Remote monitoring heart and respiration rates using structured light and multi band camera

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Video based heart rate estimation based on the PPG technique is a remote optical technique allowing to determine the heart rate and breath rate through the intensity or motion variations. This paper proposes a new monitoring method for simultaneous estimation of the heart and respiratory rates using a vision system with structured light and a color camera.

Introduction

Recent advances in optics and computer vision technology have allowed the camera to become an instrumentation for monitoring vital signs remotely. The ability to determine physiological parameters, including the heart rate (HR) and the respiratory rate (RR), using a video camera has been recently reported in [1-3]. The majority of investigations are focused on how to decrease influence of head pose variations and facial expressions. In general, three basic steps in Imaging Photo Plethysmography (IPPG) can be distinguished: extraction of the intensity fluctuation signal, determination of the PPG signal, and heart rate estimation. Depending on the final application these three stages can be realized in many ways. The first step is selecting the most useful points or a set of points from the face image. The most common areas are determined automatically by finding the edge of face. For more accurate positioning, algorithms for facial features detection may be used. In the next step an unwanted low and high frequency noises are eliminated, caused by illumination changes and movements, respectively. This is realized using a bandpass filter [4] or signal detrending algorithms [5] connected with an averaging algorithms [6]. For a multidimensional signal (as RGB) a signal dimension reduction by linearly combining the channels is used. The two most popular techniques of Blind Source Separation (BSS) are based on ICA [7] or PCA (Principal Component Analysis) [5] methods. The HR estimation can be realized using a frequency analysis. The most popular algorithms are based on Fast Fourier Transform [4,5,7]. Determination of RR is usually done using the same process as for HR, by changing the range of bandpass filter. However, these methods are not effective, so it is often necessary to use a separate breath tracking system. Many solutions use time of flight (ToF) 3D image sensors [8]. The approach proposed in this work enable estimation of heart rates using a multiband camera, while respiratory rates are determined using a camera and a laser projection system.

Breath monitoring

The respiratory rate is calculated from a video of a chest and abdominal motions. We propose a novel technique to determine breath frequencies based on a structured light analysis and automatic procedure for type (chest or abdominal) recognition. Fig. 1 (left) provides an overview of the method and the test setup configuration.

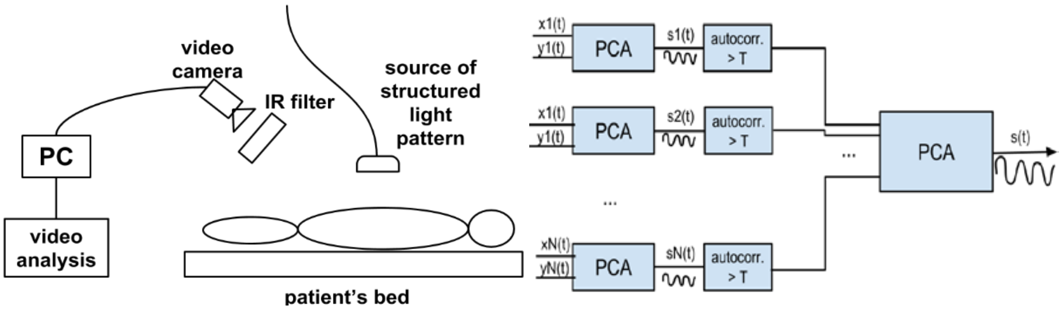

Fig.1 Structured light system setup and signal analysis process

The structured light random pattern is projected on the human thorax. The movements of the chest and abdominal are associated with breathing and are observed as the pattern deformation. The current frame is captured by the video camera and prepared for the further analysis. The projected and deformed light patterns are analyzed using a two-step approach. The first step uses the Lucas-Kanade optical flow method to track characteristic points.

The data analysis process consists of four main steps: dimension reduction of the landmark motion vector, false signal elimination, signal decomposition by PCA and spectrum analysis by fast Fourier transform. The first step allows to eliminate the motion artifacts and boost analyzed signals (Fig. 2). In order to further improve the signal quality and to determine the type of breath, an analysis of the signal autocorrelation coefficient is used. The respiration rate was determined by the signal analysis in the frequency domain as shown in Fig. 2 The peak of the respiratory rate can be easily identified after filtration corresponding to the signal bandwidth (0.04 Hz - 2 Hz).

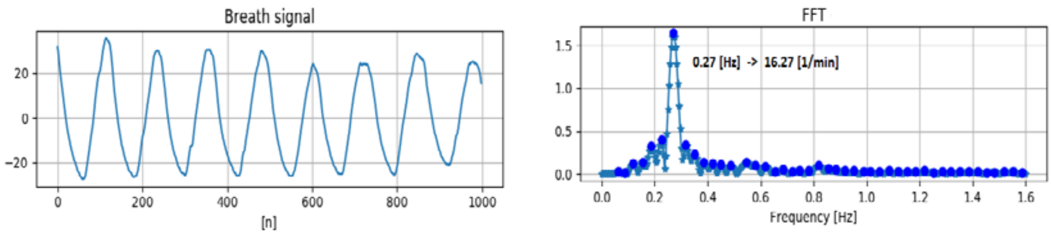

Fig. 2 Output breath signal with a calculated breath ratio 16.27/min

Blood pulse monitoring

The developed blood pulse monitoring system (Fig. 3) provides an idea of the method of extracting the blood pulse from a four-band image captured by a vision system. The proposed system consists of two cameras: a depth camera with RGB image and additional experimentally selected band (narrow red 590-610 nm).

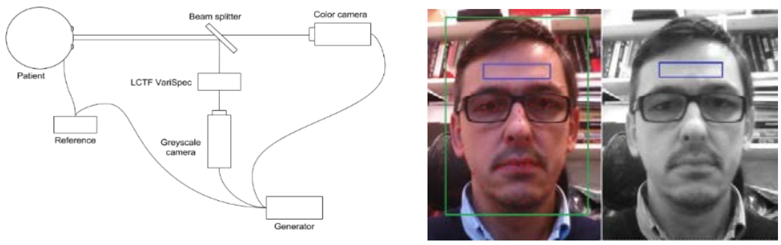

Fig. 3 The four-band camera system for blood-pulse monitoring (left). A sample RGB image with landmarks and nR-channel (narrow red) frame (right).

The reconstructed model is then used to carry data through different images. All steps are performed automatically, the only process where human intervention is needed is the calibration. The face detection algorithm [9] bases on the sliding window approach, utilizing two types of features: an extended set of Haar features and Histogram of Gradient (HOG) features. The set of features is then boosted into a strong classifier using the GentleBoost algorithm. The facial landmark detector finds the coordinates of facial landmarks on the patient's face in each frame of the video., using the method based on a K-Cluster Regression Forests solution [10]. Basing on these points the region of interest (ROI) is selected. Next, a spatial average of the four color channels (red, green, blue, narrow red) pixel values within the resulting ROI are calculated for each frame (Fig. 4). The raw traces are detrended using a technique based on empirical mode decomposition EMD [11]. This allows removing of only very low-frequency components of the signal, without damaging the high-frequency information. Then the ICA is applied to recover source signals from the observations. The heart rate is determined by finding the maximum frequency peak in the FFT spectrum. The spectrum is filtered using a Butterworth filter with low- and high-frequency cutoffs at 0.8 and 2.5 Hz, respectively, corresponding to acceptable pulse frequencies.

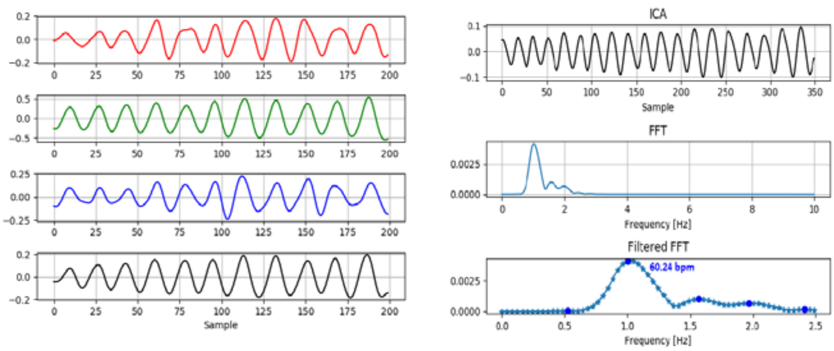

Fig. 4. Pulse signal processing: a) signals from four color channels, b) signal processing with heart rate peak detection.

Tests

To evaluate the performance of the proposed system, a series of experiments has been performed, in which avital signs of 15 persons have been detected. The reference heart rate (HR) was measured by the contact PPG device.

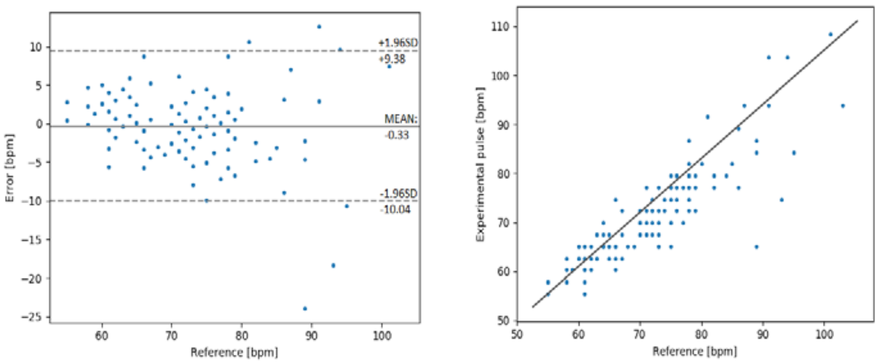

Figure 5. Correlation between experimental and reference measurements, Bland-Altman error plot.

The obtained results show that experimentally computed heart rate is well correlated with the reference measurements (Fig. 5). Pearson correlation coefficient is equal to 0.88. Differences between the experimental and the reference examinations were calculated. The resulted Bland-Altman plot with mean error value and 95% limits of agreement is presented on Fig. 5.

Conclusion

The proposed system based on structured light projector and video camera can be used for monitoring of the respiratory rate. Analysis based on Lukas-Kanade optical flow algorithm and Principal Component Analysis is a reliable method of estimation the respiratory rate. Additional autocorrelation analysis can improve the results of this method and be used for improving the signal quality or determining the type of breathing. We presented remote monitoring heart rates using a multiband camera system. The obtained results are comparable with similar approaches presented in [4,6,7]. The correlation coefficient between the camera and the reference contact finger measurements equals 0.88, which is an acceptable value for the video pulse monitoring method. Both setups, for breath and pulse monitoring, were resistant to small patient's movements.

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