FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

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

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WORKING VERSION

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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.

Acknowledgements

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The Name of the Author

"You should be glad that bridge fell down.
I was planning to build thirteen more to that same design"

Isambard Kingdom Brunel

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Abbreviations

ADT	Abstract Data Type
ANDF	Architecture-Neutral Distribution Format
API	Application Programming Interface
CAD	Computer-Aided Design
CASE	Computer-Aided Software Engineering
CORBA	Common Object Request Broker Architecture
UNCOL	UNiversal COmpiler-oriented Language
Loren	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Sed vehicula lorem commodo dui
WWW	*World Wide Web*

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 [**?**]. Which provides enough information to assess the heart rate in a contact-free way using a camera [**?**, **?**, **?**, **?**].

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] [**?**] 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." [**?**]

[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 [**?**, **?**, **?**], and even a smartphone [**?**].

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

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* [**?**] – *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 [**?**], 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 3 presents the approach taken to solve the problem. Moreover, it introduces the testing and evaluation methodologies.

Chapter 4 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 2.2. Before that, a similar research, which uses the Independent Component Analysis model to assess the cardiac pulse, is described in more detail on section 2.1. In addition, a description of the technologies to be used will be described on section 2.3.

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 [**?**]. 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 [**?**].

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 [**?**, **?**].

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, [**?**] 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.

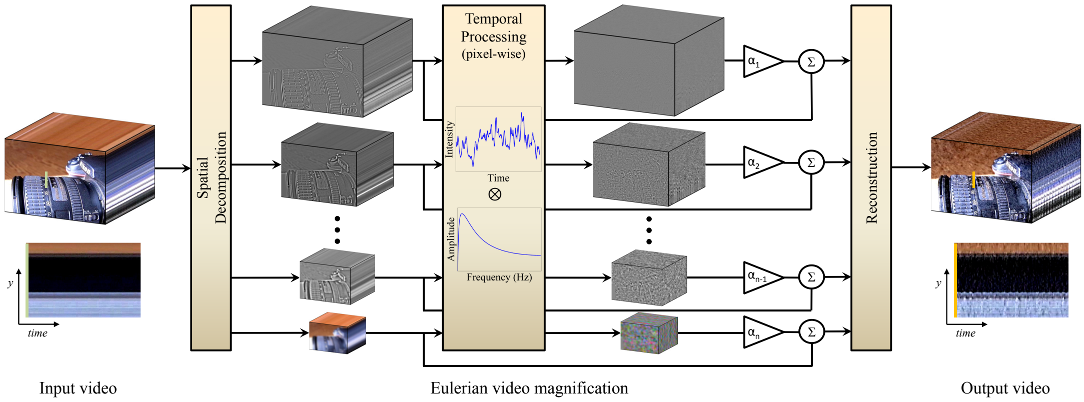


Figure 2.1: Overview of the Eulerian Video Magnification method.

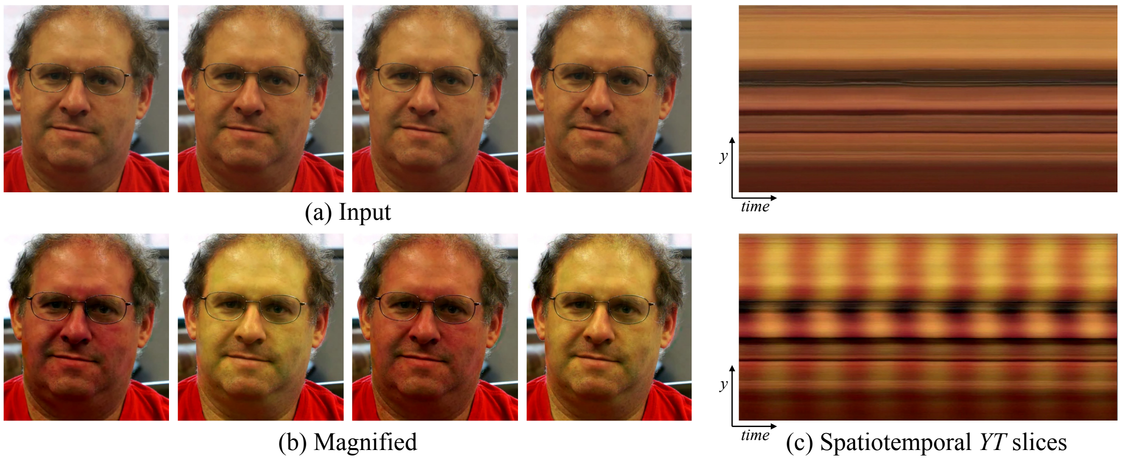
The approach of this method to motion magnification is the exaggeration of motion by amplifying temporal color changes at fixed positions, instead of, explicitly estimation of motion.

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 [**?**] 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 [**?**]. 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 [**?**].

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.” [**?**]

Chapter 3

Approach

In this chapter, a simple description of the approach to be taken during this research work is presented on section 3.1. Moreover, the solution perspective and the difficulties and problems that may arise are described on section 3.2 and 3.3, respectively. The last section 3.4, describes the evaluation process.

3.1 Overview

The approach or methodology taken to reach this research work objectives is an incremental implementation of the application features or requirements. It should be taken into consideration that this approach plan may be modified during the duration of the research work and is not a strict line of action.

Starting with the creation of a simple *Android* application that uses the *OpenCV* library. Follows the implementation of face detection using the *OpenCV* library, and the Eulerian Video Magnification method showing the resulting video in real-time. Then, after the implementation of a simple heart rate detection algorithm based on the Eulerian Video Magnification method, the evaluation of application will be executed. This evaluation should then be executed every time a significant modification to the heart rate detection algorithm is made.

3.2 Solution Perspective

To extract the cardiac pulse from a person's face, first, a face must be discovered on the input video, for that a simple *OpenCV* face detection algorithm will be used.

Then, in order to obtain the heart rate signal, there is the need to focus on an area to extract that signal. However, the amplitude variation of the signal of interest is often must smaller than the noise inherent in the video. To enhance these subtle signals spatial polling can be used. Despite of that if the spatial polling applied is not large enough, the signal of interest will not be revealed.

Retrieved from the article [?], the equation 3.1 gives an estimate for the size of the spatial polling need to revel the signal of interest at a certain noise power level.

$$S(r) = \sigma'^2 = k\frac{\sigma^2}{r^2} \tag{3.1}$$

Where σ^2 is the noise power level, which can be estimated by using a technique as in [?], and $S(r)$ is the signal power of such spatial polling filter. Thus, since the filtered noise power level, σ'^2, is inversely proportional to r^2, it is possible to solve the equation 3.1 for r, where k is a constant that depends on the shape of the spatial filter.

This area of interest can then be tracked using a simple *OpenCV* feature tracking algorithm to deal with artifacts' motion.

In addition, the Eulerian Video Magnification method can be configured to amplify the color variation as explained on section 2.2.1.

The signal extracted should be recognizable as a cardiac pulse signal, however further processing may be needed to detrend the signal. Also, since the pulse computation may be affected by noise, historical estimations to reject artifacts may be implemented as in [?].

To create the *augmented reality effect* of the blood flow, the raw Eulerian Video Magnification method result is added to the input video.

An important part of the development is focused on the complete implementation of the Eulerian Video Magnification since the available framework is not destined to be used in real-time nor on smartphones.

3.3 Difficulties

During the course of this research work a number of possible problems may occur which will hinder the development of the project and research. Some of these difficulties have been predicted and a few possible solutions to those will be described below.

- **Problem** Noise created by smartphone and person motion, and by lighting changes.

  Every small movement may heavily influence the method result since it also amplifies motion. Thus, too much noise may obfuscate the cardiac pulse intended to be detected.

  Solution Perspective Noise reduction may be accomplished by using face detection (and feature tracking) to focus on a small area on the person's face that is independent enough to not suffer large intensity variations due to the identified artifacts. In addition, historical estimations to reject artifacts may be implemented and specific configuration to the Eulerian Video Magnification method to emphasize the color change as much as possible [?] as explained on section 2.2.1.

- **Problem** Smartphone computing power may not be enough for real-time processing.

  The Eulerian Video Magnification method is able to run in real-time [**?**]. However, the lower computing power of smartphones and extra processing, such as, face detection and tracking, noise reduction techniques, and signal normalization algorithms, may cause the method to not be able to execute in real-time.

  Solution Perspective If this problem arises, a possible solution is to reduce the computing power required, by switching to different approaches or even the removal of some features, such as, feature tracking.

3.4 Evaluation

The evaluation main goal is the validation of the cardiac pulse assessed. This may be accomplished, by comparing the signal and average of the heart rate detected by the application with the one captured by an heart rate monitor or a pulse oximeter. These measurements should be done simultaneously so they can be correctly compared.

In addition, these measurements will be obtained in different settings, such as, indoor, outdoor, with face motion, with face tilting, while the person is speaking, during lighting variations, to verify the application robustness.

At the end, the application will also be compared against the one developed by *Philips* – Vital Signs Camera. The comparison will focus on both: average heart rate detected, and application performance.

Approach

Chapter 4

Work Plan

This chapter describes the tasks to be accomplished during the following 5 months. Each task will be subsequently divided into subtasks and provide an estimated time.

The calendatization of the tasks during the next 5 months will be presented in the section 4.2.

4.1 Tasks

Literature Review

In order to implement key features of this research work, several concepts and algorithms need to be deeper analysed and studied.

- Explore *OpenCV* face detection algorithms.
- Explore Eulerian Video Magnification method for heart rate detection.
- Explore *OpenCV* feature detection and tracking algorithms.
- Explore noise reduction to improve heart rate detection using the Eulerian Video Magnification method.

Estimated time: 4 weeks.

Implementation

Implement an *Android* application for detecting a person heart rate using the smartphone's camera.

- Integrate *Android* and *OpenCV* library.
- Implement face detection using *OpenCV* library.
- Implement real-time *Augmented Reality* using Eulerian Video Magnification method.
- Implement heart rate detection based on the values obtained by the Eulerian Video Magnification method.
- Implement feature detection and tracking using *OpenCV* library.
- Implement noise reduction solutions explored.
- Improve application design and user experience.

Estimated time: 10 weeks.

Evaluation

Compare the heart rate detected to the one obtained from the *Philips* [**?**] application – *Vital Signs Camera* – and to the measurement of an heart rate monitor or pulse oximeter in different settings.

Estimated time: 4 weeks.

Thesis Writing

Thesis writing, including a detailed description of the algorithms and methods used, and the results obtained.

Estimated time: 6 weeks.

4.2 Schedule

Figure **??** is a Gantt diagram containing the schedule of the previously defined tasks for the next 5 months.

Tasks *Literature Review* and *Implementation* overlap because important parts of the implementation will be heavily influenced by a few articles. And, *Implementation* and *Evaluation* overlap because the evaluation phase may provide further insight for improving the implemented application and algorithms.

Work Plan

References