Extraction of Temporal Motion Velocity Signals from Video Recordings of Neonatal Seizures by Optical Flow Methods

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Abstract—**This paper presents a procedure developed to extract quantitative information from video recordings of neonatal seizures in the form of temporal motion velocity signals. These signals are obtained from the velocity fields computed for successive frames of the video recording by a variety of optical flow methods. The experimental results provide evidence that the motion velocity signals produced by the proposed procedure constitute an effective representation of videotaped clinical events and can be used for seizure recognition and characterization.**

Keywords—**Motion velocity signal, neonatal seizure, optical flow, velocity field, video recording**

I. INTRODUCTION

Seizure occurrence represents the most frequent clinical sign of central nervous system disorders in the newborn [4], [9], [10]. Thus, prompt recognition of seizures in the neonatal intensive care unit is very important with regard to diagnosis and management of underlying neurological problems. Video recording is typically used with synchronized EEG and other polygraphic measures to analyze the characteristics of a seizure after its recording [3], [4], [9], [10]. Recent developments in video processing and analysis research can facilitate the characterization and recognition of neonatal seizures. This can be accomplished by extracting from video recordings of neonatal seizures quantitative information that is relevant only to the seizure. This information can be used to: 1) refine the characterization of repetitive motor behaviors, and 2) facilitate the differentiation of certain clinical seizures from other abnormal paroxysmal behaviors not due to seizures.

Neonatal seizures can be quantified in terms of temporal motion strength and motor activity signals [6], [7]. This paper introduces a new approach to extracting quantitative motion information from video recordings of neonatal seizures in the form of temporal motion velocity signals. Motion velocity signals are obtained from the velocity fields computed for successive frames of the video recording by a variety of optical flow methods.

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II. OPTICAL FLOW METHODS

Optical flow is the term used to indicate the velocity field generated by the relative motion between an object and the camera in a frame sequence. Optical flow provides important information for analyzing motion in video. In the absence of any additional assumptions about the nature of motion, optical flow computation based on two successive frames is an ill-posed problem. A problem is called ill-posed if its solution is not unique and/or if its solution does not depend continuously on the data [2].

Let $I = I(x, y, t)$ denote the continuous space-time intensity distribution. If the intensity remains constant along a motion trajectory, then $dI(x, y, t)/dt = 0$. This latter condition can also be written as

$$\frac{\partial I}{\partial x} u + \frac{\partial I}{\partial y} v + \frac{\partial I}{\partial t} = 0, \qquad (1)$$

where $u \doteq dx/dt$ and $v \doteq dy/dt$ denote the components of the coordinate velocity vector in terms of the continuous spatial coordinates. Equation (1) is known as the optical flow equation (OFE). The OFE is not sufficient to uniquely specify the 2-D velocity field. The remainder of this section outlines the methods employed in this study to estimate the velocity field [1], [5], [8].

A. Block Motion Model

This method is based on the assumption that the velocity vector remains unchanged over a block B of pixels, that is, $\mathbf{w}(x, y, t) = \mathbf{w}(t) = [u(t) \;\; v(t)]^T$, $\forall \; (x, y) \in B$ [8]. Optical flow can be estimated by minimizing

$$E = \sum_{(x,y)\in B} (I_x u(t) + I_y v(t) + I_t)^2, \qquad (2)$$

where $I_x \doteq \partial I/\partial x$, $I_y \doteq \partial I/\partial y$, and $I_t \doteq \partial I/\partial t$. The conditions $\partial E/\partial u(t) = 0$ and $\partial E/\partial v(t) = 0$ give

$$\sum_{(x,y)\in B} (I_x u(t) + I_y v(t) + I_t)\, I_x = 0, \qquad (3)$$

$$\sum_{(x,y)\in B} (I_x u(t) + I_y v(t) + I_t)\, I_y = 0. \qquad (4)$$

The velocities $u(t)$ and $v(t)$ can be obtained by solving the set of linear equations (3) and (4).

B. Horn and Schunck Method

The Horn and Schunck method seeks a motion field that satisfies the OFE with the minimum pixel-to-pixel variation among the velocity vectors [5]. The pixel-to-pixel variation of the velocity vectors can be quantified by

$$\varepsilon_s^2(u,v) = \left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 . \quad (5)$$

According to (5), $\varepsilon_s^2(u,v)$ measures the smoothness of the velocity field.

According to the Horn and Schunck method, the velocity vector at each point (x,y) can be estimated by solving the following minimization problem

$$\min_{u,v} \int_A \left(\varepsilon_{of}^2(u,v) + \alpha^2 \varepsilon_s^2(u,v)\right) dx dy , \quad (6)$$

where $\varepsilon_{of}(u,v,t)$ is defined in terms of the OFE as

$$\varepsilon_{of}(u,v,t) = I_x u + I_y v + I_t , \quad (7)$$

and A denotes the continuous image support. The regularization parameter α controls the strength of the smoothness constraint and is usually selected heuristically. The minimization problem in (6) can be dealt with by solving the following equations [5]

$$\alpha^2 \nabla^2 u = (I_x u + I_y v + I_t) I_x , \quad (8)$$

$$\alpha^2 \nabla^2 v = (I_x u + I_y v + I_t) I_y , \quad (9)$$

where $\nabla^2 \doteq \partial^2/\partial x^2 + \partial^2/\partial y^2$ denotes the Laplacian operator. Horn and Shunck proposed the following iteration to estimate the optical flow [5]

$$u^{(n+1)} = \overline{u}^{(n)} - I_x \frac{I_x \overline{u}^{(n)} + I_y \overline{v}^{(n)} + I_t}{\alpha^2 + I_x^2 + I_y^2} , \quad (10)$$

$$v^{(n+1)} = \overline{v}^{(n)} - I_y \frac{I_x \overline{u}^{(n)} + I_y \overline{v}^{(n)} + I_t}{\alpha^2 + I_x^2 + I_y^2} , \quad (11)$$

where n is the iteration counter and all partial derivatives are evaluated at the point (x,y,t). According to the Horn and Schunck method, the velocity is estimated locally by averaging the velocities over an area W , that is,

$$\overline{u}^{(n)}(x,y,t) = \frac{1}{|W|} \sum_{(x,y)\in W} u^{(n)}(x,y,t) , \quad (12)$$

where $|W|$ denotes the cardinality of the set of pixels in W, and

$$\overline{v}^{(n)}(x,y,t) = \frac{1}{|W|} \sum_{(x,y)\in W} v^{(n)}(x,y,t) . \quad (13)$$

C. Modified Horn and Schunck Method

The Horn and Schunck method is one of the most powerful and widely used methods for optical flow computation. Nevertheless, there are some drawbacks intrinsically related to this approach. Perhaps the most notable of these drawbacks relates to the smoothness constraint imposed to the flow field in order to produce a solution. This constraint causes the estimated field to be incorrect where motion discontinuities are present. Bartolini and Piva [1] suggested that the use of median filtering preserves better motion boundaries. According to their approach, $\overline{u}^{(n)} = \overline{u}^{(n)}(x,y,t)$, and $\overline{v}^{(n)} = \overline{v}^{(n)}(x,y,t)$ can be obtained as

$$\overline{u}^{(n)}(x,y,t) = Median\left\{u^{(n)}(x,y,t),(x,y)\in W\right\} , \quad (14)$$

and

$$\overline{v}^{(n)}(x,y,t) = Median\left\{v^{(n)}(x,y,t),(x,y)\in W\right\} . \quad (15)$$

The modified method lacks the capability of the original Horn and Schunck method to fill in motion estimation where gradient information is poor. On the other hand, the modified method produces better velocity estimates at the motion edge [1].

III. EXTRACTION OF TEMPORAL MOTION VELOCITY SIGNALS FROM VIDEO

For each frame of the video recording, motion can be readily visualized by superimposing at each frame of the video recording the velocity vector $\mathbf{w} = [u \; v]^{\mathrm{T}}$ produced for this frame by optical flow computation. Moreover, the results of optical flow computation can be used to extract temporal motion velocity signals from video recordings of neonatal seizures. Such signals were obtained according to the procedure outlined below: Motion at frame $t = t_0$ was quantified by the maximum velocity

$$w_{\max}(t_0) = \max\{w(x,y,t_0),(x,y)\in \Re(t_0)\} , \quad (17)$$

where $\Re(t_0)$ is the region of the frame that contains the moving body part and $w(x,y,t_0)$ is the length of the velocity vector at the location (x,y) of frame t_0. The maximum velocity was used to quantify weak motion of body parts due to seizures. The temporal motion velocity signal was obtained for the entire video recording by plotting the maximum velocities as a function of time, i.e., for all frames of the recording.

IV. EXPERIMENTAL RESULTS

Figures 1 and 2 show the motion velocity signals extracted from the video recordings of neonatal seizures by utilizing the optical flow methods outlined in this paper. The locations of the moving body parts during the clinical event are shown in a representative frame of each video recording. The values of the signals corresponding to the frames shown at the top of each figure are indicated by dots, while the moving body part in each video recording is shown within a box. Figures 1 and 2 also show the velocity field produced for the region of the frame within the box.

Figure 1 shows some results produced by utilizing the block motion model and the Horn-Schunck method to compute the optical flow of a video recording of a myoclonic seizure affecting the infant’s right foot. The block motion model produced spurious velocity vectors of substantial magnitude for the background area below the infant's right foot. When tested with $\alpha = 1$, the Horn-Schunck method produced velocity vectors of substantial magnitude for the infant's right foot that was affected by the seizure. However, this method also produced velocity vectors of substantial magnitude and arbitrary direction for the background area and for locations at the infant's right leg that were not affected by the seizure. The velocity field was considerably smoother when the Horn-Schunck method was tested with $\alpha = 25$. In this case, almost all of the velocity vectors located at the infant's right foot were consistent with its motion along the horizontal direction. Finally, the velocity vectors located at the background were of lower magnitude compared with those produced by the same method tested with $\alpha = 1$. Comparison of the motion velocity signals produced for the entire video recording indicates that the optical flow methods tested in the experiments produced a motion velocity peak right after frame 160. This is consistent with the motion of the infant's right foot observed in the video recording. However, the three motion velocity signals differ in terms of the actual velocity estimates produced for a neighborhood around frame 160. These differences are revealed in Figure 1 by the height of the motion velocity peak. Frame-by-frame inspection of the entire video recording indicated that the most reliable motion velocity signals are those produced by the block motion model and the Horn-Schunck method tested with $\alpha = 25$.

Figure 2 shows the velocity fields and the motion velocity signals produced by the block motion model, the Horn-Schunck method, and the modified Horn-Schunck method outlined in this paper. Both versions of the Horn-Schunck method were tested in the experiments with $\alpha = 25$. The velocity vectors produced by the block motion model reveal the motion of the infant's right leg but most of them reveal substantial motion along the horizontal and vertical directions. In fact, the velocity field shown in Figure 2(a) does not reveal that the infant's right leg moves along the diagonal, which would constitute a better representation of the clinical event. The motion of the infant's right leg was better captured by the original Horn-Schunck method as indicated by Figure 2(b). However, this method distributed the velocity vectors almost uniformly over the entire area of the frame occupied by the infant's right leg. Frame-by-frame inspection of the entire video recording indicated that the motion caused by this seizure was better captured by the modified Horn-Schunck method. This method produced velocity vectors of substantial magnitude along the boundary of the infant's right leg. Compared with the original Horn-Schunck method, the modified Horn-Schunck method produced a motion velocity signal of higher amplitude. In fact, this signal constitutes a better representation of the rhythmic movement due to the focal clonic seizure. The motion velocity signal produced by the modified Horn-Schunck method is very similar with that produced by the block motion model. Thus, the block motion model seems to be more accurate in estimating the magnitude than the direction of the velocity vectors.

V. CONCLUSIONS

This paper describes the results of a study that utilized optical flow methods to quantify motion in video recordings of neonatal seizures. The computation of optical flow from video recordings of neonatal seizures can be a valuable motion visualization tool in clinical settings. In particular, visualization of motion would be of high diagnostic value during retrospective review. The experimental study outlined in this paper also indicated that the velocity fields computed from successive frames of the video recording can be used to produce a temporal motion velocity signal for the entire video recording. The results of this experimental study were used to evaluate the motion velocity signals produced by the block motion model, the Horn-Schunck method, and a modified version of the Horn-Schunck method. Further improvement and refinement of the procedure developed in this study can produce temporal motion velocity signals that constitute a consistent and effective representation of videotaped clinical events. This will be accomplished by testing the proposed procedure on a large database of video recordings of neonatal seizures and clinical events not due to seizures, which is currently in progress.

REFERENCES

[1] F. Bartolini and A. Piva, "Enhancement of the Horn and Schunck optical algorithm by means of median filters," *Proceedings, of 13th International Conference on Digital Signal Processing,* vol. 2, July 2-4, 1997, pp. 503-506.

[2] M. Bertero, T. A. Poggio and V. Torre, "Ill-posed problem in early vision," *Proceedings of the IEEE*, vol. 76, pp. 869-889, August 1988.

[3] C. D. Binnie, A. J Rowan, J. Overweg, H. Meinard, T. Wisman, A. Kamp, F. L. da Silva, "Telemetric EEG and video monitoring in epilepsy," *Neurology,* vol. 31, pp. 98-303, 1981.

[4] G. M. Fenichel, *Neonatal Neurology,* 3rd ed. New York, NY: Churchill-Livingstone, 1990.

[5] B. K. P. Horn and B. G. Schunck, "Determining optical flow," *Aritificial Intelligence*, vol. 17, pp. 185-203, 1981.

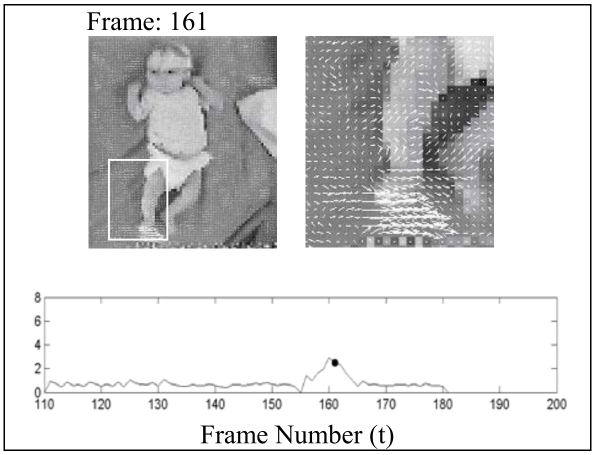
[6] N. B. Karayiannis, "Advancing videometry through applications: Quantification of neonatal seizures from video recordings," *Proceedings of Fourteenth International Conference on Digital Signal Processing,* Santorini, Greece, July 1-3, 2002, pp. 11-21.

[7] N. B. Karayiannis, S. Srinivasan, R. Bhattacharya, M. S. Wise, J. D. Frost Jr., and E. M. Mizrahi, "Extraction of motion strength and motor activity signals from video recordings of neonatal seizures," *IEEE Transactions on Medical Imaging,* vol. 20, no. 9, pp. 965-980, 2001.

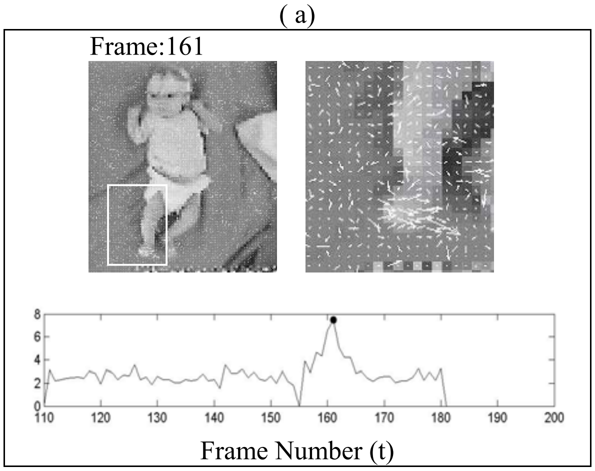
[8] B. D. Lucas and T. Kanade, "An iterative image registration technique with an application to stereo vision," *Proceedings of DARPA Image Understanding Workshop*, pp. 121-130, 1981.

[9] E. M. Mizrahi, "Neonatal seizures," in *Pediatric and Adolescent Medicine*, S. Shinnar, N. Amir, D. Branski (Eds.), Basel, Karger, vol. 6, pp. 18-31, 1995.

[10] J. J. Volpe. *Neurology of the Newborn*. Philadelphia: WB Suanders, 1995.



(a)



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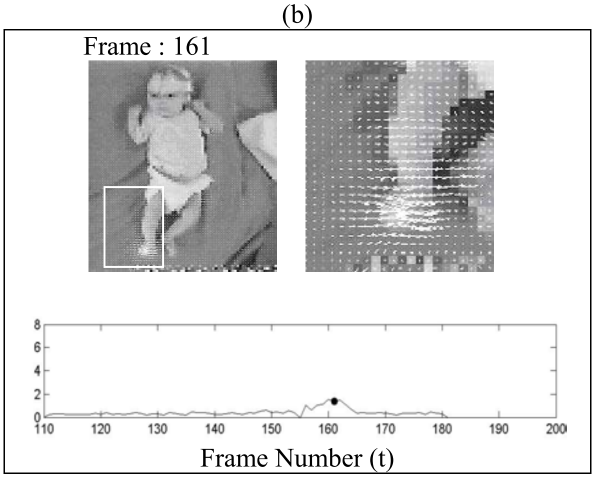
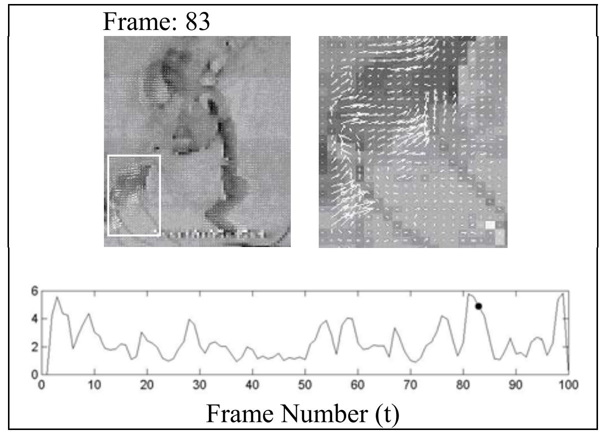
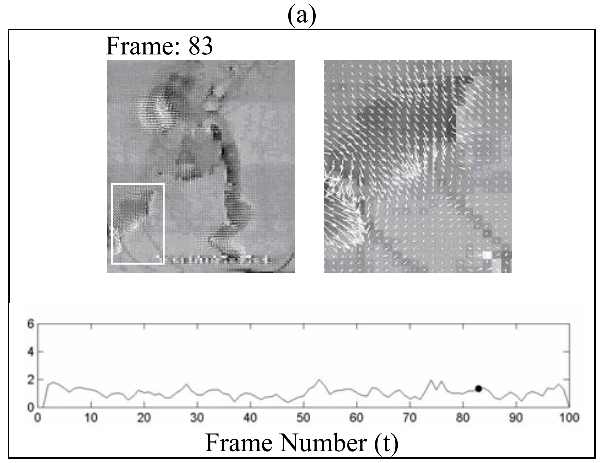


(c)

Figure 1: A selected frame of a myoclonic seizure affecting the infant's right foot shown with the velocity field produced for the magnified region of the frame and the motion velocity signal produced for the entire video recording by: (a) the block motion model, (b) the Horn-Schunck method with $\alpha = 1$, and (c) the Horn-Schunck method with $\alpha = 25$.



(a)



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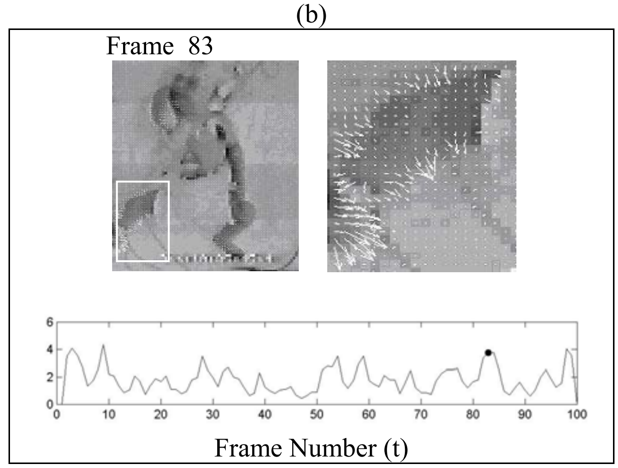

(c)

Figure 2: A selected frame of a focal clonic seizure affecting the infant's right leg shown with the velocity field produced for the magnified region of the frame and the motion velocity signal produced for the entire video recording by: (a) the block motion model, (b) the Horn-Schunck method with $\alpha = 25$, and (c) the modified Horn-Schunck method with $\alpha = 25$.