A Motion-based System to Evaluate Infant Movements Using Real-time Video Analysis

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Abstract — **This paper proposes a marker-less motion measurement and analysis system for quantitative evaluation of movements of infants. In this system, movements of infants are measured using a single video camera, and then changes of body position and motion in infants are calculated from binarized images, which are extracted using background subtraction or inter-frame difference. Furthermore, eight indices are derived for quantitative evaluation of movements of infants, such as body activity level and amount of body motion. Base on these data, doctors can therefore get an intuitive understanding of the movements of infants without long-period observation. This is considered helpful for supporting diagnosis and detecting of infants' disability or function diseases in the early stages. In this paper, the evaluation indices and features of movement between 14 full-term infants (FTIs) and 11 low-birthweight infants (LBWIs) are compared using the prototype developed. The experimental results show that, with some LBWIs, the upper body moves more than the lower body compared with FTIs, demonstrating that the proposed system can quantitatively evaluate the difference between the movements of FTIs and LBWIs.**

Keywords — **infant, movement analysis, video image processing, monitoring system**

I. Introduction

Early detection of neuromotor disorders and prediction of later movement problems in infants is of paramount importance to improve and mitigate the severity of such conditions. Techniques for detection of infant neuromotor disorders based on infant movements have been widely adapted and discussed in clinical environments [1][2]. However, objective and quantitative evaluation of infant movements is difficult even for highly trained doctors. Techniques that enable simple screening test and quantitative evaluation of the movements of newborn babies would therefore be useful in the early detection of infant neuromotor disorders, and would also reduce the burden on doctors.

Recently, quantitative evaluation methods for the movement of newborns have been developed using three-dimensional movement analyses [3][4]. These previous studies suggest the possibility of distinguishing between full-term and pre-term infants [4]. However, these camera systems are concerned with the burden on newborn babies, since a large number of markers are necessary to measure the movements. Furthermore, it might be difficult to measure the movements for screening in general clinical environments, because such systems are expensive and time-consuming. To overcome these problems, it is preferable to develop a method that can measure and evaluate movements quantitatively, without using markers.

This paper proposes a system to measure and quantitatively evaluate infant movements. In this system, feature quantities related to body movements of infants are extracted from video images recorded by a single video camera without using markers. The body movements are then evaluated using eight indices (such as body activity, amount of body motion and symmetry of limb movements), computed from the feature quantities. Display of the evaluation results and feature quantities enables users to easily understand the changes in an infant's condition.

II. System for measurement and analysis system

The structure of the proposed system is shown in Fig. 1. The details of each process are explained in the following subsections.

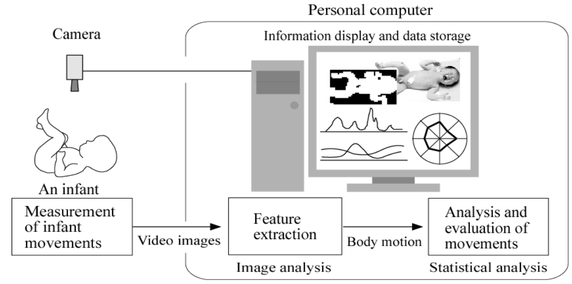

Fig. 1 Concept of the proposed motion measurement and analysis system for the infants

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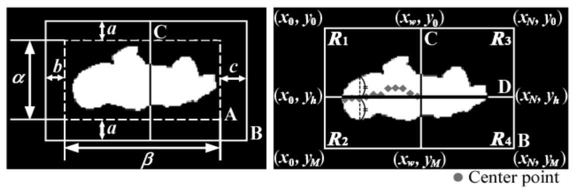
(a) Input image captured CCD camera (b) Difference image between input image and the background (c) Difference image between successive two input images

Fig. 2 Binary images obtained from input images



(a) An example of analysis (b) An example of divided area

Fig. 3 Initialization of motion analysis image

A. Measurement of infant movements

A camera is used to measure the movements of an infant in an incubator. The video images were stored on a computer database using a video image grabber board (sampling frequency: f_S [Hz]).

B. Feature extraction

Examples of video images and binary images for extraction of the movement features are shown in Fig. 2. In this paper, brightness components are extracted from video images, and are then binarized using background subtraction (to create a *body position distribution image*) with a threshold T (the pixel values of the area are set as 1 (white), and those of the background area are set as 0 (black); see Fig. 2(b)). In addition, a binary image representing the infant's movement area (called as a *movement distribution image*) is extracted using inter-frame difference (the pixel values of the movement areas become 1; see Fig. 2(c)).

Here, in order to improve the computational efficiency, the region-of-interest (ROI) area related to infant's body movement is extracted for analysis. First, a rectangle around the white pixels of the body position distribution image integrated for a number of consecutive seconds is defined as area A ($\alpha \times \beta$ [pixels]) (see Fig. 3(a)). Then, margins (a, b, and c) are set on the four sides of area A, respectively, and the extended area is defined as B (see Fig. 3(b)). The origin point (x_0, y_0) of area B is top-left. Suppose the number of pixels on the x- and y-axes are N and M, the numbers of pixels on the x- and y-coordinates of the image are set as x_n ($n = 1, 2, \ldots, N$) and y_m ($m = 1, 2, \ldots, M$), respectively.

By setting baselines in the area B, it can be divided into four areas, one represents each of the infant's limbs. First, area A is divided at the ratio of d to (1-d) based on the ratio of upper to lower body, and the row $x = x_w$ is then defined as baseline C. Further, the area of the upper body ($x_0 < x_n < x_w$, $y_0 < y_m < y_M$), which is extracted from area A by baseline C, is divided into the left and right sides of the body, and that line is then defined as baseline D. In this paper, for the decision of baseline D, the middle points of the longest row of white pixels are calculated in each row of the y-axis. The line of the x-axial $y = y_h$ ($0 < h < M$) included in the large numbers of the middle points is decided as baseline D. Here, the areas corresponding to each region divided using baselines C and D are defined as R_k ($k = 1, 2, \ldots, 9$), where R_1 to R_4 represent the area of the infant's left shoulder, right shoulder, left leg and right leg, respectively. In addition, R_5 is the area of the upper body, R_6 is the lower body, R_7 signifies the left side of the body, R_8 describes the right side of the body, and R_9 is the entire body.

As the feature quantities of infant movements in each area R_k ($k = 1, 2, \ldots, 9$), the *change of position* ${}^{(k)}W_l$ and *motion* ${}^{(k)}O_l$ with respect to time are defined as follows:

$$ {}^{(k)}W_l = \sum_{n=0}^{N-1}\sum_{m=0}^{M-1} {}^{(k)}g_l(x_n, y_m) \tag{1}$$

$$ {}^{(k)}O_l = \sum_{n=0}^{N-1}\sum_{m=0}^{M-1} {}^{(k)}g_l'(x_n, y_m) \tag{2}$$

$$ {}^{(k)}g_l'(x_n, y_m) = \left| {}^{(k)}g_l(x_n, y_m) - {}^{(k)}g_{l-1}(x_n, y_m) \right| \tag{3}$$

Here, ${}^{(k)}g_l(x_n, y_m)$ is the value of each pixel in the body position distribution image in area R_k (${}^{(k)}g_l(x_n, y_m) = 1$ represented by the white pixels, and ${}^{(k)}g_l(x_n, y_m) = 0$ by the black pixels; ${}^{(k)}g_0(x_n, y_m) = {}^{(k)}g_1(x_n, y_m)$), l ($l = 1, 2, \ldots, L$) is the frame number, and L describes the total number of frames in the video image.

C. Analysis and evaluation of movements

In the analysis and evaluation stage, quantitative evaluation indices are calculated based on medical knowledge [5] from the feature quantities of body movements. In this paper, the computational and standardization methods of eight indices to enable comparison of the differences in movements are described as follows.

(1) Body activity and amount of body motion

Body activity and amount of body motion referred as the rate of activity time and the amount of motion within the measurement time are calculated from the change in motion ${}^{(k)}O_l$. First, the threshold ${}^{(k)}M_{th}$ defined by Eq. 4 is used to judge whether movement has occurred in the infant.

$$ {}^{(k)}M_{th} = r\,{}^{(k)}W_l \quad (0 < r < 1) \tag{4}$$

Points at which the change in motion ${}^{(k)}O_l$ increases to threshold ${}^{(k)}M_{th}$ are defined as the infant's activity time, and body activity ${}^{(k)}ACT$ is then calculated from the ratio of activity time to all measurement time as follows:

$$ {}^{(k)}ACT = \frac{1}{L}\sum_{l=1}^{L} {}^{(k)}A_l \times 100 \tag{5} $$

$$ {}^{(k)}A_l = \begin{cases} 1 & ({}^{(k)}O_l \geqq {}^{(k)}M_{th}) \\ 0 & ({}^{(k)}O_l < {}^{(k)}M_{th}) \end{cases} \tag{6} $$

Next, the amount of body motion ${}^{(k)}MOV$ during the movement per unit time is calculated using Eqs. 7 and 8.

$$ {}^{(k)}MOV = \frac{1}{L}\sum_{l=1}^{L} \frac{{}^{(k)}M_l}{{}^{(k)}S} \tag{7} $$

$$ {}^{(k)}M_l = \begin{cases} O_l & ({}^{(k)}O_l \geqq {}^{(k)}M_{th}) \\ 0 & ({}^{(k)}O_l < {}^{(k)}M_{th}) \end{cases} \tag{8} $$

Here, ${}^{(k)}S$ is the number of pixels in each area.

(2) Displacement and fluctuations in COG

Center of gravity (COG) displacement of body position and fluctuations in COG x- and y-axially are extracted from the change of position ${}^{(k)}W_l$ and the body position distribution image. From this image, the coordinates of COG ($G_{x,l}$, $G_{y,l}$) are calculated by Eqs. 9 and 10.

$$ G_{x,l} = \frac{1}{{}^{(k)}W_l}\sum_{n=0}^{N\text{-}1}\sum_{m=0}^{M\text{-}1} x_n \, {}^{(9)}g_l(x_n, y_m) \tag{9} $$

$$ G_{y,l} = \frac{1}{{}^{(k)}W_l}\sum_{n=0}^{N\text{-}1}\sum_{m=0}^{M\text{-}1} y_n \, {}^{(9)}g_l(x_n, y_m) \tag{10} $$

Displacement in the COG D_m is defined as follows:

$$ D_m = \frac{1}{L}\sum_{n=0}^{N\text{-}1}\left(\frac{\sqrt{D_{x,l}^2 + D_{y,l}^2}}{{}^{(k)}W_l} \right) \tag{11} $$

where $D_{x,l} = G_{x,l} - G_{x,l\text{-}1}$, $D_{y,l} = G_{y,l} - G_{y,l\text{-}1}$, $G_{x,0} = G_{x,1}$, $G_{y,0} = G_{y,0}$. In addition, fluctuations in COG x and y signify the center frequencies of the power spectrum density calculated using the fast Fourier transform (FFT) from the x- and y-coordinates of the COG.

(3) Symmetry of movement, ratio of amount of body motion and ratio of body activity

Symmetry of movement describes the correlation between each area divided in the images calculated using the standardized cross-correlation function from the change in motion ${}^{(k)}O_l$ smoothed through a second-order Butterworth low-pass filter (cutoff frequency: f_p [Hz]). In addition, the ratios of amount of body motion and of body activity are defined as the ratio between feature quantities of each area.

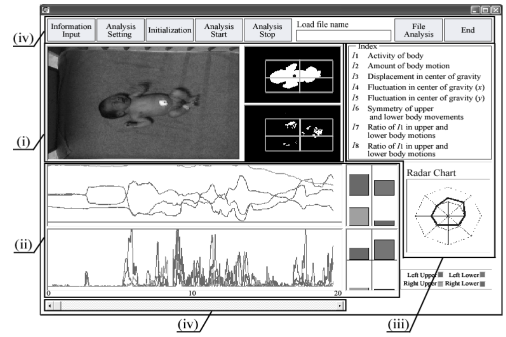


Fig. 4 An example of the operation scene of the prototype system

(4) Standardization of indices

The calculated evaluation indices for the infant are normalized to enable comparison of the differences in movement. In this paper, the standard normally distributed variables I_j are converted to the mean and standard deviations of the measurement data for full-term infants using Eq. 12.

$$ I_j = (z_j - \mu_j) / \sigma_j \tag{12} $$

Here, j corresponds to the index number, z_j is the computed value in each index, and μ and σ describe the average and standard deviation of each index in the full-term infant group, respectively. In the proposed method, I_1 represents the activity of the entire body ${}^{(9)}ACT$, I_2, I_3, …, I_8 signify the amount of entire body motion ${}^{(9)}MOV$, the entire displacement in COG D_m, and fluctuations in COG x- and y-axially, the symmetry of movement, the ratio of body mot-ion activity ${}^{(5)}ACT$ / ${}^{(6)}ACT$, and the ratio of amount of body motion ${}^{(5)}MOV$ / ${}^{(6)}MOV$, respectively.

D. Graphical output

The measured infant movements, the feature quantities, and the indices are provided to doctors on a display. A screenshot of interface of the proposed system is shown in Fig. 4. During operation, the monitor displays the following information: (i) a video image of the infant recorded using a camera, and the extracted binary images (distribution of body position and movement); (ii) feature quantities of position and movement calculated from the distribution of body position and movement; (iii) indices and radar charts computed from the feature quantities of position and movement; (iv) operation buttons and a scrollbar to allow video playback for a specific period, and changes in the scale of the waveform. The doctor can visually check infant's movements by playing the section of video corresponding to the time when abnormality appears in the feature quantities or radar chart.

III. Experiments

Method: Subjects consisted of 14 full-term infants (FTIs) (A-N) and 11 low-birthweight infants (LBWIs) (2,500 [g] or less) (O-Y). The 10 FTIs (A-J) were measured for 5 minutes, and the other infants were tested for about 50 minutes. In addition, the evaluation indices were extracted for 5-minute intervals, and the mean value and standard deviation for all measurement times were then calculated. The calculated indices were standardized on the basis of the values obtained from the 14 FTIs. The parameters of the experiments were f_S=30 [Hz], f_p=5 [Hz], d=0.55, r=0.01 and T=15 or T=45. The window length of FFT was 128 sets of sampled data, and the number of overlapping was 127; the corresponding values for the standardized cross-correlation function were 300 and 299, respectively.

Results: Radar chart representation of results of the indices is shown in Fig. 5 (a) and (b), which illustrate the indices of FTIs and LBWIs, respectively. Each axis shows the standard deviation of the 14 FTIs (A-N), the solid lines describe the average number of FTIs, and the dotted lines show the minus triple, triple and sextuplicate of the standard deviation in Fig. 5. Further, the heavy line shows the average value, and the shaded area indicates the standard deviation in each index. As an example of the feature quantities used for index computation, the change in motion of the upper and lower body of an FTI and a LBWI are shown in Fig. 6. The horizontal axis represents time, and the vertical axis describes the change in motion $^{(k)}O_l$.

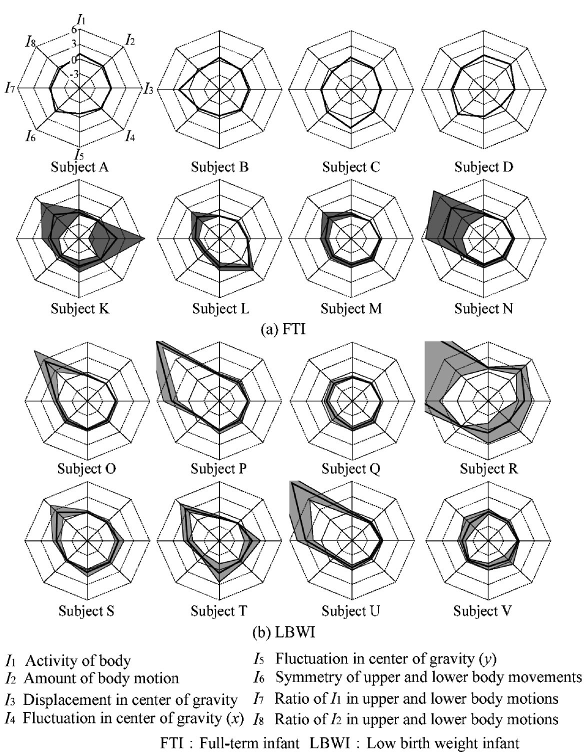


Fig. 5 Evaluation indices in each FTI and LBWI

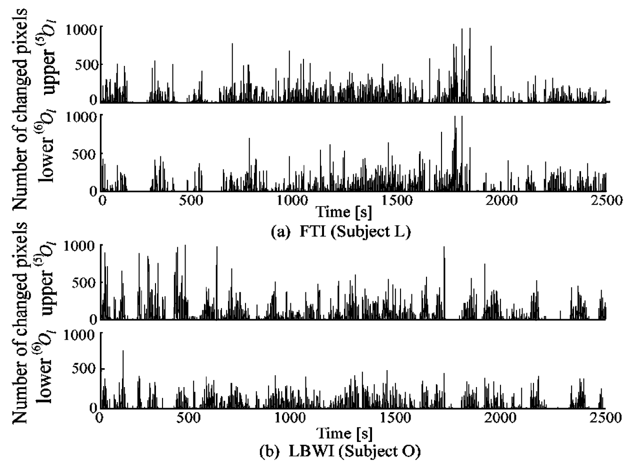


Fig. 6 The change of the FTI Subject L and LBWI Subject O

IV. Discussion

The evaluation experiments demonstrated that all indices were close to the average value for all FTIs, except subjects K and N, but the indices are of large variation with most LBWIs (especially subjects O, P, R, T and U). Since the values of index I_8 for these subjects were large, it is thought that the lower body movements were small compared with movement of the upper body. Further, from the example of the movements of subject O (Fig. 10), it can be observed that those of the upper body were larger than those of the lower body. These results lead us to the conclusion that the extracted evaluation indices were able to reflect the movements of infants.

On the other hand, it is observed that some LBWIs have the same tendency as the mean values of the FTIs (subjects Q, S, and V). These results mean that the LBWIs do not have diseases despite their low birthweight and high risk of impaired motility function. Further, although subjects K and N were FTIs, their evaluation index variance was large, suggesting that their movements might be near those of LBWIs because their birthweights were comparatively low (subjects K and N were 2,738 [g] and 2,562 [g], respectively). Since the number of experimental subjects was small and the measurement time was short, it is necessary to investigate and make improvements for accurate evaluation.

V. Conclusion

This paper proposes a quantitative system to measure and evaluate infant movements. The system calculates eight evaluation indices from feature quantities of motion extracted from binarized images of infants without markers using a single video camera. This enables doctors to understand changes in an infant's movement condition, as video images, feature quantities and evaluation indices can be monitored on a real-time basis. In future research, we plan to increase the number of infants and measurement time, and investigate the relationships between motility function and abnormal movements in disabled and high-risk infants.

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