ISTANBUL UNIVERSITY –
JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING

YEAR : 2006 (53 - 59)
VOLUME : 6
NUMBER : 1

TISSUE-MOTION ANALYSIS OF ARTERY PULSATION IN CRANIAL ULTRASONOGRAM OF NEWBORN BABY

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ABSTRACT

Tissue-motion is an important physical parameter that can be considered in discussing the strength of artery pulsation of newborn baby for pediatrics diagnosis. In this paper, we have used optical flow technique to determine the tissue-motion velocity quantitatively in cranial ultrasonogram of newborn baby. We have estimated the tissue-motion by using gradient-based optical flow method and then the time variant tissue motion velocities are analyzed by using Fourier transform. Strong pulsation is observed in the harmonic frequency of tissue-motion that has a relation to the heartbeat frequency of a newborn baby.

Keywords: *Tissue-motion, pulsation, newborn baby, optical flow*

1. INTRODUCTION

Ultrasonogram uses routinely at the various sites of medical diagnosis because of its convenience, easy to use, low cost in compared with magnetic resonance imaging (MRI) and X-ray computed tomography (CT). Pediatricians use an ultrasonogram to find the cranial abnormalities in a newborn baby, since they can observe the brain tissue through the anterior fontanel [7]. A key point of diagnosis is whether there is the artery pulsation accompanied with blood flow or not [7]. However, there are a few attempts were taken to analyze the tissue-motion from the moving images of ultrasonogram for pediatrics diagnosis.

In order to detect artery pulsation from a series of noisy ultrasound echo images of newborn baby head for pediatric diagnosis, a digital image processing system was developed by using the algorithm based on Fourier transform [9]. In order to observe artery pulsation in neonatal cranium at the site of diagnosis, a real time processing system developed for continuous display and detection of artery pulsation from moving images of neonatal cranial ultrasonogram [3]. The entire algorithms used above mainly based on the time sequence variation of pixel value (intensity) in a series of ultrasound echo images. However, the pixel value can easily vary. Therefore, the above methods were very sensitive to the brightness of the original ultrasonogram movie.

Received Date :
Accepted Date:

In this paper, we have calculated the tissue-motion due to artery pulsation in cranial ultrasound image sequences by using a gradient-based approach with local optimization method, which is not sensitive to image brightness change. This is very helpful for quantitative characterization of artery pulsation. Finally, Fourier transform analyzes the time variant tissue-motions, emphasizing that the tissue-motion at a particular frequency has a relation with heartbeat frequency of newborn baby.

The rest of the paper organizes as follows: Firstly, we give a brief introduction of brain tissue-motion, artery pulsation and explains the technique of estimating tissue-motion. Secondly, the proposed analysis of tissue-motion by Fourier transform is illustrated. Thirdly, some experimental results of our methods are illustrated. Finally, we conclude this paper.

2. TISSUE-MOTION ESTIMATION BY OPTICAL FLOW

The optical flow method uses for visualizing and qualifying the dynamics of tissue-motion from a series of ultrasound echo images. Gradient-based approaches of optical flow are able to establish motion sequences of ultrasound B-mode images. Such motion estimation needs as a diagnostic tool in medical use of ultrasound imagery. The estimation of an approximated motion field can be very useful for 3D motion estimation, object tracking, segmentation and so on.

Tissue-motion and Artery pulsation

The velocity experience by brain tissue due to blood flow is the tissue-motion velocity. The nature of the tissue motion velocity is periodic due to periodic nature of heartbeat and it varies time to time, baby to baby, and it depends on physical condition. Therefore, tissue motion contains so many harmonic components of the pulsation frequency. The instantaneous value of tissue-motion velocity expresses by the following equation:

$$v(t) = \int_k v_k(t)\cos\left(\omega_k t + \theta(t)\right)dt \qquad (1)$$

The tissue-motion velocities repeat themselves due to the periodic nature of heartbeat. Since the heartbeat also varies due to physical condition of newborn babies, the tissue motion velocities vary from time to time, baby to baby.

Artery pulsation is the periodic beating of arteries as blood pumps through arteries, and pulsation strength represents the rating of blood flow to the brain-tissue through essential arteries in the brain. The tissue motion velocity is associated with blood flow. Therefore, pulsation strength can consider as the magnitude of tissue motion velocity, and therefore, a relationship exits between motion and heartbeat interval. Therefore, pulsation strength is lower or higher depends upon the blood flow rate or flow velocity.

Tissue-motion Estimation

The cranial ultrasonogram of newborn baby takes as noisy, speckle-like gray scale image including non-rigid tissues such as cerebrums and arteries with local motion due to artery pulsation of blood flow [2]. Therefore, the tissue-motion may vary with time and place. For our analysis, we assume that artery in the cranial ultrasound is locally rigid and keeps its structure during instantaneous motion. Several methods [1][4][6] are available for estimating object motion. In order to calculate tissue-motion as the instantaneous optical flow over a local region, we have used a gradient-based approach with local optimization.

Gradient-based approaches provide a solution to motion estimation from the observation in time of changes in the image brightness. These changes model by means of partial differential equations, which call constraint equations. The field of velocity vector obtained by solving such partial differential equations is normally called as optical flow or image flow. Optical flow is based on the observation of the changes in the image brightness. The local optimization finds the solution of constraint equation using least square technique. The most important partial differential equation for modelling the tissue-motion obtains by considering the change of image brightness as stationary with respect to time t.

Let $p(x, y, t)$ be the image brightness in a neonatal cranial ultrasonogram image sequence at location (x, y) of the image at time t. Let $v_x(x, y) = dx/dt$ and $v_y(x, y) = dy/dt$ be the optical flow velocity component as well as tissue-motion component in horizontal and vertical directions. Then following Horn and Schunck [4], we assume that the brightness value

at time $t+\delta t$ at point $(x+\delta x, y+\delta y)$, $\delta x = v_x \delta t$, $\delta y = v_y \delta t$ will be the same:

$$p(x+\delta x, y+\delta y, t+\delta t) = p(x, y, t) \qquad (2)$$

Expanding left hand side of (2) in a Taylor series expansion around the point (x, y, t) and take the limit of its first order components as $\delta t \to 0$, we get the optical flow constraint (OFC) or gradient constraint equation. This equation relates the temporal gradient, $p_t = \partial p / \partial t$ and spatial gradients, $p_x = \partial p / \partial x$ and $p_y = \partial p / \partial y$ at a point (x, y) in the image plane to the instantaneous velocity (v_x, v_y) at that point in the image.

$$\frac{\partial p}{\partial x} v_x + \frac{\partial p}{\partial y} v_y + \frac{\partial p}{\partial t} = 0 \qquad (3)$$

For a sequence of ultrasound image, we assume that motion is locally stationary, i.e. we can assume $\left[\frac{\partial v_x}{\partial x} = \frac{\partial v_y}{\partial x} = \frac{\partial v_x}{\partial y} = \frac{\partial v_y}{\partial y} = 0 \right]$.

For considering a unique constant tissue-motion velocity in the local region, S the following system of equations can form:

$$S \in \begin{cases} p_x^{(1)} v_x + p_y^{(1)} v_y + p_t^{(1)} = 0 \\ p_x^{(2)} v_x + p_y^{(2)} v_y + p_t^{(2)} = 0 \\ \cdots\cdots\cdots\cdots \\ p_x^{(N)} v_x + p_y^{(N)} v_y + p_t^{(N)} = 0 \end{cases} \qquad (4)$$

The above system of equations arrange as a matrix, which leads an over-determined system.

$$\begin{bmatrix} p_x^{(1)} & p_y^{(1)} \\ p_x^{(2)} & p_y^{(2)} \\ \vdots & \vdots \\ p_x^{(N)} & p_y^{(N)} \end{bmatrix} \begin{bmatrix} v_x \\ v_y \end{bmatrix} = - \begin{bmatrix} p_t^{(1)} \\ p_t^{(2)} \\ \vdots \\ p_t^{(N)} \end{bmatrix} \qquad (5)$$

In general, the over determined system has no exact solution. An approximate solution finds by minimizing the square of residual vector, r define the following equation [6]:

$$r \equiv p_x v_x + p_y v_y + p_t \qquad (6)$$

Now, the value of motion, $\vec{v}(v_x, v_y)$ is approximated so that the square of r might be minimized with least square method. By using least square technique, the tissue-motion velocity at each pixel position in the cranial ultrasonogram images give by the following equations:

$$v_x(x, y, t) = \frac{p_{yt} p_{xy} - p_{xt} p_{yy}}{p_{xx} p_{yy} - p_{xy}^2} \qquad (7)$$

$$v_y(x, y, t) = \frac{p_{xt} p_{xy} - p_{yt} p_{xx}}{p_{xx} p_{yy} - p_{xy}^2} \qquad (8)$$

where, $p_{ij} = \sum_{(i,j:x,y,t)} \sum p_i(x, y, t) p_j(x, y, t)$

From motion components, the absolute value of tissue-motion, $V(x, y, t) = \sqrt{v_x^2 + v_y^2}$ and the phase angle, $\phi = \tan^{-1}(v_y / v_x)$ is determined. In order to estimate degree to which the OFC equation is satisfied at each pixel, we normalized the residual by the spatial gradient of brightness at each pixel by the following equation:

$$\varepsilon = \frac{\left| p_x v_x + p_y v_y + p_t \right|}{\sqrt{(p_x)^2 + (p_y)^2}} \qquad (9)$$

If OFC equation is completely satisfied over a local region, ε becomes zero.

Estimation of Gradients

An image does not provide only the discrete pixel values, but there is a strong correlation among pixels. Therefore, an accurate and consistent estimation of gradients are necessary for motion estimation. For estimating gradients, we have used central divided difference method including all pixels within local region. p_x, p_y, and p_t at position (x, y, t) in the ultrasonogram images estimate as:

$$p_x = \frac{1}{4}\sum_{h=t}^{t+\delta t}\sum_{g=y}^{y+\delta y}\{p(x+\delta x,g,h) - p(x-\delta x,g,h)\}$$

$$p_y = \frac{1}{4}\sum_{h=t}^{t+\delta t}\sum_{f=x}^{x+\delta x}\{p(f,y+\delta y,h) - p(f,y-\delta y,h)\}$$

$$p_t = \frac{1}{4}\sum_{f=x}^{x+\delta x}\sum_{g=y}^{y+\delta y}\{p(f,g,t+\delta t) - p(f,g,t-\delta t)\}$$

3. FREQUENCY ANALYSIS OF TISSUE-MOTION

The discrete Fourier transform is meaningful to inspect magnitude versus frequency plot for changes the discrete tissue motion versus time at a particular frequency than to observe the tissue-motion with time variation. Since time variant tissue-motions contain different frequency components, so the analysis by Fourier transform is helpful to detect such frequency in which pulsation occurs.

The tissue-motion at any pixel position $V(x,y,t)$ can state as $V(k\delta t)$, at any position (x,y) with sampling interval, δt where k is the sample index . $[0 \le k \le n-1]$

Now, the discrete Fourier transform, $V(f)$ of n-number of samples, time variant tissue-motion as one-dimensional function, $V(k\delta t)$ defines as [5]:

$$V(f) = \sum V(k\delta t)e^{-\frac{j2\pi fk}{n}} \qquad (10)$$

Where, f = frequency index.

At a particular frequency $V(f)$ has two parts; i.e. one is real part that contains cosine term, $R(f) = \Re[V(f)]$ and the other is imaginary term, $I(f) = \Im[V(f)]$ and therefore the power spectral density of motion, $P(f)$ gives as:

$$P(f) = |V(f)|^2 = R^2(f) + I^2(f) \qquad (11)$$

Pulsation frequency, f_p at which the maximum spectral density occurs, evaluates among different frequency components by the following relationship:

$$f_p = \max_{1 \le f \le n/2}\{P_f(x,y)\} \qquad (12)$$

where P_f is the power spectrum at any position in the harmonic image.

4. EXPERIMENTAL RESULTS AND ANALYSIS

The original cranial ultrasound images of the newborn baby head takes in B-mode by using an ultrasound probe of 5 MHz and recorded on video tapes at the site of pediatricians. Then, PCI-based PC captured a series of ultrasound echo images (32 frames, 640×480 pixels/frame, 8 bits/pixel, 33 ms/frame) with video digitizer. Figure 1 shows a typical image in the anterior coronal section in the cranial ultrasonogram. The detailed scheme of essential tissue in this section shows in Fig.2.

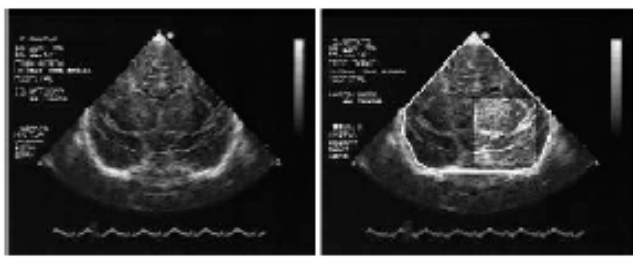

Figure 1. Typical ultrasound image in the anterior coronal section of a neonatal cranium.

In the right hand side of Fig. 1, the necessary tissues and organs show within the white boundary line. Outside it, there are cranial bone and echo artifacts. From figure 2, it is also found that coronal image has almost the symmetric property with left and right parts.

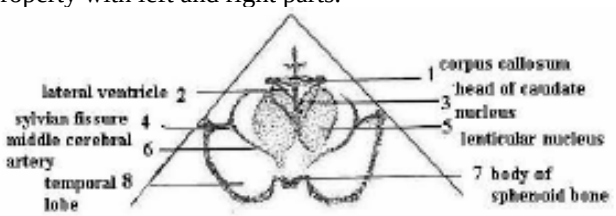

Figure 2. The essential tissue-scheme in the anterior coronal section.

Therefore, we can use a portion of the image square block with enhanced brightness, Fig. 1 in a sequence in our analysis.

As preprocessing steps, we have checked several critical conditions of the image sequence, such as

- Sway of the ultrasound probe
- Sway of the head of baby
- Discontinuity of the image frames
- Completely dark or bright of any image

We calculate the tissue-motion velocity at each pixel by using a local region of 3×3 window around the calculated pixel in consecutive three frames of cranial ultrasound echo images of the newborn baby head by using the spatial and temporal gradients. For computing the frequency components of tissue-motion, we use fast Fourier transform [8]. We do not consider the motion appeared outside cranial bone. In addition, motion is absent at the region of cranial bone. For simplicity, we have used a portion of the image in the sequence, since it contains the essential tissues and organs such as middle cerebral artery, sylvian fissure and temporal lobe, shows as enhance in Fig. 1.

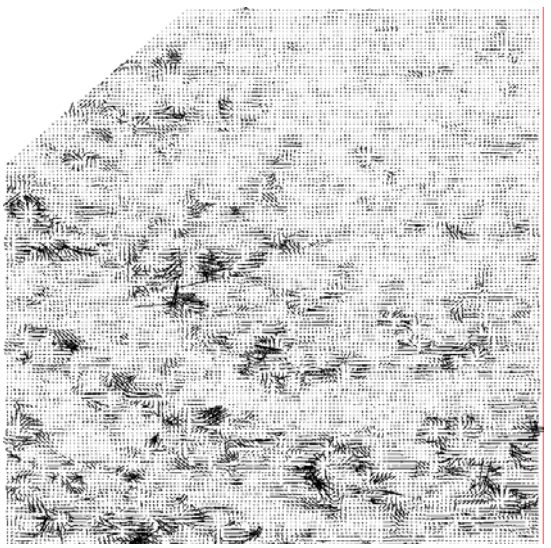

Figure 3. Two-dimensional maps of time-variant tissue-motion vectors in the anterior coronal section of cranial ultrasonogram of newborn baby head.

Figure 3 shows the two-dimensional maps of time-variant tissue-motion vector of the portion of cranial ultrasonogram. The magnitude of tissue-motion vectors normalize so that the distance between two neighbour pixels in the map corresponds to 0.5 pixels/frame. The tissue-motion vectors vary with place and its magnitude becomes up to a few pixel/frame at several region within the cranial bone. The middle cerebral artery is one of the essential arteries in the brain and there are fine arteries around sylvian fissure and corpus callosum. The spatial distribution of large motion vectors has found in the above regions. On the other hand, motion vectors become zero on the cranial bone and at such tissues as lenticular nucleus. Furthermore, the maximum vectors align to the same directions at many regions of the images.

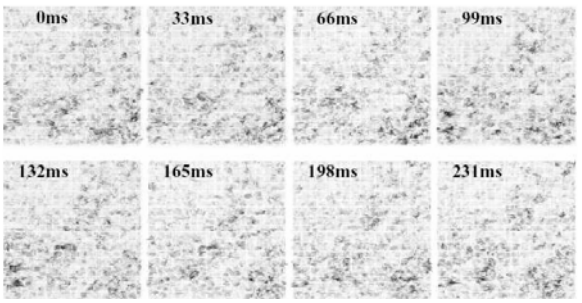

Figure 4. Time-variant tissue-motion velocities

The motion vectors do not vary only place but also with time, which shows Fig. 4. Pulsation regions are found with strong pulsation and the magnitude of motion is high in the region of middle cerebral artery and near region. Thus, it is very useful to observe the periodical variation of motion as well as the magnitude of tissue motion over time in different area where different organs are involved.

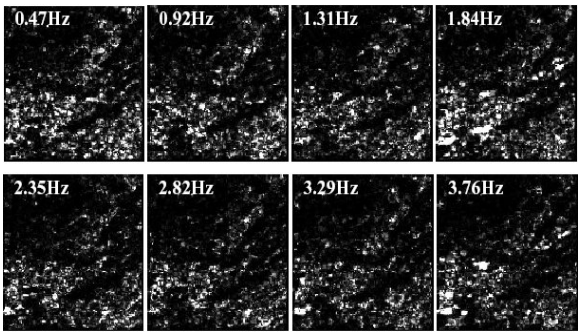

Figure 5. Power spectrum of tissue-motion at different frequency.

The heart rate of the typical baby is 140 per minute observed at the time of image sequence capturing. Therefore, the heartbeat interval of this typical baby is 429ms. The corresponding pulsation frequency is 2.33Hz. By using sampling interval 33 ms and the number of samples 64, the frequency resolution is obtained at 0.47 Hz. Therefore, fundamental frequency of the heartbeat occurs in between 4th and 5th harmonic frequency of tissue-motion. This illustrates in Fig. 5, where the power spectrum of tissue-motion at different frequency is shown.
We show only a few images out of a large number of images. The strong pulsation is found in the image that corresponds to the frequency of 1.84Hz and 2.35 Hz. Therefore, strong pulsation is found in a frequency, which is not the fundamental frequency of heartbeat frequency but the harmonic frequency of pulsation frequency.

This fact represents that pulsation is not sinusoidal, and the period of Fourier transform is not equal to the integer time of the period of heartbeats. The normalized power spectral density is shown in Fig. 6 at different frequency. Here 31 frequency components are shown. It is clear that tissue-motion contains several harmonic pulsation frequency components.

From figure 6, it is clear that the strong pulsation occurs at 4th harmonic frequency of heartbeat frequency and the tendency of the neighbor frequency is high enough. We have tested several sections, using both 32 and 64 samples, several cranial ultrasonogram images of newborn babies, and find the similar results. The babies exhibit different pulsation, since their physical conditions were different. The plot in Fig. 7 shows the normalized power spectrum of some babies at different pulsation frequency.

It is shown that some cases exhibit the fluctuations whereas the other cases the fluctuations is not significant. The strong pulsation is not found in the fundamental frequency, it is found in the harmonic frequency. For each case, the fundamental heartbeat frequency is different and it is the harmonic frequency of pulsation frequency.

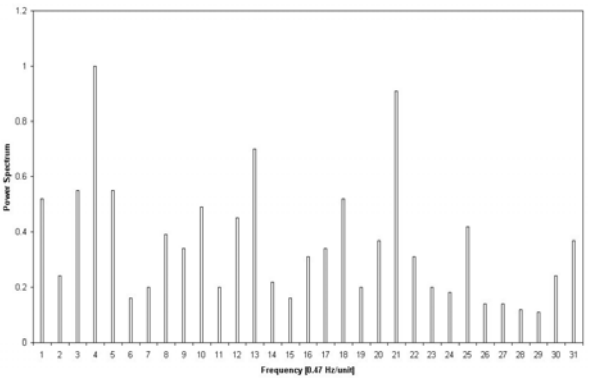

Figure 6. Histogram showing the power spectral density at different frequency.

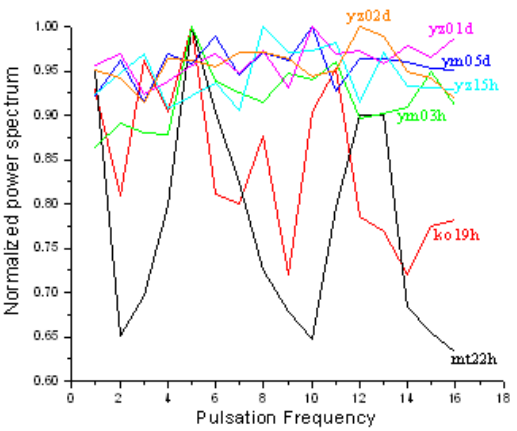

Figure 7. Pulsation frequency with normalized power spectrum for some cases.

5. CONCLUSIONS

In order to characterize artery pulsation quantitatively, the tissue-motion computes successfully at each pixel by using gradient-based approach with location optimization optical flow technique. Since tissue-motion does not affect the spatial variation of image brightness, therefore the strength of artery pulsation can estimate quantitatively by using the magnitude of tissue-motion velocity. From frequency analysis, it is found that pulsation is associated with blood flow. Blood flow changes periodically with heartbeat and Fourier transform of time variant motion verifies the fact. Strong pulsation finds at a harmonic frequency, which relate to the heartbeat frequency, and the tissue-motions are not sinusoidal.

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