Non-Contact Automated Heart Rate Measurements using Video Imaging

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***Abstract*—Remote Monitoring of vital signs such as Blood Pulse pressure(BP), Heart Rate(HR), Heart Rate Variability(HRV) and Respiratory rate has gained significant importance in the recent times. They are vital for knowing the physical state of an individual. The current methods for monitoring these parameters are invasive, expansive and not portable, most of them typically require patients to strap sticky electrodes, bulky sensors and chest straps and on their bodies. In this paper, we discuss a method of caliculating the heart beat using Independent Component Analysis and using the concept of photo-plethysmography(PPG). PPG is based on the concept of measuring changes in reflection of light because of volumetric change in concentration of blood. Experimental results show that the algorithm produces heart rate very close to that of the observed values. We have also explored the Eulerian Video Magnification method, which reveals subtle changes in motion and color during during respiration, artery pulse motion and many other invisible motions.Most of these motions are not visible to human eye.In our this paper we narrow our attention to change in human skin color during respiration which can help in finding heart beat and respiratory rate. The results of the method have also been documented in the report.**

I. INTRODUCTION

Non-contact medical devices can play a significant role in monitoring the health of the individual. Normal people, can have access and control over the vital signs and hence they can play an active role in management of their health. Hence, the remote monitoring of Vital signs such as Blood Pulse pressure(BP), Heart Rate(HR), Heart Rate Variability(HRV) Blood Oxygen Saturation Rate, Respiration Rate(RR) etc., has gained importance in the recent times.

Human heart rate is one of the most important and commonly measured parameter used to know the medical condition of an individual. It is vital to the proper functioning of heart. Heart rate data can be used to indicate several parameters including, the presence of disease, presence of stress or fatigue and even to know if there are any blockages in the arteries of the heart. The current methods for monitoring these parameters are invasive, expansive and not portable, most of them typically require patients to strap sticky electrodes, bulky sensors and chest straps and on their bodies. These are not only irritating but also can leave severe marks on the skin if not well taken care of. Hence there were a lot of efforts made to access these parameters using non-contact means.

Some of the earliest works for measuring cardiac pulse include using piezoelectric measurements [8] thermal imaging [4], Optical phenomenon[6], ultrasonic phenomenon [5] and using Principal Component Analysis[7]. Sergey[1] has used thermal imaging of the superficial temporal artery for caliculating the heart beat. His method uses measurement of arterial pulse from Superficial artery pulse(STA) using passive thermal Infra Red sensors.

L Tarassenko[2] has devised a novel method which cancels out aliased frequency components caused by artificial light flickr, using auto-regressive(AR) modeling and pole cancellation. Unlike most of the methods which work well only under sunlight, their method was designed for working under artificial fluorescent light. They have been able to calculate the accurate maps for spatial distribution of heart rates and respiratory rates of the double monitored patients undergoing haemodialysis in the Oxford Kidney Unit. Jovanov[3] was successfully able to analysize the Heart Rate Variability of people with very slow breathing (at frequency of less than 0.04 Hz - more than 25 seconds/breath). Motion Aritifact reduction(MA) is one of the major problems when non-contact imaging methods are used. The movement of subject makes it extremely difficult to differentiate between the pulse motion and the subject motion. It is a very important factor which must be carefully taken care of. There have been several approaches reported for the MA reduction in the recent times.

Asoka et.al[9] has used Cycle by Cycle Fourier Series Analysis(CFSA) for extracting artifact free Photoplethysmographic(PPG) from PPG signals corrupted from motion artifacts. The idea was that since PPG signal is quasi periodic and nonstationary, fourier series is directly not applicable to PPG, they have over come the problem by applying Fourier series on cycle by cycle basis.

Hyvrinen et.al[10] has propsed a method based on the concept of applying Independent Component Analysis and block interleaving the signal with low pass filter can reduce the motion artifacts. Raghu[11] has proposed a method which uses adaptive step-size least mean squares filter(ASLMS) adaptive filter for reducing MA in corrupted Photoplethysmographic(PPG) signals. The idea has been derived from the fact the noise sigal for an adaptive filtering process is generated from a PPG signal corrupted from MA instead of

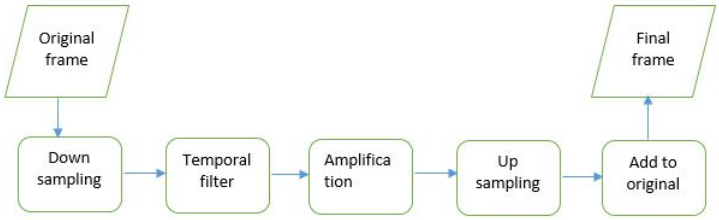


Fig. 1: Overview of Eulerian Video Magnification

using a special hardware for acquiring noise reference signal.

II. Eulerian Video Magnification

Eulerian Video Magnification is a method to magnify subtle changes in motion, color etc ... These changes are usually not visible to the naked eye, examples of such motions include variation of human skin color during respiration, artery pulse motion and many other invisible motions like involuntary eye movement. In our project we narrow our attention to change in human skin color during respiration which can help in finding heart beat and respiratory rate.

Eulerian Video Magnification is a method developed by Hao-et al. The basic approach is, given a video sequence as an input, we analyze the color variation in each pixel over time and amplify the variation and add back to the original video which results in a magnified version of the video.

A. Description

Firstly, spatial decomposition of the given video sequence is done to obtain different spatial frequency bands. This step is mainly done because of possible different signal-to-noise ratios of the bands and they may be magnified differently. A full Laplacian Pyramid is computed usually but for computational efficiency we apply a spacial low pass filter followed by down sampling. Then, a temporal filter is applied over all the bands. We apply a band pass filter to obtain the frequency bands of interest. Now the obtained signal is amplified by a factor α and then added back to the original signal.

We have a choice in the type of temporal band pass filter, amplification factor and spatial cutoff frequency. In our process we mostly used ideal band pass filter, the spatial cut frequency changes depending on the video and we experimented with various values of α. The steps involved in the EVM is described in the figure1.

B. Mathematical standpoint

The relationship between temporal processing and motion magnification can be understood by taking a simple case of 1D and can be generalized to 2D as well.

Let I(x, t) denote the intensity at position x and time t. Let d(t) be displacement in time t. Intensities at time 0 and time t can be written as

$$I(x,0) = g(x)$$

$$I(x,t) = g(x + d(t))$$

Our aim is to achieve

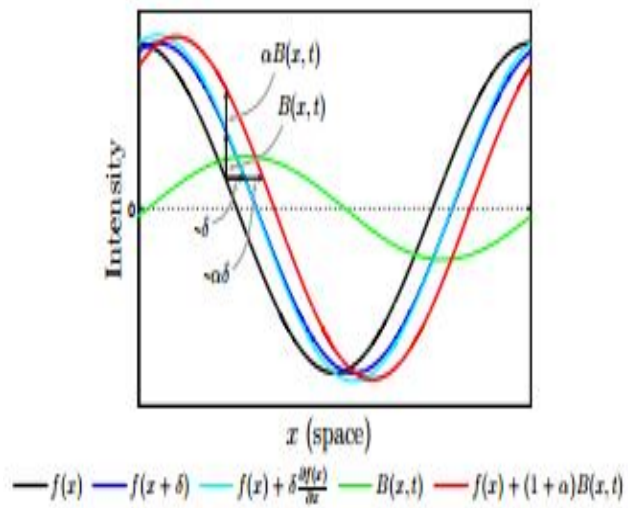
$$\hat{I}(x,t) = g(x + (1+\alpha)d(t))$$

By 1st order Taylor series expansion I(x,t) can be written as,

$$I(x,t) = g(x + d(t)) = g(x) + d(t)\frac{dg(x)}{dx}$$

Let the signal obtained from the temporal filter be A(x, t). We have to choose the cut off frequency such that d(t) is in the pass band of the filter. Then A(x,t) can be expressed as,

$$A(x,t) = d(t)\frac{dg(x)}{dx}$$



Now an amplifying factor Alpha chosen and A(x,t) is amplified by a factor of Alpha and add back to original signal resulting in

$$\hat{I}(x,t) = I(x,t) + \alpha A(x,t)$$

$$\hat{I}(x,t) = g(x) + (1+\alpha)d(t)\frac{dg(x)}{dx}$$

$$\hat{I}(x,t) = g(x + (1+\alpha)d(t))$$

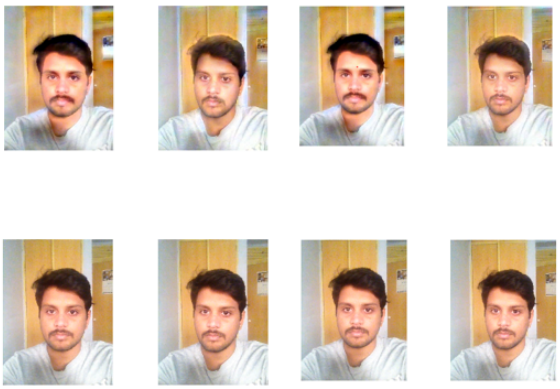


Fig. 2: Results of Eulerian Video Magnification. The upper row contains the magnified version and the bottom row contains the original frames.

The process is illustrated using a sinusoid in figure 2.

In practice it is not always possible to find a cut off frequency that would have entire d(t) in its pass bands. So we get different components of d(t) in the pass band. Let the components of d(t) be $d_k(t)$ where k is the index. Now for capturing different components of d(t) we apply different temporal filters with factors γ_k. Now the band passed signal is given as follows,

$$A(x,t) = \sum_k \gamma_k d_k(t) \frac{dg(x)}{dx}$$

This signal is amplified with a factor of α. This will result in new frequency dependent amplification factor α_k=γ_k α giving a new amplified singal

$$\hat{I}(x,t) = g(x + (1+\alpha_k)d_k(t))$$

C. Results

In the process of respiration when we breath-in the face color changes to red and when we breath-out the face changes its color to pale. This color change happens due to the blood circulation in the body.These color changes happen in very minute amount, not visible to naked eye and can be found using Eulerian Video magnification. The results are show in the figure 2.

III. Heart Rate approximation using ICA approach

A. Photo-plethysmography

Every Heart beat involves contraction and expansion. During every contraction, blood is pumped out of the heart. This pumped out blood flows through every tissue in the body. When these tissues are filled with blood, they block the passage of light through them and reflect more light than the usual from the skin. This volumetric change in blood concentration in the capillaries of skin tissues is directly

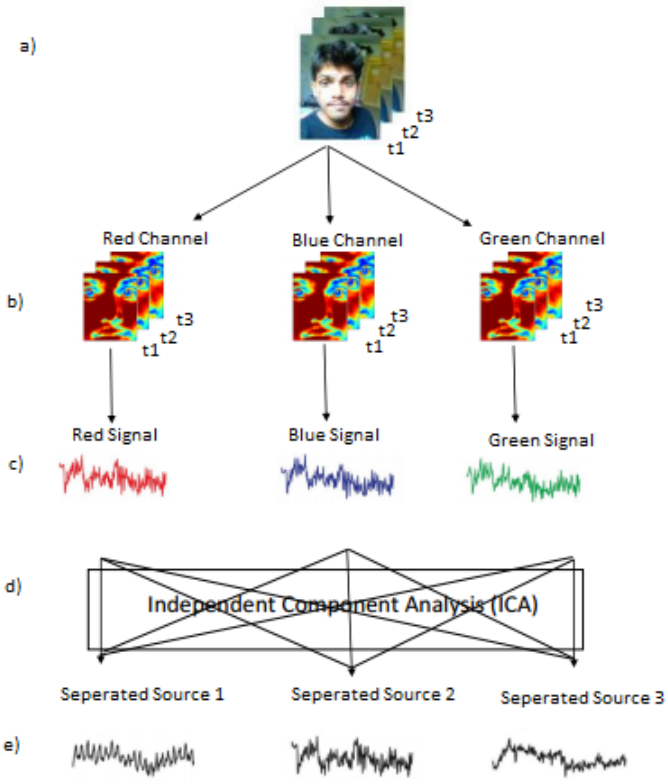


Fig. 3: a)Detecting of the ROI from the video (b)Decomposing each frame into red green and blue channels (c) RGB signals after averaging and normalising (d) ICA is applied to the normalised signals are three independent sources are obtained.

related to the amount of reflected light. This change in light can captured using a camera and a measure can be used to quantify various health parameters. This concept of measuring changes in reflected light because of volumetric changes in concentration is known as Photo-plethysmography.

B. Independent Component Analysis

Independent Component Analysis is a type of blind source separation method where we do not know the source signal and we try to find the sources responsible from a large number of observed signals that are composed of linear mixtures of the underlying sources.[12]

In our case, the underlying source signal is the cardiac pulse which modifies the reflection of light due to volumetric changes in the facial blood vessels. These changes are picked up by the camera and are recorded and stored in a video. The red, green and blue sensors of the camera, pick up a mixture of PPG signal along with other sources of fluctuations such as noise and motion artifacts. Each sensor picks up a mixture of original source signal with slightly different weights. Let the observed signals from red, blue and green sensors be y_r, y_b

and y_g respectively and the underlying source signals be $g1$,$g2$ and $g3$.The independent component analysis assumes that the observed signals are a linear mixture of sources i.e,

$$y_r = g_1 * a + g_2 * b + g_3 * c$$

$$y(t) = B * g(t)$$

where a,b,c are some variables and y and g are the column vectors y(t) = [$y_r(t)$,$y_r(t)$,$y_r(t)$]^T and g(t) = [$g_1(t)$, $g_2(t)$, $g_1(t)$]^T containing the observed signals and source signals respectively.The goal of ICA is to find a approximation of de-mixing matrix A which is the inverse of the signal mixing matrix B as follows:

$$\hat{g}(t) = A * y(t)$$

C. Experimental Procedure

All measurements were performed with minimal light conditions. They were performed indoor with sunlight as only source of illumination. All videos were recorded using the front camera of a mobile(iPhone 4s).All the videos were recorded at 29 frames per second in 24-bit at a resolution of 640x480 pixels. Each video was taken for a duration of 10 seconds. So, each video recorded consisted of 240 frames. All videos were saved in MOV format and were used as the input to the matlab for further processing.

Cardiio, an application developed based on the research in MIT Media labs, has been used to compare the results. Cardiio is a very popular application available on app store, which calculates the heart rate based on principle of light reflection using the concept of photoplethysmographic(PPG) signal.

To estimate the heart rate, we have implemented the Pohs method [13]. The analysis and processing of data has been done using MatlabR2012b. Firstly, the video is read using the application and the region of interest is selected. The area between the eyes and the upper lip has been used as the ROI, using a face detection algorithm written in Matlab. The ROI was further separated into red, green and blue channels and spatially averaged over all the pixels to yield a single measurement for each frame(x_r(t),x_g(t),x_b(t)). The RGB traces were further normalized as follows :

$$x_i'(t) = \frac{x_i(t) - \mu_i}{\sigma_i}$$

Where i = {r,g,b} and μ_i , σ_i are the median and standard deviation of the signal $x_i(t)$ respectively.The above transformation transforms the signal into the one with unit variance and zero mean.These traces were further averaged using a five-point moving filter.These smoothed raw traces were decomposed into three independent source signals using ICA. We have used JADE algorithm for calculating the underlying source signals. The ICA procedure produced three independent source signals. The ordering of these independent components is random. Hence the one witch contained the highest peak in the power spectrum was selected and given for further processing.

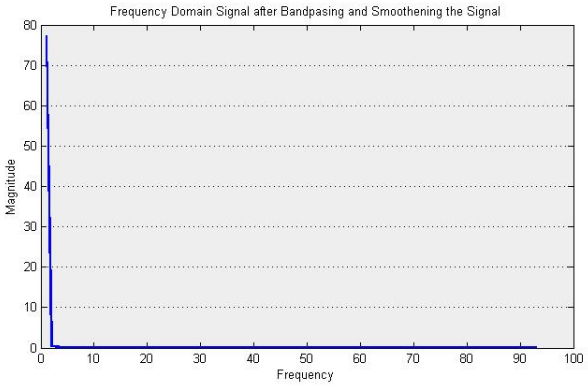


Fig. 5: The Frequency Domain Signal after Smoothening and Bandpassing. The peak can clearly be observed at a frequency corresponding between 0.5 and 4Hz

D. Quantification of Heart Beat

The extracted source signal was smoothed using a 5 point averaging filter. The signal was further band pass filtered using a Hamming Window filter of size 128 between 0.7 and 4 Hertz(corresponding to pulse rate between 42 and 240 bpm). The signal was further interpolated using cubical spine function at a frequency of 256 Hz. The highest peak of this signal was selected and is divided upon 60 to get the actual heart beat.

Algorithm 1 Procedure

1: Load the Video and extract the ROI
2: Decompose the Video into RGB Channels
3: Average each channel on entire frame and normalise the signal
4: Apply Independent Component Analysis on the three signals
5: Convert the source signals into frequency domain and select the signal having the highest peak.
6: Apply a five point smoothing filter and bandpass the selected signal between range 0.7 to 4 Hz.
7: Apply Cubical Spine Function at a frequency of 256Hz to the band passed signal

IV. CONCLUSIONS

The experiment was conducted among a sample data set of 10 videos of students of DAIICT. The results obtained were given the table:

TABLE I: Experiment Results

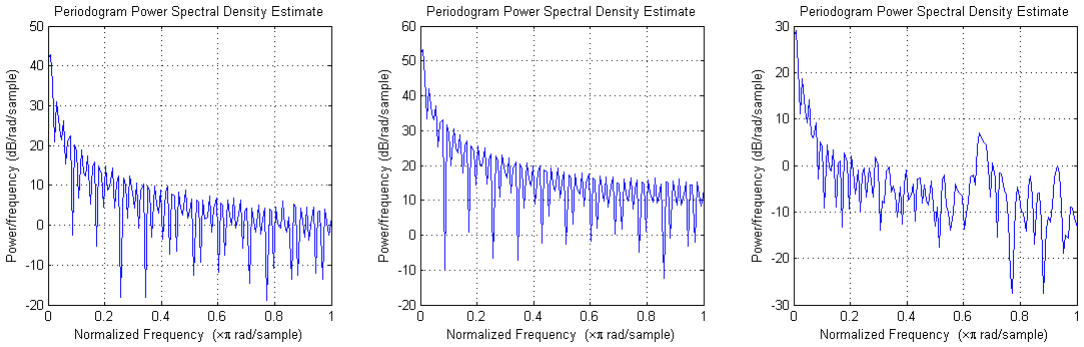


Fig. 4: The three underlying source signals after the ICA process. The signals have been plotted in the frequency domain. In this case, the second component has the highest peak.

Experiment	Observed Value	Actual Value
Data 1	68	72
Data 2	65	63
Data 3	60	64
Data 4	82	78
Data 5	75	70
Data 6	55	62
Data 7	62	61
Data 8	77	79
Data 9	80	75
Data 10	72	70

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