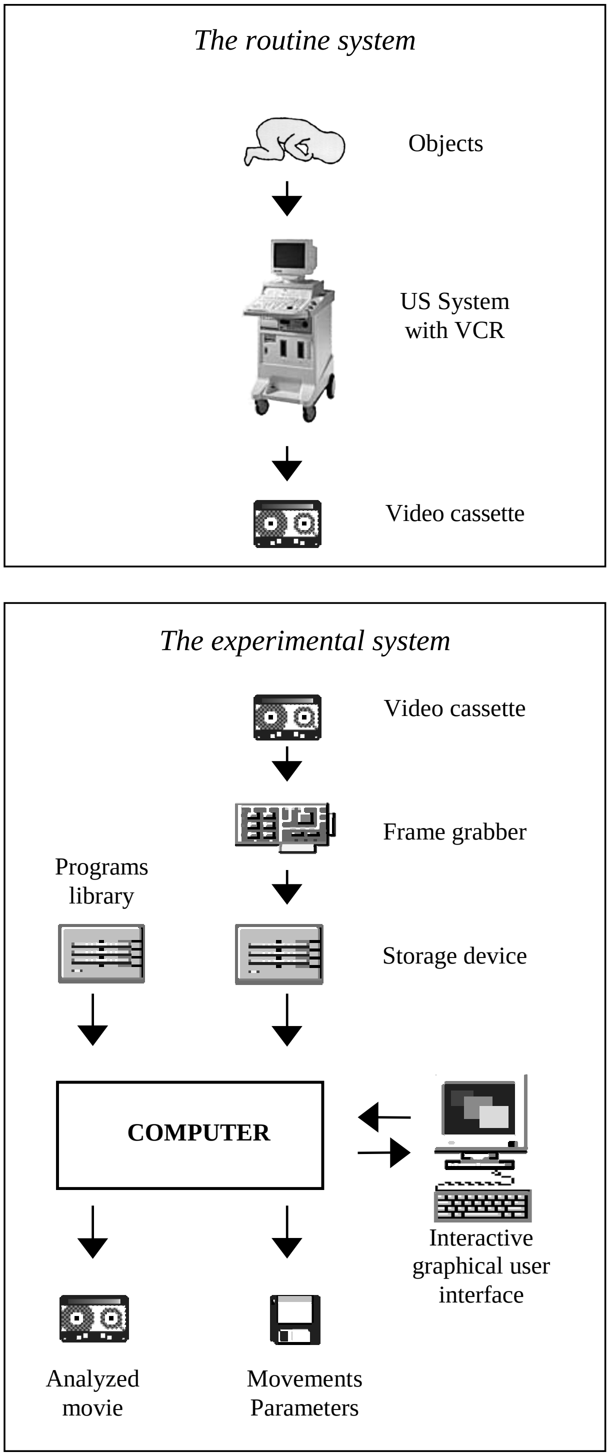

Fig. 1: Block diagrams of the routine and experimental systems.

The main obstacles for the reliable organ tracking are:

• The target organ is camouflaged by other organs in the field of view;
• Images are spatially very inhomogeneous;
• The target image changes considerably in the video sequence.

The developed techniques for solving these problems are based on nonlinear signal processing in the domain of orthogonal transforms.

2 THE DEVELOPED TECHNIQUES

2.1 Image Calibration Techniques

Image calibration and denoising techniques implemented in the system include:

2.1.1 Filtering Periodic Noise

The characteristic feature of periodic noise is that it has in its Fourier spectrum only a few components. A filter has been developed that automatically detects and then removes the noise spectral components thus producing periodic noise free images.

2.1.2 Filtering Speckle Noise

US images suffer from a specific type of acoustic noise called speckle noise that can be observed as a granular structure. Ultrasonic speckles, like similar phenomena encountered in laser and microwave radar imaging are the result of a coherent interference effect caused by the scattering of the ultrasonic beam from microscopic tissue inhomogeneities. A filter has been designed that suppresses the speckle noise efficiently, while preserving image edges and transient structures. The filter works in a running window in the domain of Discrete Cosine Transform and nonlinearly transforms local DCT spectral coefficients to obtain an estimate for the central pixel of the window ([3,4,5]). In the filter simplest modification, noise suppression is achieved by removing those DCT spectral components in the moving window whose magnitude does not exceed a certain threshold. For the signal dependent speckle noise, the threshold is determined by the signal dc component in the window (Fig. 2).

2.2 Organ Tracking Techniques

Organ tracking techniques include optimal adaptive correlator, image homogenization, image geometrical transforms and target coordinate measurement with subpixel resolution.

2.2.1 Optimal Adaptive Correlator

In order to secure the high organ tracking reliability we use, to determine the organ coordinates in the US image sequence, the optimal adaptive correlator ([2,3]). The optimal adaptive correlator minimizes localization errors due to false identification of the target object with one of the background objects and it is adaptive to cluttered background. For fast computation, the optimal adaptive correlator is implemented in the Fourier transform domain. Experimental tests have confirmed the superiority of the optimal adaptive correlator to conventional localization methods in terms of the localization reliability and the capability of reliable discriminating between slightly rotated copies of the target object that is crucial for measurements of target rotation parameters.

2.2.2 Image Homogenization

To further improve the organ tracking reliability, an image homogenization procedure has been implemented that compensates to a certain degree image inhomogeneity by means of equalizing image local mean and local variance in a running window of the target object size.

2.2.3 Tracking with subpixel accuracy

The target coordinates are estimated from the position of the signal highest peak at the output of the Optimal Adaptive Correlator. In order to achieve the subpixel localization accuracy, Shifted DFT fast discrete sinc-interpolation ([6]) of the correlator output signal has been implemented, the interpolation being carried out in a small region surrounding the main correlation peak.

2.2.4 Fast and Accurate Geometrical Transformation

In order to measure rotation angle of the organ in the video sequence, a fast accurate geometrical transform algorithm has been suggested and implemented. The algorithm is applicable for an arbitrary geometrical transform. The image transformation accuracy is that of the discrete sinc-interpolation ([6]). If the same transformation has to be applied many times with different mapping parameters to the same input image, as is the case of image rotation for the determination of rotation angle, the computational time is the same as that of the transformation with nearest-neighbor interpolation.

3 EXPERIMENTAL RESULTS

The tracking results obtained from the tested movies (Fig. 3) prove that the developed techniques and software are capable of reliable measuring the fetal movement parameters. The results imply the following distinctive features of the developed system:

- The developed system is robust to speckle noise;
- The tracking procedure is robust to slow changes of organ throughout the movie;
- The organ detection is robust to cluttered background.

The accuracy of the developed system was estimated by comparison of the movement parameters results obtained with the system to the parameters measured manually. For the tested movie, the accuracy is found to be higher than 99%. The developed tracking system is applicable also for non-US images (Fig. 4).

4 CONCLUSION

An image processing technology for quantitative analysis of fetal movement in ultrasound image sequences has been developed. The technology is based on an extensive use of processing in Fourier and Cosine transform domains for the implementation of optimal, adaptive and fast algorithms for image calibration, object tracking, signal interpolation and image geometrical transformations. The work was carried out in collaboration with Drs. Ilan Gull and Ariel Jaffa, Dept. of Obstetric and Gynecology, Serlin Maternity Hospital, Tel Aviv, Israel.

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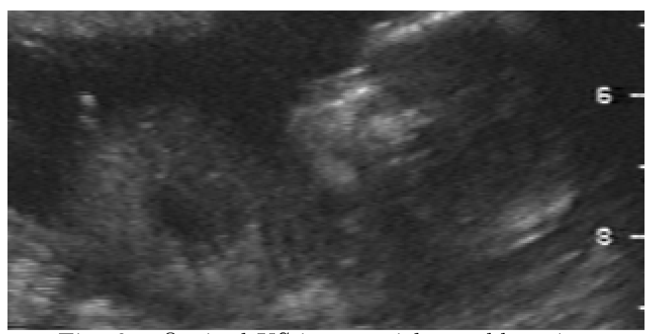

Fig. 2a: Orginal US image with speckle noise.

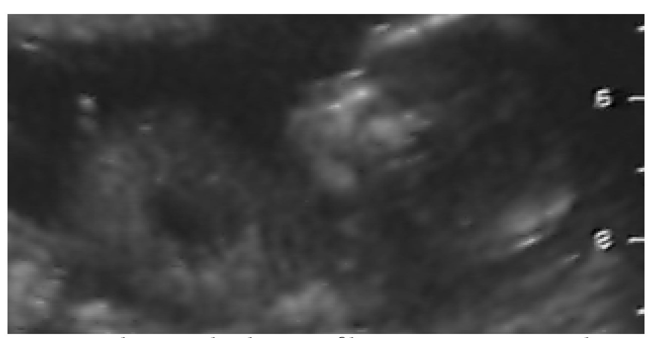

Fig. 2b: Local adaptive filtering in a 7x7 pixels window.

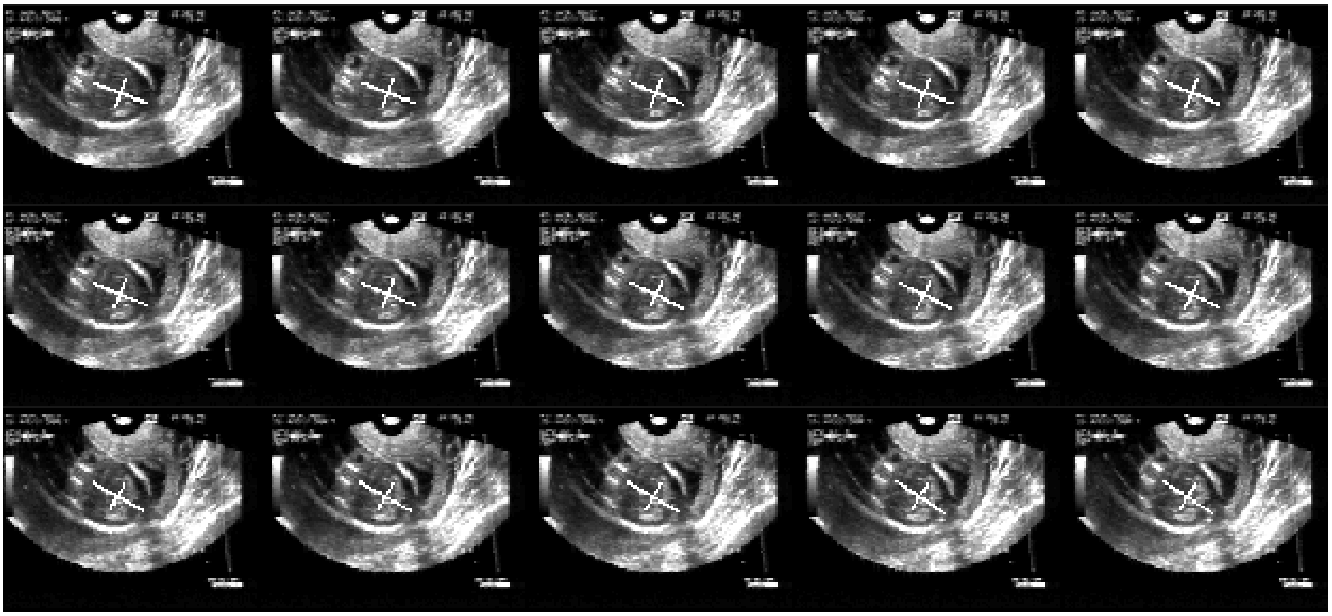

Fig. 3: Illustration of tracking fetal head in US images sequence.

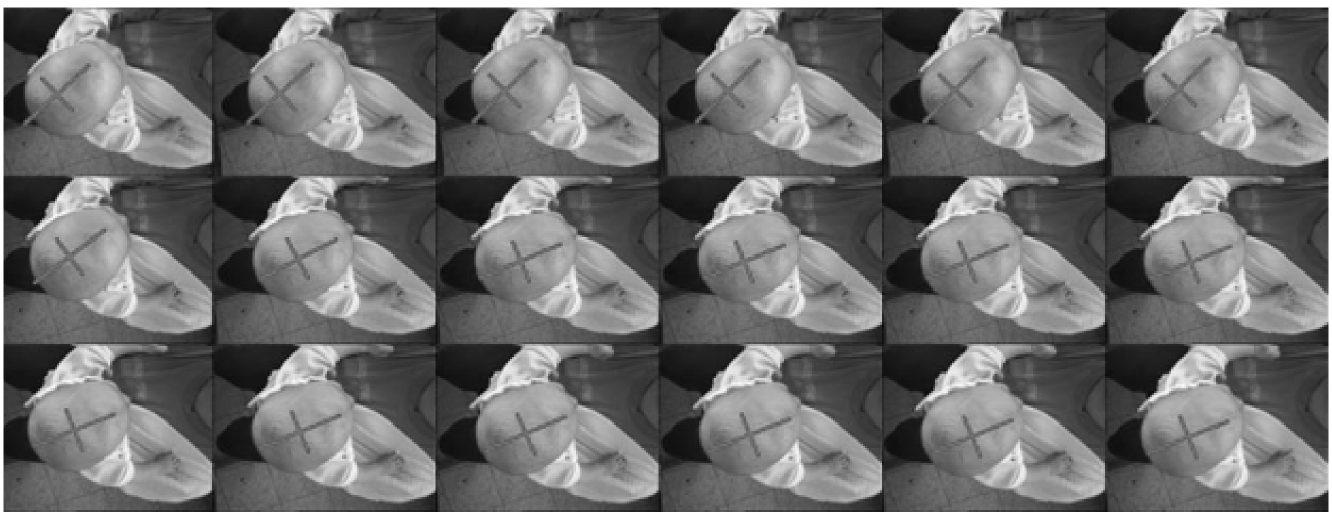

Fig. 4: Tracking the head of an infant in TV image sequence.