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Remote respiratory monitoring system based on developing motion magnification technique

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ABSTRACT

The aim of this study is to detect and measure the rate and timing parameters of the respiratory cycle at a distance from different sleeping positions of a baby based on video imagery. This study relied on amplifying motion resulting from movement of the chest caused by inhalation and exhalation. A motion magnification technique based on a wavelet decomposition and an elliptic filter was used to magnify breathing movement that is difficult to see with the naked eye. A novel measuring method based on motion detection was used to measure respiratory rate and its time parameters by detecting the fastest moving areas in the magnified video frame sequences. The video frames were converted into a corresponding logical matrix. The experimental results on several videos for the baby at different sleeping positions show that the remote respiratory monitoring system has an accuracy of 99%. The proposed system has very low computational complexity, is feasible and safe making it suitable for the design of next generation non-contact vital signs monitoring systems.

1. Introduction

Remote, non-invasive detection of vital signs has an increasing of research interest in clinical and biomedical applications. Respiratory rate is one of the most important vital parameters of interest in a clinical diagnostic and monitoring system. Generally, respiration measurement can be achieved by using contact methods, including nasal thermocouples, a respiratory-effort belt transducer, piezoelectric transducer, oximetry probe and electrocardiography (ECG). However, all of these methods are inconvenient and constrain the patient [1–3]. Therefore, researchers have developed a variety of non-contact methods to extract respiratory rate, including approaches based on radar sensors [4–10]. But using Doppler radar in measuring vital signs needs specialized hardware to provide radar frequencies and receive a reliable return signal. Current systems suffer significant signal to noise ratio (SNR) decreases at distances greater than 1 m between the radar and the patient due to increased free space loss at the frequencies employed [4]. In addition, the radar antenna must face the chest wall and any movement of the body during sampling will corrupt the measurements [4–10]. Furthermore, focused radar energy may have harmful side effects on biological tissue [11]. Some studies [2,12,13] used image sequence analysis captured by video camera to detect optical flow of movements of body surface on a bed resulting from respiration as non-contact methods to measure respiratory rate. Because the studies relied on optical flow calculations, the results were affected by motion artefacts, ambient light and computational complexity. Thermal cameras have been used in several studies [1,14–19] to measure respiratory rate based on skin temperature differences associated with inspiration and expiration of the patient. Although non-contact systems based on thermal cameras have succeeded as a way to monitor respiratory rate, its measurements are also corrupted by the body movements, head rotation, and particularly any apparatus that covers the face. These systems are unable to detect respiratory rate when the nasal region is not visible. Recently, several researchers have utilized video photoplethysmography imaging (PPGI) signals [20–23] to measure variations in the skin blood volume resulting from respiratory rhythms. Though PPGI is attractive in principle, previous studies were affected by illumination conditions, skin colour, and distance [21] that causes background noise to fall within the frequency band of interest. These methods cannot be utilized to reveal physiological signs in unclear regions of interest (ROIs); therefore, PPG cannot work on a baby that moves into many poses. The aim of this study is to develop a vision based remote respiratory monitoring system that is able to

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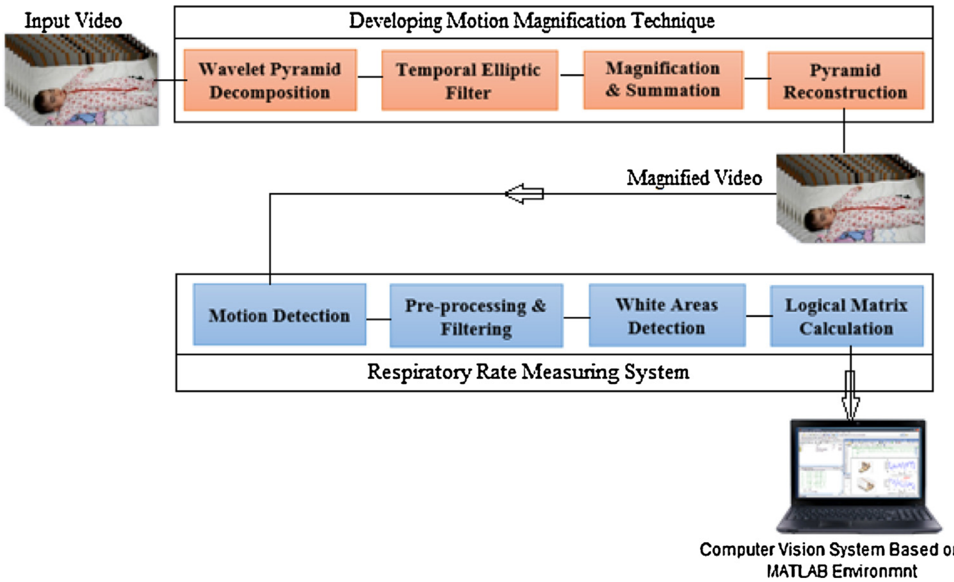

Fig. 1. Proposed system diagram of the remote respiratory monitoring system.

measure respiratory parameters at different baby positions, while being safe, cost effective, reliable and easy to use.

This study uses a video camera as an non-contact sensor to measure respiratory parameters by amplifying and monitoring chest or blanket movement based on two processing systems. The first processing system is called the developing video magnification technique. The video magnification technique [24] is developed by using a wavelet pyramid decomposition instead of Laplacian pyramid decomposition and an elliptic band pass filter instead of a Butterworth band pass filter. The developing motion magnification technique was used to magnify respiratory chest movements of the baby at different positions and it has higher values of peak signal to noise ratio (PSNR) than the Eulerian video magnification used in [24]. The second processing system performs motion detection based on frame subtraction. This algorithm was applied to magnified video to monitor respiratory parameters by detecting white areas in the frame sequences that correspond to respiratory motion. Then, a new measuring method was used to convert video frames into a logical matrix to calculate respiratory rate based on the average distance between ones in the logical matrix.

The paper is organised as follows. Section 2 presents the methodology of the proposed system. Section 3 presents experimental setup & proposed flowchart. Results obtained in this work are given in Section 4. Finally, results discussion and conclusions are given in Sections 5 and 6 respectively.

2. Methodology

There are two main processing systems for the remote respiratory monitoring system. The first system is called the developing motion magnification system. The second system is called the respiratory rate measuring system. A full system diagram for this study is shown in Fig. 1.

2.1. Developing motion magnification system

We enhanced and developed the video magnification system to suit the proposed application using wavelet pyramid decomposition and an elliptic band pass filter in terms of noise removal and video quality. Wavelet pyramid decomposition techniques were first applied to decompose input video into different spatial pools of frequencies and observe the differences in the video quality and video performance. Both spatial and temporal processing were implemented to observe small motion in the input video. We used one colour channel and converted RGB frames to YIQ colour space because it allows straight forward magnification of image intensity functions. The time series of the pixel value on all spatial levels of the pyramid were converted to the frequency domain through FFT for fast computation. The spatial bands obtained by decomposition were then passed through temporal elliptic band pass filters with selected frequencies of 0.4–0.8 Hz, corresponding to 24–48 breaths/min to extract the frequency bands of interest as well as attenuating the noise frequencies for the frames and thus increasing SNR. The extracted bands from temporal processing were then magnified by multiplying them with amplification factor (α) and these magnified signals were added back to the standard input video signals. To explain the relationship between head motion magnification and temporal processing and how the video magnification technique operated, let $I(x,t)$ denote the image intensity function that has moved between two frames at position x at time t. After a translational motion, the image intensity function can be given as:

$$I(x,t) = f\left(x + \delta(t)\right) \quad (1)$$

where $\delta(t)$ is a motion function (displacement function) and $I(x,0) = f(x)$ is the initial image function without any motion. Based on 1D Taylor series expansion [25,26], the image intensity function can be approximated at a time t as

$$I(x,t) \approx f(x) + \delta(t)\frac{\partial f(x)}{\partial x} \quad (2)$$

Taylor series expansion can also be applied to a 2D image. Assuming intensity variation function $B(x,t)$ is the result of applying a temporal band-pass filter to $I(x,t)$. The intensity variation function $B(x,t)$ can be expressed with the motion $\delta(t)$ falling within a passband filter range as:

$$B(x,t) = \delta(t)\frac{\partial f(x)}{\partial x} \quad (3)$$

To get the magnified intensity function $\hat{I}(x,t)$, the amplified function $B(x,t)$ by magnification factor (α) will be added back to the original intensity function $I(x,t)$, as follows

$$\hat{I}(x,t) \approx I(x,t) + \alpha B(x,t) \quad (4)$$