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Android-based implementation of Eulerian Video Magnification for vital signs monitoring

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Abstract

Eulerian Video Magnification is a recently presented method capable of revealing temporal variations in videos that are impossible to see with the naked eye. Using this method, it is possible to visualize the flow of blood as it fills the face. From its result, a person's heart rate is possible to be extracted.

This research work is an internal project of *Fraunhofer Portugal* and its goal is to test the feasibility of the implementation of the Eulerian Video Magnification method on smartphones by developing an *Android* application for monitoring vital signs based on the Eulerian Video Magnification method.

There has been some successful effort on the assessment of vital signs, such as, heart rate, and breathing rate, in a contact-free way using a webcamera and even a smartphone. However, since the Eulerian Video Magnification method was recently proposed, its implementation has not been tested in smartphones yet.

The application will include features, such as, detection of a person's cardiac pulse, dealing with artifacts' motion, and real-time display of the magnified blood flow. Then, the application performance will be evaluated through tests with several individuals and the assessed heart rate compared to the one detected by the *Philips* application, and to the measurement of an heart rate monitor or a pulse oximeter.

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Abbreviations

EVM	Eulerian Video Magnification
ICA	Independent Component Analysis

Chapter 1

Introduction

Eulerian Video Magnification is a method, recently presented at *SIGGRAPH*[1] 2012, capable of revealing temporal variations in videos that are impossible to see with the naked eye. Using this method, it is possible to visualize the flow of blood as it fills the face [WRS+12]. Which provides enough information to assess the heart rate in a contact-free way using a camera [WRS+12, PMP10, PMP11, Phi13].

1.1 Context

The main field of this research work is *image processing and computer vision*, whose main purpose is to translate dimensional data from the real world in the form of images into numerical or symbolical information.

Other fields include *medical applications*, *software development for mobile devices*, *digital signal processing*.

This research work is an internal project of *Fraunhofer Portugal*[2] proposed by Luís Rosado. Fraunhofer Portugal a is non-profit private association founded by Fraunhofer-Gesellschaft[3] [Por13] and

> "aims on the creation of scientific knowledge capable of generating added value to its clients and partners, exploring technology innovations oriented towards economic growth, the social well-being and the improvement of the quality of life of its end-users." [Por13]

[1] http://www.siggraph.org/
[2] http://www.fraunhofer.pt/
[3] http://www.fraunhofer.de/en/about-fraunhofer/

1.2 Motivation

Due to being recently proposed, the Eulerian Video Magnification method implementation has not been tested in smartphones yet.

There has been some successful effort on the assessment of vital signs, such as, heart rate, and breathing rate, in a contact-free way using a webcamera [WRS+12, PMP10, PMP11], and even a smartphone [Phi13].

Other similar products, which require specialist hardware and are thus expensive, include *laser Doppler* [UT93], *microwave Doppler radar* [Gre97], and *thermal imaging* [GSMP07].

Since it is a cheaper method of assessing vital signs in a contact-free way than the above products, this research work has potential for advancing fields, such as, *telemedicine*, *personal health-care*, and *ambient assisting living*.

Despite the existence of a very similar product by *Philips* [Phi13] – *Vital Signs Camera* – to the one proposed on this research work, the product to be developed during this research work will have additional features, such as, feature tracking while assessing the heart rate, and augmented reality to visualize the blood flow.

1.3 Objectives

This research work goal is to test the feasibility of the implementation of the Eulerian Video Magnification method on smartphones by developing an *Android* application for monitoring vital signs based on the Eulerian Video Magnification method.

The proposed application should include the following features:

- heart rate detection and assessment based on the Eulerian Video Magnification method;
- display real-time changes, such as, the magnified blood flow, obtained from the Eulerian Video Magnification method;
- deal with artifacts' motion, due to, person and/or smartphone movement.

The application performance will then be evaluated through tests with several individuals and the assessed heart rate compared to the one detected by the *Philips* application [Phi13], and to the measurement of an heart rate monitor or a pulse oximeter.

In order to achieve the objectives proposed and solve any possible problem, a review of the state of the art in the domain of vital signs monitoring through image processing and analysis that can be applicable to smartphones will also be held during this research work.

1.4 Outline

The rest of the document is organized as follows:

Chapter 2 introduces the concepts necessary to understand the presented problem. In addition, it presents the existing related work, and a description of the technologies to be used.

Chapter ?? presents the approach taken to solve the problem. Moreover, it introduces the testing and evaluation methodologies.

Chapter ?? presents the work to be completed during the master thesis, split in main tasks, including an estimated schedule.

Chapter 2

State of the art

In this chapter, the background needed to understand the problem of heart rate detection using the Eulerian Video Magnification method is presented on section **??**. Before that, a similar research, which uses the Independent Component Analysis model to assess the cardiac pulse, is described in more detail on section **??**. In addition, a description of the technologies to be used will be described on section **??**.

2.1 Related Work

Successful attempts have already been made on real-time, contact-free heart rate assessment using a webcamera. In these attempts, two methods have been used: Independent Component Analysis, and Eulerian Video Magnification.

An *iOS* application named *Vital Signs Camera*, developed by *Philips*, has also been able to detect a person's heart rate and breathing rate using the smartphone's camera [Phi13]. However, as far as I know, there is no research work available to the public since its technology was developed internally by *Philips*.

2.1.1 Independent Component Analysis

Independent Component Analysis is a special case of *blind source separation* and is a relatively new technique for uncovering independent signals from a set of observations that are composed of linear mixtures of the underlying sources [Com94].

In this case, the underlying source signal of interest is the cardiac pulse that propagates throughout the body, which modify the path length of the incident ambient light due to volumetric changes in the facial blood vessels during the cardiac cycle, such that subsequent changes in amount of reflected light indicate the timing of cardiovascular events.

By recording a video of the facial region, the red, green, and blue (RGB) color sensors pick up a mixture of the reflected plethysmographic signal along with other sources of fluctuations in light due to artifacts. Each color sensor records a mixture of the original source signals with slightly different weights. These observed signals from the red, green and blue color sensors are denoted by $x_1(t)$, $x_2(t)$ and $x_3(t)$ respectively, which are amplitudes of the recorded signals at time point t. In conventional Independent Component Analysis model the number of recoverable sources cannot exceed the number of observations, thus three underlying source signals were assumed, represented by $s_1(t)$, $s_2(t)$ and $s_3(t)$. The Independent Component Analysis model assumes that the observed signals are linear mixtures of the sources, i.e. $x_i(t) = \sum_{j=1}^{3} a_{ij} s_j(t)$ for each $i = 1, 2, 3$. This can be represented compactly by the mixing equation

$$x(t) = As(t) \tag{2.1}$$

where the column vectors $x(t) = [x_1(t), x_2(t), x_3(t)]^T$, $s(t) = [s_1(t), s_2(t), s_3(t)]^T$ and the square 3×3 matrix A contains the mixture coefficients a_{ij}. The aim of Independent Component Analysis model is to find a separating or demixing matrix W that is an approximation of the inverse of the original mixing matrix A whose output

$$\hat{s}(t) = Wx(t) \tag{2.2}$$

is an estimate of the vector $s(t)$ containing the underlying source signals. To uncover the independent sources, W must maximize the non-Gaussianity of each source. In practice, iterative methods are used to maximize or minimize a given cost function that measures non-Gaussianity [PMP10, PMP11].

2.2 Eulerian Video Magnification

In contrast to the Independent Component Analysis model that focus on extracting a single number, the Eulerian Video Magnification uses localized spatial pooling and temporal filtering to extract and reveal visually the signal corresponding to the cardiac pulse. This allows for amplification and visualization of the heart rate signal at each location on the face. This creates potential for monitoring and diagnostic applications to medicine, i.e. the asymmetry in facial blood flow can be a symptom of arterial problems.

Besides color amplification, the Eulerian Video Magnification method is also able to reveal low-amplitude motion which may be hard or impossible for humans to see. Previous attempts to unveil imperceptible motions in videos have been made, such as, [LTF+05] which follows a *Lagrangian* perspective, as in fluid dynamics where the trajectory of particles is tracked over time. By relying on accurate motion estimation and additional techniques to produce good quality synthesis, such as, motion segmentation and image in-painting, the algorithm complexity and computation is expensive and difficult.

On the contrary, the Eulerian Video Magnification method is inspired by the *Eulerian* perspective, where properties of a voxel of fluid, such as pressure and velocity, evolve over time.

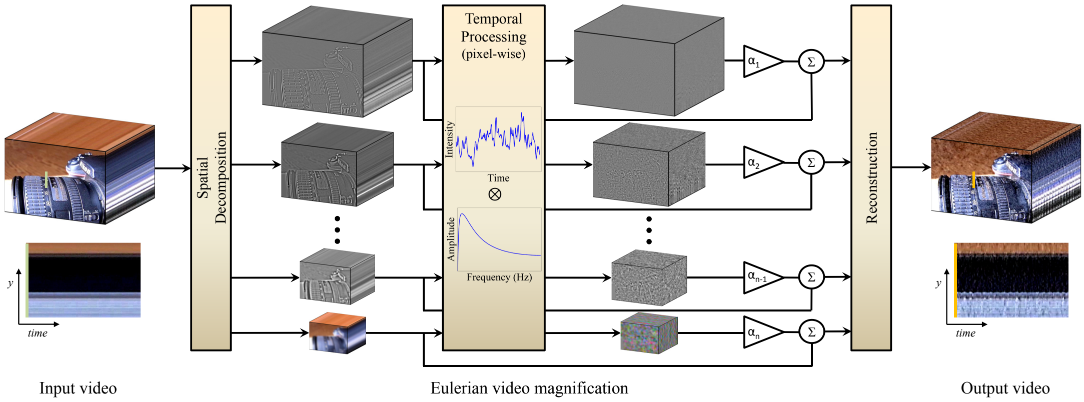


Figure 2.1: Overview of the Eulerian Video Magnification method.

The approach of this method to motion magnification is the exaggeration of motion by amplifying temporal color changes at fixed positions, instead of, explicitly estimation of motion.

This method approach, illustrated in figure 2.1, combines spatial and temporal processing to emphasize subtle temporal changes in a video. First, the video sequence is decomposed into different spatial frequency bands. Because they may exhibit different signal-to-noise ratios, they may be magnified differently. In the general case, the full Laplacian pyramid [BA83] may be computed. Then, temporal processing is performed on each spatial band. The temporal processing is uniform for all spatial bands, and for all pixels within each band. After that, the extracted bandpass signal is magnified by a factor of α, which can be specified by the user, and may be attenuated automatically. Finally, the magnified signal is added to the original and the spatial pyramid collapsed to obtain the final output.

2.2.1 Emphasize color variations for human pulse

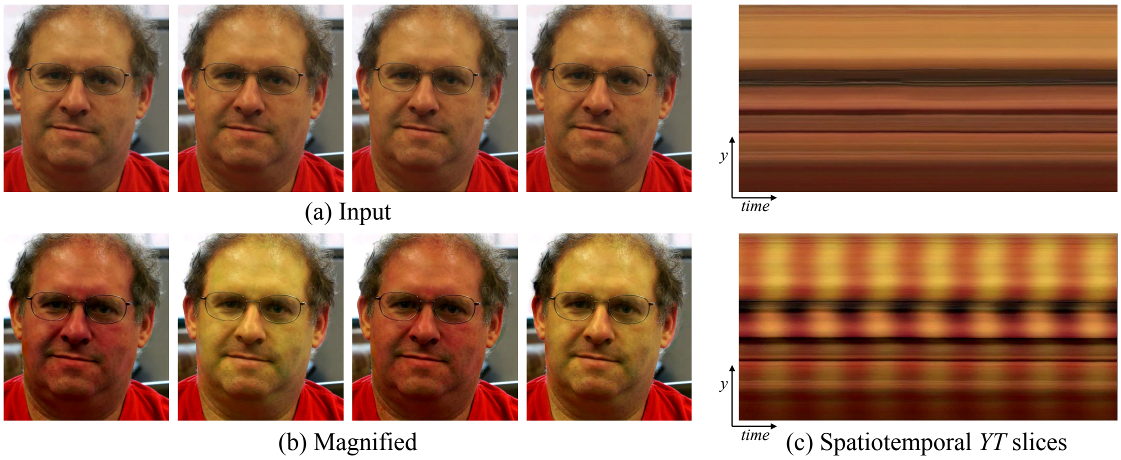
The extraction of a person's cardiac pulse using the Eulerian Video Magnification method was demonstrated in [WRS+12]. It was also presented that using the right configuration can help extract the desired signal. There are four steps to take then processing a video by Eulerian Video Magnification:

1. select a temporal bandpass filter;

2. select an amplification factor, α;

3. select a spatial frequency cutoff (specified by spatial wavelength, λ_c) beyond which an attenuated version of α is used;

4. select the form of the attenuation for α —- either force α to zero for all $\lambda < \lambda_c$, or linearly scale α down to zero.



(a) Input

(b) Magnified

(c) Spatiotemporal *YT* slices

Figure 2.2: Emphasis of the face color changes using the Eulerian Video Magnification method.

For human pulse color variation, two temporal filters may be used, first selecting frequencies within 0.4-4Hz, corresponding to 24-240 beats per minute (bpm), then a narrow band of 0.83-1Hz (50-60 bpm) may be used, if the extraction of the pulse rate was successful.

To emphasize the color change as much as possible, a large amplification factor, $\alpha \approx 100$, and spatial frequency cutoff, $\lambda_c \approx 1000$, is applied. With an attenuation of α to zero for spatial wavelengths below λ_c.

The resulting output can be seen in figure 2.2.

2.3 Technologies

Below are short descriptions of the main technologies that will be used during this research work.

Android SDK

Android SDK is the development kit for the *Android* platform. The *Android* platform is an open source, Linux-based operating system, primarily designed for touchscreen mobile devices, such as, smartphones.

Because of its open source code and permissive licensing, it allows the software to be freely modified and distributed. This have allowed *Android* to be the software of choice for technology companies who require a low-cost, customizable, and lightweight operating system for mobile devices and others.

Android has also become the world's most widely used smartphone platform with a worldwide smartphone market share of 75% during the third quarter of 2012 [IDC13].

OpenCV – Computer Vision Library

OpenCV is a library of programming functions mainly aimed at real-time image processing. To support these, it also includes a statistical machine learning library. Moreover, it is a cross-platform and open source library that is free to use and modify under the BSD license.

> "OpenCV was built to provide a common infrastructure for computer vision applications and to accelerate the use of machine perception in the commercial products." [Its13]

2.4 Chapter summary

Chapter 3

Problem description

3.1 Eulerian Video Magnification

3.2 Chapter summary

Problem description

Chapter 4

Solution architecture

4.1 Eulerian Video Magnification

4.2 Chapter summary

Solution architecture

Chapter 5

Implementation details

5.1 Eulerian Video Magnification

5.2 Android

5.3 Performance

5.4 Chapter summary

Chapter 6

Results

6.1 Heart rate comparison

6.2 Algorithm performance

6.3 Chapter summary

Chapter 7

Conclusions

7.1 Objective satisfaction

7.2 Future work

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