ISTANBUL TECHNICAL UNIVERSITY
ELECTRICAL-ELECTRONICS FACULTY

# CAN ESTANDARD THERMAL CAMERAS DETECT BLOOD PERFUSION ON HUMAN FACE ?

SENIOR DESIGN PROJECT

Lucia CATANIA PAYO

ELECTRONICS AND COMMUNICATION ENGINEERING DEPARTMENT

AUGUST, 2023

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**Project Advisor: Prof. Tayfun AKGUL**

**AUGUST, 2023**

**İSTANBUL TEKNİK ÜNİVERSİTESİ**
**ELEKTRİK-ELEKTRONİK FAKÜLTESİ**

# ESTANDARD TERMAL KAMERALAR İNSAN YÜZÜNDEKİ KAN PERFÜZYONUNU ALGILAYABİLİR Mİ?

**LİSANS BİTİRME TASARIM PROJESİ**

**Lucia CATANIA PAYO**
**(912210131)**

**Proje Danışmanı: Prof. Tayfun AKGUL**

**ELEKTRONİK VE HABERLEŞME MÜHENDİSLİĞİ BÖLÜMÜ**

**AĞUSTOS, 2023**

I am submitting the Senior Design Project Report entitled as “CAN ESTANDAR THERMAL CAMERAS DETECT BLOOD PERFUSION ON HUMAN FACE ?”. The Senior Design Project Report has been prepared as to fulfill the relevant regulations of the Electronics and Communication Engineering Department of Istanbul Technical University. I hereby confirm that I have realized all stages of the Senior Design Project work by myselve and I have abided by the ethical rules with respect to academic and professional integrity .

**Lucia CATANIA PAYO**
(**912210131**)

## FOREWORD

When starting this academic project, I mentally proposed to put all my enthusiasm and curiosity to study and explore with an open mind a topic that besides being new and interesting, combines several aspects of my interest such as technology, physiology and medical imaging.

In relation to thermographic cameras and their potential uses in the health field and the investigation of the possibilities offered by these cameras for the recognition of blood perfusion in the face have been the ones that have guided us in the creation of this study.

It is highly demonstrated that thermography is very versatile in many fields and among them in industrial applications and environmental monitoring, which have helped to advance greatly in these fields.At this point, we discovered that the potential applications within the medical field were still largely unexplored and even more so when it comes to human physiological health assessments.

The human face is a canvas, which through thermo-graphic imaging can reveal a significant amount of physiological information through its intricate vascular network.From the point of view of blood perfusion, using it as a physiological parameter of utmost importance, this study had and has as its main objective to open the door to future research on the use of thermal imaging technology for medical diagnosis.

With thermal imaging, it will be possible to assess wound healing, find and track vascular disorders, and identify particular conditions when it is possible to detect and track blood flow dynamics in the human face, all without the use of invasive methods. My interest has focused on exploring the theoretical underpinnings of blood perfusion and thermo-graphic imaging, and those rules that appear to control their interaction.

The ultimate aim of this study, above all, was to reach conclusions that could be useful and relevant for future research, and I have tried to delve into

thepractical aspects of the application of thermographic cameras and the subsequent analysis of the data obtained.

All this work would not have come to fruition without the guidance and advice of the esteemed professor and director Tayfun Akgull, whose experience and support have been the solid foundation on which the process of this research has been based, and without him this work would not have been possible.

I would also like to extend my sincere thanks to the ARIS LAB team, whose spirit of cooperation and joint experience have enriched this research. I would also like to thank the volunteer participants who volunteered their time and cooperation for the data collection procedure, which ultimately served to complete this study.

Finally, I cannot forget my family and friends for their support, love, and patience throughout the process. I am incredibly grateful for their belief in my abilities, and their unwavering support, which has served to encourage me throughout the process.

August 2023 Lucia CATANIA PAYO

**TABLE OF CONTENTS**

## ABBREVIATIONS

| | |
|---|---|
| **EVM** | **:** Eulerian Video Magnification |
| **ROI** | **:** Region of Interest |
| **FOV** | **:** Field of View |
| **HFOV** | **:** Horizontal Field of View |
| **VFOV** | **:** Vertical Field of View |
| **IFOV** | **:** Instantaneous Field of View |

## LIST OF TABLES

**Page**

## LIST OF FIGURES

**CAN STANDARD THERMAL CAMERAS DETECT BLOOD PERFUSION ON HUMAN FACE?**

## SUMMARY


The project seeks to analyze and study the different color variations in the thermal videos by comparing them with the optical videos obtained by a mobile phone, and also makes use of Eulerian amplification techniques to try to magnify these colors allowing the possible study of blood perfusion in certain areas of interest in human faces.

To carry out this project and meet the objectives, we took thermal and optical videos for analysis. We calculated the mean color values for certain regions of interest (forehead and preorbital areas). These means were then analyzed using statistical tests such as t-student and ANOVA. With them we compared the means of the different groups: from normal versus amplified videos to thermal versus normal videos. And on the other hand, an inter-factor study to analyze the possible interactions between the amplified videos and the two types of camera with respect to color changes.

The analysis on the color variations of the videos shows that the Eulerian amplifications do have a significant impact on the color changes with respect to non-amplified videos. This underlines the potential of these techniques.

On the other hand, the ANOVA results show that amplification and camera types (optical and thermal) do not have a significant interaction in terms of color changes.

Therefore, the Eularian amplification, that we have been using, affects colour perception in a similar way in both camera types. This can be due to the thermic camera resolution standard or due to the measurements used for acquiring the video record.

To sum up, this study will provide useful information about the differences between the thermal and standard video records regarding the change of the colour. These findings will help to the comprehension of the video processing techniques and the visual features, with potential applications in several industries like health care, biomedical and technological industries.

**STANDART TERMAL KAMERALAR İNSAN YÜZÜNDEKİ KAN PERFÜZYONUNU TESPİT EDEBİLİR Mİ?**

## ÖZET

Proje, termal videolardaki farklı renk varyasyonlarını cep telefonuyla elde edilen optik videolarla karşılaştırarak analiz etmeyi ve incelemeyi amaçlıyor ve ayrıca bu renkleri büyütmeye çalışmak için Eulerian amplifikasyon tekniklerinden yararlanıyor, böylece insan yüzlerindeki belirli ilgi alanlarındaki kan perfüzyonunun olası çalışmasına izin veriyor.

Bu projeyi yürütmek ve hedeflere ulaşmak için analiz amaçlı termal ve optik videolar çektik. Belirli ilgi alanları (alın ve preorbital bölgeler) için ortalama renk değerlerini hesapladık. Bu ortalamalar daha sonra t-student ve ANOVA gibi istatistiksel testler kullanılarak analiz edildi. Bunlarla farklı grupların ortalamalarını karşılaştırdık: normal ve güçlendirilmiş videolardan termal ve normal videolara. Öte yandan, renk değişimleri açısından güçlendirilmiş videolar ve iki kamera türü arasındaki olası etkileşimleri analiz etmek için faktörler arasında bir çalışma yapıldı.

Videoların renk değişimleri üzerine yapılan analizler, Eulerian amplifikasyonlarının amplifiye edilmemiş videolara göre renk değişimleri üzerinde önemli bir etkisi olduğunu göstermektedir. Bu da bu tekniklerin potansiyelinin altını çizmektedir.

Öte yandan, ANOVA tarafından sağlanan sonuçlar, amplifikasyon ve kamera türlerinin (optik ve termal) renk değişiklikleri açısından çok önemli bir etkileşim göstermediğini göstermektedir. Dolayısıyla, kullanılan Eulerian amplifikasyon her iki kamera türünde de renk algısını benzer şekilde etkilemektedir. Bu durum standart termal kameranın çözünürlüğünden ya da video kaydı için kullanılan ölçümlerden kaynaklanıyor olabilir.

Sonuç olarak, bu proje renk değişimleri açısından termal ve normal videolar arasındaki farklara dair içgörü sağlamaktadır. Bu bulgular, medikal, biyomedikal ve teknoloji gibi çeşitli sektörlerde potansiyel uygulamaları olan video işleme tekniklerinin ve görsel özelliklerin anlaşılmasına katkıda bulunmaktadır.

# 1. INTRODUCTION

## 1.1 Purpose Context and Justification of the study

The detection of blood perfusion in the human face using standard thermal cameras is the focus of the project. The project aims to the study the color changes after Eulerian amplification by means of thermal videos and their comparison with normal videos in order to try to analyze blood perfusion in human faces. And the question arises whether such cameras are capable of detecting blood flow with a thermal video.

Our study area will be the face, since it is an easily accessible and visible part of the body, which speeds up video capture and analysis. In addition, the face contains a dense and complex vascular network. The blood vessels in the facial skin are closer to the surface, which may allow for better visualization and detection of subtle changes in blood perfusion.

Microcirculation consists of the blood flow present in capillaries and arterioles, and plays a fundamental role in the health and function of body, and therefore facial, tissues. In addition, it represents approximately 99% of the blood vessels in adults and mediates between the arterial and venous parts of the cardiovascular system, both structurally and functionally. The microcirculation of the skin consists of two vascular plexuses: superficial and deep. The microcirculation unit includes vessels with a diameter of less than 150 μm, i.e. arteries, small veins, lymphatic vessels and arteriovenous anastomoses. Cutaneous microcirculation can be affected in both systemic pathologies and specific skin disorders.

The state of the microcirculation is an important aspect of health to evaluate, which can be studied with the temporary color changes that we see in thermal videos and that with the application of EVM we can observe in greater detail.

There are already several potential applications of this type of study in the medical field. The possibility of detecting changes in facial blood perfusion will certainly be very useful for medical diagnosis, helping in the early detection of diseases or conditions related to facial blood circulation problems. All this could also serve as an effective assessment tool for monitoring the effectiveness of medical treatments, as changes in blood perfusion could be indicators of a patient's response to a particular treatment.

Unfortunately, thermal cameras are not always accurate in detecting such changes. This is because skin temperature can be affected by a variety of factors, such as ambient temperature, clothing color, and even makeup.
Eulerian video magnification (EVM) is a technique that can be used to enhance subtle color changes in video footage. Highlighting small color changes by magnifying them due to its operation with pixel motion tracking. [5].

EVM has already demonstrated its effectiveness in detecting subtle color changes in the face [1]. This suggests that EVM could be used to improve the accuracy of thermal cameras in detecting blood perfusion.

While there are already some studies [1] [2] that employ EVM techniques to study physiological variations, more research is currently needed to determine the accuracy of EVM in detecting blood perfusion in a clinical setting. And how its application would be useful for such settings.

## 1.2 Research Objectives

The purpose of this study is to study color changes using the Euler video enhancement technique. It will also investigate whether EVMs can be used to improve the accuracy of thermal cameras in detecting blood perfusion in the face. The focus is on applying these techniques to amplify subtle color changes in video images to reveal information about blood perfusion in the face. To achieve the main objective, the following sub-objectives are proposed:

Evaluation and analysis of Eulerian video enhancement techniques available in the scientific literature. studied how to use these techniques specifically to detect color changes in faces. The sensitivity, accuracy, and robustness of these techniques are checked to ensure the most appropriate research method is selected.

Collect video image data of human faces, especially young college students. These video images are then used to apply Euler video enhancement techniques and analyze color changes in specific areas of the face. Data collection was conducted ethically, respecting the privacy and consent of subjects participating in the research.

Based on a review of existing techniques and collected data, an existing Euler video enhancement algorithm suitable for emphasizing and amplifying subtle color changes in human faces is adopted. The algorithm is tuned to account for specific features of facial blood flow and optimized for accurate and reliable color change detection.

The achievement of these goals is expected to yield results examining the feasibility and effectiveness of Euler video enhancement techniques in detecting perfusion-related color changes in human faces. These results could have major implications for the medical field, as they provide a non-invasive and inexpensive tool to assess facial blood perfusion in various clinical applications.

### 1.3 Methodology Employed

The methodology used in this study consisted of selecting videos produced by a thermal imaging camera (AT3003FE) at the university's AKAL laboratory and applying Eulerian video enhancement techniques. A more detailed evolution of the methods used to study each phase is presented below.

These videos are carefully selected, taking into account a variety of factors. Aspects such as diversity of subjects (male and female ages 19 to 24), subtle variations in facial skin color, and variability in blood perfusion were taken into account.

Data is collected using a standard thermal imaging camera. Using this camera, a thermal image of the skin surface can be taken, showing the distribution of heat. We took precautions to maintain a constant distance between the camera and the subject's face and to provide adequate lighting during the recording. The specific data for the termal camera used (AT3003FE) are shown below:

| Resolution | Focal Length | FOV(HxV) | IFOV |
|---|---|---|---|
| 384x288 | 7.8mm | 47ºx35.6º | 2.17 mrad |

**Table 1.1.** AT300 Lens Parameters. [9].

Where FOV (Field of View) is the angle of view that the infrared camera can see HFOV is the horizontal angle of FOV, VFOV is the vertical angle of FOV. IFOV (Instantaneous Field of View) is a resolution measure method of infrared thermal camera (that is the field of view of a pixel) [9].

| | |
|---|---|
| **Resolution** | 384x288 |
| **Thermal Sensitivity** | ＜50mK(40mK is optional) @25℃ |
| **Image Frequency** | 50 Hz |
| **Focus** | Support Auto-focus/Manual focusing |

**Table 1.2**. AT300 Imaging and Optical Data [9].

| | |
|---|---|
| **Detector Type** | VOx, Uncooled FPA detector |
| **Spectral Range** | 8～14 um |
| **Pixel** | 17 um |

**Table 1.3**. Detector Data [9].

| | |
|---|---|
| **Object Temperature Range** | 0ºC ～ 50ºC |
| **Measurement Tools** | Any fixed point<br>Full screen max./min. temperature capture<br>Center spot<br>Line/Area analysis tool<br>Manually choose temperature width |

**Table 1.4**. Temperature Measurement [9].

| | |
|---|---|
| **Brightness and Contrast Adjustment** | Manual/Auto 0(defaulted)/Auto 1 |
| **Polarity** | Black hot/white hot |
| **Palette** | 18 palettes are available |
| **Image Flip** | Left and right/up and down/diagonal |
| **ROI** | Support |

**Table 1.5.** Image Adjustment [9].

| | |
|---|---|
| **Operating Temperature Range** | 10℃～40℃（16℃～32℃ accurate measurement） |
| **Storage Temperature Range** | -45℃～85℃ |
| **Humidity (operating & storage)** | 5%～95%RH (no condensation) |
| **Vibration** | 4.3g, random vibration, all axial |

**Table 1.6**. Environmental Data [9].

| | |
|---|---|
| **Weight** | 430g±5g (without adapter bracket) |
| **Thermal Camera（L×W×H）** | 55mm×55mm×110mm |
| **Base Installation** | Fix the adapter bracket on the thermal camera with 4 M2*6 screws |
| **Housing Material** | Aluminum |

**Table 1.7**. Physical Data [9]

The thermal resolution of our camera determines its ability to distinguish temperature differences. The lower the thermal resolution and the higher the number of pixels, the more detailed and accurate images of temperature changes will be obtained. On the other hand, the camera's refresh rate determines the speed at which images are captured or videos are taken. A high refresh rate is beneficial for detecting rapid changes in perfusion in dynamic areas of interest or in response to external stimuli.

The videos were captured under controlled conditions, avoiding the presence of external heat sources that could affect the results. In addition, informed consent was obtained from the participants, who were informed about the purpose of the study and how the data collected would be used.

The sample population consists of 4 young university students (3 males and 1 females).

The following criteria are defined in the sample of individuals:

Inclusion criteria:

- Body temperature within normal range.
- Age (university students), older than 19 years and younger than 26 years.

Exclusion criteria:

- Not being under any type of medication or any type of cardiovascular and/or neuromuscular disease.
- Non-compliance with any of the conditions of the measurement protocol: fever (>38ºC), shower or bath in the last 2 hours, use of creams or application of ice to facial areas in the last 3 hours.

Subsequently, the same videos were taken but with a cell phone, specifically an Iphone 11 with the following characteristics:

Camera:

- Dual 12 Mpx camera system with wide-angle and ultra wide-angle: This feature allows capturing high-resolution images with different perspectives and angles.
- Portrait Mode with advanced bokeh effect and Depth Control: This mode enables images with a sharp focus on the main subject and a blurred background.
- Portrait Lighting with six effects: These lighting effects allow you to adjust the image lighting.
- Optical Image Stabilization (wide angle): This feature helps reduce unwanted movement during image capture, which can be useful for clear, sharp images of skin.

Video recording:

- 4K and 1080p HD video recording: The ability to record high-resolution video.

- Optical image stabilization for video (wide angle): Optical image stabilization helps reduce unwanted movement during video recording, which can result in more stable and clearer videos.

Here are some pictures of the data aquisition of the experiment:


**Figure 1.1** Thermal camera employed.


**Figure 1.2** Thermal camera with the tripod and (left) and X connected to the camera as to a laptop to be able to load the videos taken on it (rigth).

## 2. THEORETICAL FOUNDATIONS

### 2.1 Video Magnification and its Application in Detecting Subtle Color Changes

This study is based on theoretical foundations importants for the comprehesion of the video amplification and its aplication in color changes detection. Below will be develop the main points of the theoric aspects of it addressed in the project.

The video amplification is a technique used to improve subtle changes in a video that cant be seen with the human eye. This technique can be used to improve the temporal resolution of a video. This is done amplifing the frecuency, so it can check more color changes in less time. The VM amplification is base on the concept of movement. When an object is moving, the pixels of the image of the object also moves.

In the context of the proyect, amplification is used to detect subtle color changes in human faces to asses information of the blood perfusión and microcirculation. By amplifing this color changes it would be possible to analyse and visualize with the blood Flow patterns and evaluate the health.

The VM has been used with success to detect slight colour changes in the human face. There is a study, where the researchers used the video amplification to detect the colour changes in the faces of patients with heart diseases. It was found out that the video amplification allowed to detect some changes of colour that are not visible to the naked eye.

Also the VM has been used to detect slight colour changes in the patients with cancer. There is a study where the researchers searched for slight colour changes in patient with skin cancer, and the detected colour changes (no visible at naked eye) were associated to the presence of cancerous tumour in the face.

Therefore, is clear that the detection of slight colour changes could be especially significant in the context of cutaneous microcirculation, due to the blood flow in the capillaries of the skin can vary in response to the different factors like stress, temperature, disease or inflammatory reply. The capacity to detect and quantify these changes can lead to obtain valuable information for the health evaluation and medical diagnosis. It is a cheap and non-invasive tool which can be used to improve the medical diagnostic precision.

## 2.2 Eulerian Video Magnification: Concept and Basic Principles

Eulerian amplification video-techniques are based on mathematics and computational rules where it is analysed the temporal sign of each video pixel and in a selective way, the frequencies of relevant regions are amplified selectively.

In the Eulearian approach, the video signal is decomposed in the components of high and low frequency. Subsequently, to the high frequency components are applied amplifications to remark the slight changes of the video record.

Hereafter, an example is detailed to understand in a better way how the EVM works: if we have a vide with a red ball on a white background. When the ball moves, the pixels in the video also move. EVM will track the movement of the pixels and calculate the color difference between the current state of a pixel and its previous state. The color difference is magnified so that the ball appears brighter and more distinct from the background.

Here are some images that can explain better the EVM:

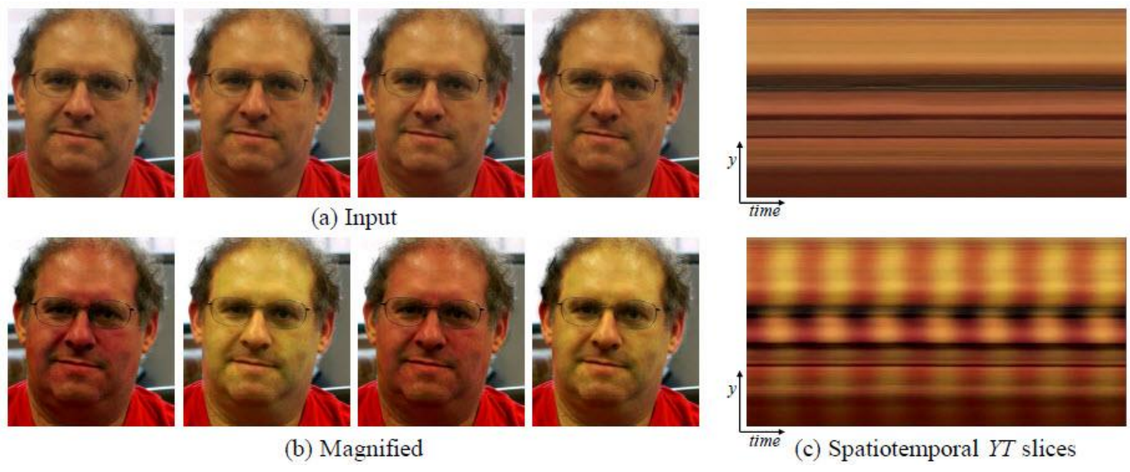


**Figure 2.1.** Example of using the Eulerian Video Magnificaction framework for visualizing the human pulse [1].

The provided input consists of four consecutive frames from the original video sequence. Subsequently, the identical four frames are presented again, but this time with an enhanced amplification of the subject's pulse signal.

Spatiotemporal slices captured from YouTube: A vertical scanning line extracted from both the initial input (upper) and the resulting output (lower) videos is graphed over time. This visualization illustrates how the technique magnifies the recurring color fluctuations. While these variations are not discernible in the input sequence, they become evident in the amplified sequence [1].

### 2.3 Significance of Color Changes in Assessing Cutaneous Microcirculation

Capillaries are the smallest vessels in the human body through which blood circulates, this circulation is known as microcirculation. They are responsible for transporting oxygen and nutrients to the tissues and eliminating waste products.

A poor supply of oxygen and nutrients to the tissues can lead to serious health problems related to tissue damage, organ failure and even death, which is why microcirculation is essential for health.

Depending on the amount of blood flow in the capillaries of the skin there is a certain skin color or another, when the flow is decreased the skin is paler [6] [7]. Thus, skin color can be used as a tool to assess microcirculation. Since such health is important for regulating body temperature and protecting the body from infection [6] [7].

There are several factors that can affect skin color, including: the amount of blood flowing through the capillaries, oxygen levels (when oxygen levels are high, the skin appears pinker than when they are low it appears bluer) and the amount of melanin which affects skin color as it is the pigment of skin color.So people with more melanin in their skin have darker skin. And furthermore, a numbre of diseases can affect the color of the skin, including anemia, heart disease, and liver disease [6] [7].

There are a number of factors that can affect microcirculation, including blood preassure(is the force of blood pushing against the walls of the blood vessels. High blood pressure can damage the capillaries), diabetes, aging (capillaries become less efficient as we age), smoking and certain medications such as chemotherapy drugs, can damage the capillaries and impair microcirculation.

Color changes in facial skin can provide valuable information about cutaneous microcirculation, which is the blood flow in the small blood vessels of the skin. Cutaneous microcirculation plays a crucial role in the regulation of body temperature, delivery of nutrients and elimination of waste products.

Changes in the cutaneous microcirculation are related to the processes of vasodilation and vasoconstriction, which are mechanisms for regulating blood flow in response to internal and external stimuli. These changes may be indicative of various physiological and pathological states, such as inflammatory response, peripheral vascular disease, stress and circulatory dysfunction.

The study of skin microcirculation can be very useful for the evaluation of the efficacy of treatments and recovery therapies, as well as for the diagnosis and monitoring of diseases. Thanks to color changes, blood perfusion, vascular responsiveness and tissue oxygenation can be analyzed.

# 3. EXPERIMENTAL DESIGN

## 3.1 Selection of Study Videos

To continue with the experimental design of the project we selected the videos that we used in the analysis, these videos were taken at the ARIS LAB of the Istanbul Teknikal Universitesi using the thermal camera mentioned above to obtain facial video sequences. To select the videos we looked for diversity of the subjects taking into account age and gender already mentioned in the inclusivity and exclusivity criteria of the project.

In addition, we took into account image quality criteria and the camera's capacity to capture facial thermal variations. We established a constant distance in all subjects between the thermal camera and the face and the same for the optical videos made with the mobile phone and we tried to maintain a correct illumination during all the recordings. While these were the intentions we should have put a white background to mitigate background noise and artifacts, as well as the movements of the rest of the lab.

We identified in this dase the different facial areas of interest that we analyzed: the forehead and the preorbital area around the eyes, due to their importance for blood perfusion and possible perceptible color changes:

- The forehead is one of the most vascularized facial regions due to its large vascular network that allows us to study facial blood perfusion. In addition, it is one of the areas in which temperature is expressed in the face so it is indicated for the study of thermal color variations of the skin surface. These can be indicative of changes in skin microcirculation allowing the study of circulatory health.
- The preorbital area refers to the area around the eyes, which is of great interest to us because it has a highly developed vascular network and the high sensitivity of the skin in this area.Changes in blood perfusion and vascular flow around the eyes may be evident through subtle variations in skin color. These changes may be related to eye fatigue, stress response, inflammatory response, or even specific medical conditions.

Identifying these areas of interest allowed us to focus the analysis on specific regions of the face that could provide relevant information about blood perfusion. This facilitated the extraction and comparison of color values in these areas between the original videos and the videos processed with the Eulerian video amplification technique.

### 3.2 Implementation of Eulerian Video Magnification Techniques on the Videos

In this chapter, we embark on the practical implementation of Eulerian Video Magnification techniques on the videos presented in this project thesis. EVM, is a revolutionary approach in video processing, as we said before, it aims to unveil subtle temporal variations in videos that are imperceptible to the naked eye. By amplifying these hidden changes, this technique offers an enhanced visualization of dynamic processes, providing valuable insights across various domains, from medical imaging to motion analysis.

The utilization of Eulerian Video Magnification in this thesis centers around a main aspect. We focus on try to visualizing the flow of blood as it fills the human face trough the thermal images captured. We aim to amplify the color in the video sequences.

Now we explore the key components, such as spatial decomposition and temporal filtering, that enable the amplification of temporal variations in videos.

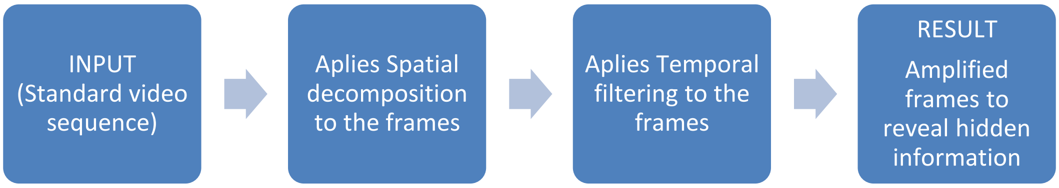


**Figure 3.1.** Schematic of how EVM works.

The spatial decomposition stage is a critical step in the Eulerian Video Magnification process. Continuing with the spatial decomposition technique used in the project, which decomposes each frame in different spatial frequency bands to then apply the temporal filter. This is explained in more detail below.

This decomposition is based on separating each frame of the video sequence into different spatial frequency bands with the help of Laplacian pyramids (multiscale decomposition technique that generates images with different levels of resolution). Such a pyramid allows us to discern between high and low frequency components in the image, where the high frequency ones are represented at the upper levels of the pyramid, while the low frequency ones are at the base.

After the decomposition of the video sequence frames, we selectively amplify certain frequency bands in the following temporal filtering section. So we are amplifying small temporal variations of particular bands and other bands are left unaltered. This, therefore, is a very important selective process of Eulerian Video Amplification.

Finally, we apply the temporal filter to each frequency band, in order to amplify the subtle temporal variations present in the video. We also use a band pass filter in order to isolate the temporal frequencies we are interested in. For example, with this filter we could amplify human heart frequencies by selecting this frequency band.

Lastly, keep in mind that the signal that is amplified is usually weak and without the spatial grouping may be masked by other noise or artifacts in the video, so temporal filtering is best applied at low frequencies so that the input signal arises above the camera sensor and quantization noise.

Overall, the temporal filtering step is a critical part of the Eulerian Video Magnification technique because it allows for the selective amplification of specific temporal frequencies in each spatial frequency band. This amplification reveals hidden information in the video data that is difficult or impossible to see with the naked eye.
Having filtered the temporal data, we proceed to amplify the resulting signal. This step is crucial in revealing hidden information and making the temporal variations more discernible. We elaborate on the signal amplification technique used, taking into account the balance between clarity and potential artifacts.

The code is written in MATLBA R2011b, it uses the pyramid toolbox by Eero Simoncelli (matlabPyroTools). And it also requires MATLAB’s Image Processing Toolbox. So we have to run “make.m” to build the pyramid toolbox libraries, which is required if using MAC OS and MATLAB newer than 2011B. This is the code for “make.m”:

```
% Build matlabPyrTools
fprintf('Building matlabPyrTools...\n');
run(fullfile('matlabPyrTools', 'MEX', 'compilePyrTools.m'));
```

The code "make.m" builds the MATLAB function package for using Laplacian pyramids called matlabPyrTools. To do so, it initially uses the function fprint tal, where it prints the message that the package is being created. Next, the script 'compilePyrTools.m' from the 'matlabPyrTools/MEX' directory is executed to compile the MEX functions that are also in the package. After executing the code we can check that the created package is compiled to avoid future errors in the amplification.
We proceed to run the code "install.m" which has the two functions shown below:

```
addpath('./matlabPyrTools');
addpath('./matlabPyrTools/MEX');
```

With these two functions we add two paths to MATLAB, the first one leads to a directory with MATLAB functions that allow working with Laplacian pyramids.

While the second one accesses a directory with MEX functions (functions grouped in binary code that can be called from MATLAB) compiled to work with Laplacian pyramids. By adding these paths, we access the MEX files and functions in these directories from our code.
We proceed to run the last code "reproduceResults.m" for the development of the EVM techniques, which shows us the resulting amplified videos. Initially we establish two directories, one for the data (raw videos, both thermal and optical) and one for the results (amplified videos, both thermal and optical) using the mkdir function. This function creates a new directory to group the obtained results, in addition, this function only uses one argument (the name of the directory to be created, in our case ResultsSIGGRAPH2012) and if this directory already exists the program will show an error and will not create a new one.

Finally, we process the videos with the Eulerian amplification techniques, with a series of specific parameters that are tested by the user and that are specific to the videos.
For example, one video is processed using the amplify_spatial_lpyr_temporal_iir function with parameters (inFile, resultsDir, 10, 16, 0.4, 0.05, 0.1), while another video is processed using the amplify_spatial_lpyr_temporal_butter function with parameters (inFile, resultsDir, 60, 90, 3.6, 6.2, 30, 0.3).

Each call to these functions applies the Eulerian Video Magnification technique to the input video file and saves the output video to the results directory.
In our case, after testing the different functions provided, we used the following one, since it is the one that best suits our videos. The parameters of the same are detailed below and are chosen by the user according to their videos and the features that is looking for:

```
amplify_spatial_Gdown_temporal_ideal(inFile,resultsDir,50,4, ...
50/60,60/60,30, 1);
```

**Table 3.1.**EVM Parameter values for all thermal and optical videos.

| Parameter | Optical Video | Thermal Video |
|---|---|---|
| Number of spatial levels | 4 | 4 |

| | | |
|---|---|---|
| Low frequency bound (Hz) | 0.83 | 0.83 |
| High frequency bound (Hz) | 1 | 1 |
| Magnification Factor | 50 | 50 |
| Attenuation factor | 1 | 1 |
| Frame rate (Hz) | 30 | 60 |

The user has the responsibility of determining various parameters within the EVM methodology. These parameters encompass factors such as the count of spatial levels, the type of filter to be employed, the specific frequency band under consideration, and the extent of magnification desired.

Here is an example of the result of the application of EVM techniques in one of the subjects thermal videos:

**Figure 3.2.** Subject 1 thermal video amplified.

**Figure 3.3.** Capture of the thermal video of subject 1 without EVM techniques.

### 3.3. Extraction of Color Values  from the Areas of Interest in the Original and Processed videos

Once all the videos have been processed, we proceed to extract information about the color magnification produced with EVM.

For this purpose we use a Matlab code that we will apply to the videos processed with the Eulerian color amplification, both thermal and optical videos. Initially, the first frame of the video is displayed in a viewing window to manually obtain the coordinates of the upper left point of the region of interest (ROI), all thanks to the "ginput" function. In addition, the width and height of the ROI are defined and stored in a matrix of bounding boxes. This is a matrix composed of several rows, where each row defines a specific ROI by means of four values: the x and y coordinates of the upper left point of the ROI, the width and the height of the ROI.
The code then iterates through each frame of the video and extracts the ROI defined in the first frame. Then the mean color values for each channel in the region of interest are calculated and stored in a matrix for later visualization. Finally, the mean color values for each channel are plotted. The graphs obtained for each of the optical and thermal videos are shown below and will be analyzed later.

In Figure X we show how the program asks the user to select the corner of the ROI manually. In the following graphs only the averages for the regions of interest of the forehead and preorbital area of the various subjects will be shown for simplicity. And when we say normal it means that the EVM techniques are not applied in that video.

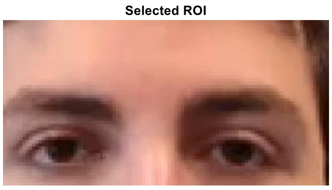


**Figure 3.4.** Selected ROI for subject1**.**

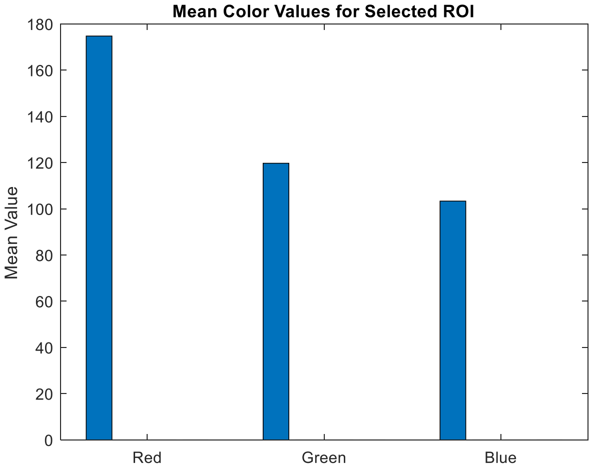


**Figure 3.5.** Subject 1 means of the optical normal video.

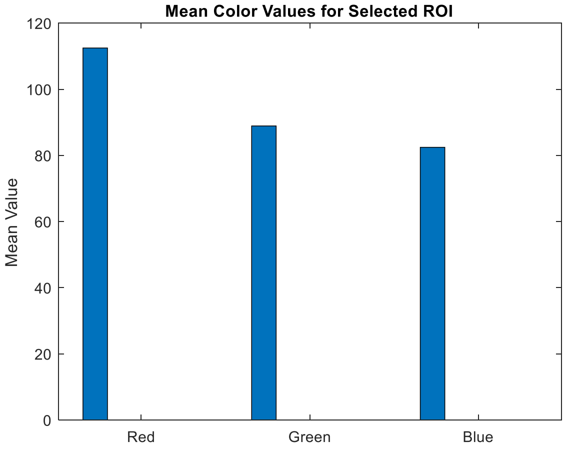


**Figure 3.6.** Subject 2 means of the optical normal video.

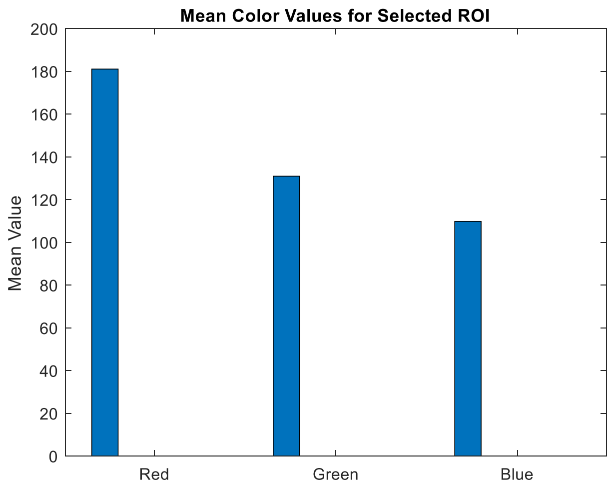


**Figure 3.7.** Subject 4 means of the normal optical video**.**

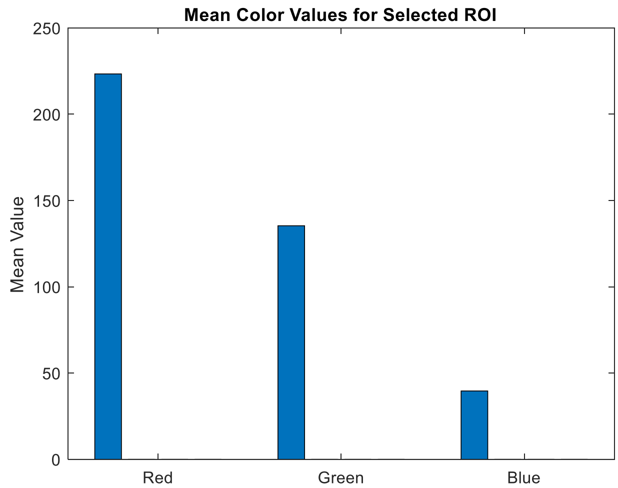


**Figure 3.8.** Subject 1 means of the thermal normal video.

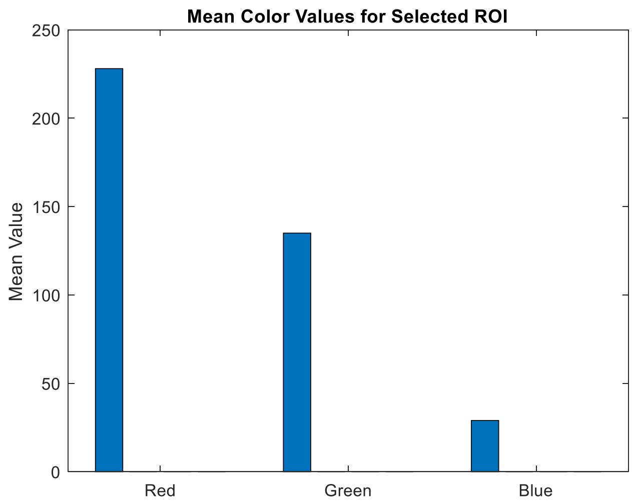


**Figure 3.9.** Subject 2 means of the thermal normal video

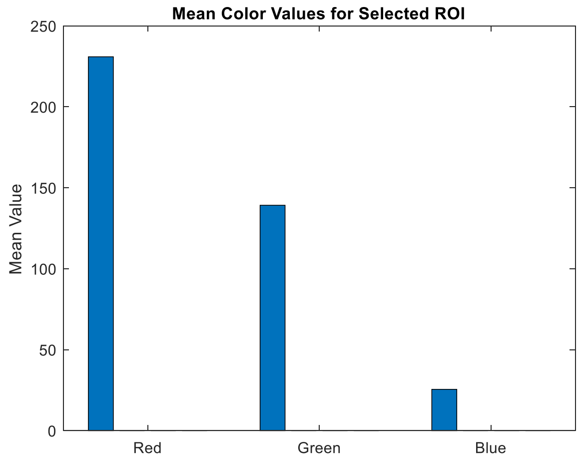


**Figure 3.10.** Subject 3 means of thermal normal video.

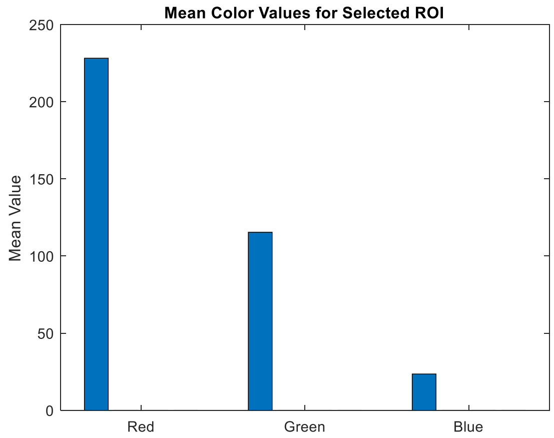


**Figure 3.11.** Subject 4 means of the normal thermal video**.**

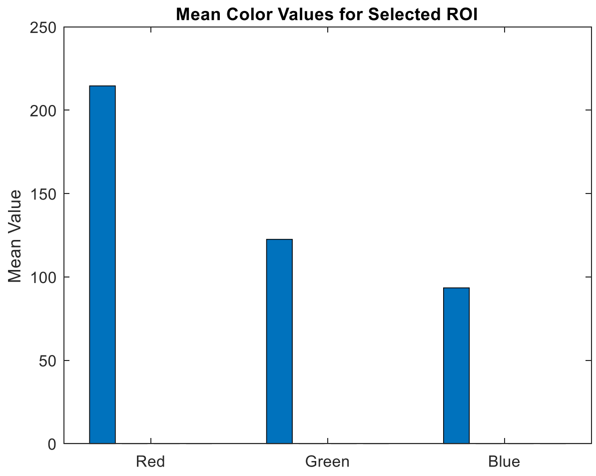


**Figure 3.12.** Subject 1 means of the optical amplified video.

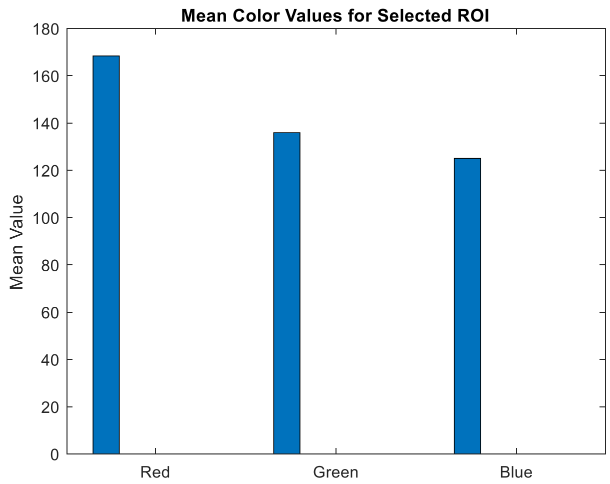


**Figure 3.13.** Subject 2 optical amplified video.

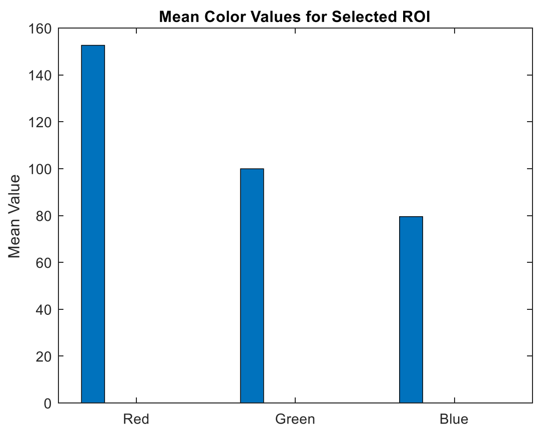


**Figure. 3.14.** Subject 4 optical amplified video

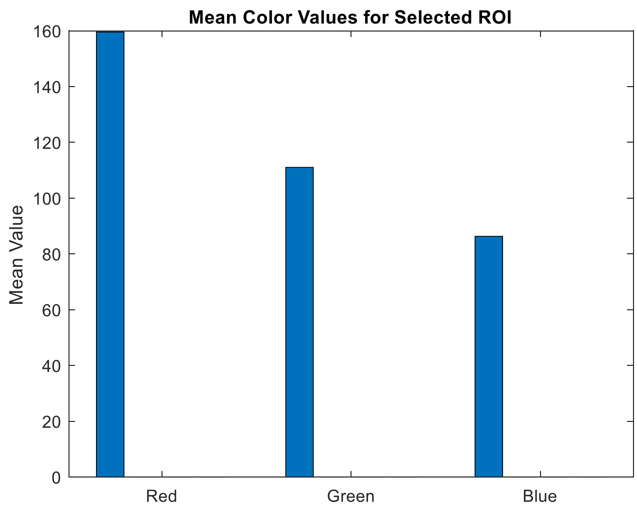


**Figure 3.15.** Subject 1 thermal amplified video.

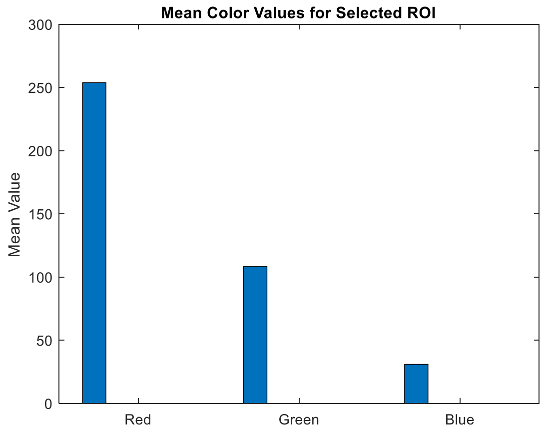


**Figure 3.16.** Subject 2 thermal amplified video

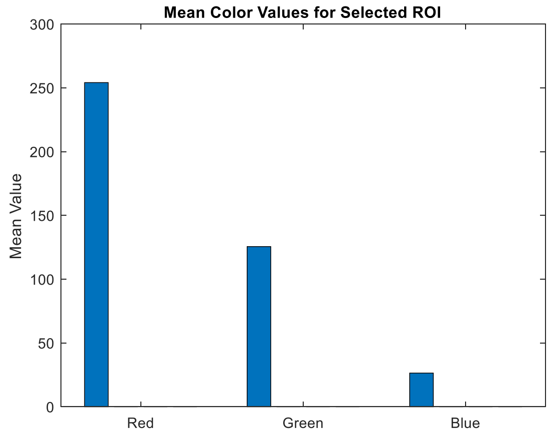


**Figure 3.16.** Subject 3 thermal amplified video.

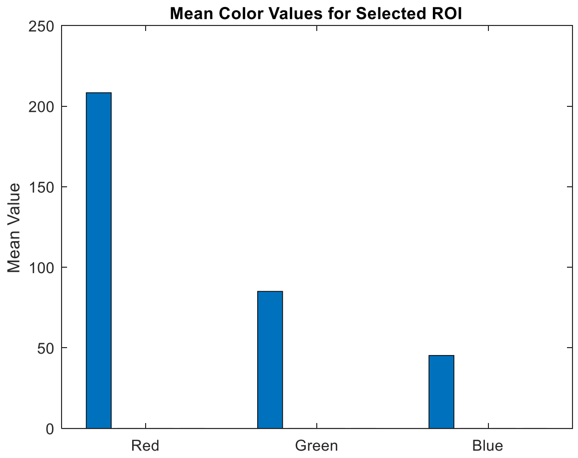


**Figure 3.17.** Subject 4 thermal amplified video.

Now if we do a preliminary analysis without performing statistical tests it includes observations and noticeable patterns in the color averages of the different types of videos (normal, thermal and amplified).

First the differences between normal and thermal videos would be that the color means for thermal videos are higher compared to normal videos in all color channels (red, green and blue). This could be due to differences in the way thermal camera systems capture the information and interpret it. The blue channel seems to be the most affected by this difference, with a significant increase in color averages in the thermal videos.

For the amplified normal videos, we see an increase in the color means compared to the unamplified normal videos. This could indicate that the Eulerian amplification is affecting the color levels in the normal videos, making the colors more intense. And in the case of the amplified thermal videos, the color averages in some channels (such as red and blue) are further increased compared to the unamplified thermal videos. This might suggest that Eulerian amplification has a more marked effect on thermal videos.

It is important to consider how changes in color channels relate to specific features of thermal and normal images. Patterns in color changes could be related to object properties, illumination, and other factors.

These are only initial analyses based on the color averages provided. To make a more robust statistical evaluation and support these observations, statistical tests, are going to be explained in the following chapter.

# 4. ANALYSIS AND RESULTS

## 4.1 Visual Comparison of Color Changes in the Areas of Interest Before and After Magnification.

In this section, we undertake a comprehensive visual analysis to qualitatively evaluate how the magnification process affects the color dynamics within these regions in the thermal videos and the normal ones. This visual comparison serves as an initial insight into the efficacy of our methodology in revealing hidden color variations that might hold significance for understanding physiological phenomena such as blood perfusion.

To conduct the visual comparison, we begin by selecting specific areas of interest within the video frames. These regions are carefully chosen based on their potential relevance to physiological changes and the likelihood of capturing distinctive color variations. Our selection might encompass regions of the face where changes in blood flow are expected to manifest, such as the cheeks, forehead, or regions around blood vessels.

Subsequently, we apply Eulerian Video Magnification to the video sequences, as detailed in Section 3.1. This involves spatial decomposition, temporal filtering, and signal amplification, to unveil subtle temporal variations that might be imperceptible to the naked eye.

With the magnified videos, we visually compare the color changes within the selected regions of interest before and after the magnification process. By juxtaposing the original and magnified frames side by side, we aim to observe and qualitatively assess the differences in color dynamics that emerge due to the applied techniques.

In this visual comparison, we pay special attention to the following aspects:

- Enhanced Color Variations: We examine whether the color changes in the areas of interest become more pronounced and apparent after magnification. The goal is to observe whether Eulerian Video Magnification succeeds in making previously subtle color shifts more discernible to the human eye.
- Consistency and Coherence: We assess whether the magnified color changes maintain consistency with the overall context of the video and the natural color transitions in adjacent regions. This coherence is indicative of the method's ability to preserve spatiotemporal integrity while enhancing specific color variations.
- Insights into Physiological Processes: We attempt to correlate the observed color changes with potential physiological processes such as blood perfusion. For example, changes in color intensity might correspond to variations in blood flow rates, providing qualitative insights into underlying circulatory dynamics.

To provide a clearer understanding, we present illustrative examples of visual comparisons for specific areas of interest within the video frames. Through annotated visualizations, we highlight the before-and-after effects of the magnification process, showcasing how certain color variations that might have been inconspicuous in the original frames become more prominent and informative following the application of Eulerian Video Magnification.

**Figure 4.1.** Capture of subject1 in the thermal amplified video.

As we can see in the screenshots of the videos, there are visible color changes after applying the Eulerian amplification techniques that show color variations in time that are not able to be seen in the same thermal video without amplification.

**4.2 Statistical Analysis of the obtained results**

In this section, we will address the quantitative analysis of the results obtained through the Eulerian Video Magnification techniques. We will use descriptive statistics to gain an initial understanding of our data. And we will calculate measures such as mean, median, standard deviation and range for the color characteristics of the regions of interest in different videos.

In our statistical analysis we develop the following hypothesis taking into account our initial goals: recognition of colour variations at the interesting areas in the human faces and the difference between the thermal camera video and the standard video cameras

- Hypothesis 1: Color Changes Detected with Eulerian Amplification
  - Null Hypothesis (H0): There are no significant differences in color changes detected between Eulerian amplified videos and normal videos.

    - Alternative Hypothesis (H1): Eulerianly amplified videos will show significantly more noticeable color changes compared to normal videos.
- Hypothesis 2: Differences between Thermal and Normal Videos
    - Null Hypothesis (H0): There are no significant differences in color changes between thermal camera videos and normal videos.
    - Alternative Hypothesis (H1): Thermal camera videos will show significantly different color changes compared to normal videos.
- Hypothesis 3: Eulerian Amplification and Thermal Videos in Conjunction
    - Null Hypothesis (H0): There is no interaction between Eulerian amplification and camera type (normal or thermal) in relation to color changes.
    - Alternative hypothesis (H1): The interaction between Eulerian amplification and chamber type (normal or thermal) will have a significant effect on color changes.

Suitable statistical tests to address our hypotheses are: two-sample t-tests(to compare characteristics between normal camera videos and thermal camera videos) Analysis of variance (ANOVA) (to analyze multiple groups of videos).

The code implemented performs statistical tests to compare color changes between different groups of videos. First, color mean matrices are defined for normal and thermal videos, as well as for amplified normal and thermal videos. Then, the color mean matrices are combined into a single matrix for each group and two-sample t-tests are performed to compare normal vs. amplified and thermal vs. normal groups. If the p-value obtained is less than 0.05, the null hypothesis that there is no significant difference between the groups is rejected. If the p-value is greater than 0.05, the null hypothesis cannot be rejected.

Finally, an ANOVA test is performed to evaluate whether there is interaction between Eulerian amplification and camera type in relation to color changes. If the p-value obtained is less than 0.05, the null hypothesis that there is no significant interaction between the factors is rejected. If the p-value is greater than 0.05, the null hypothesis cannot be rejected.

After the code that fulfills these hypotheses by studying the stored means of these color values for each group of videos, thermal and optical, amplified and non-amplified respectively, we found the following results.

For the first hypothesis (Color Changes Detected with Eulerian Amplification), we can reject the null hypothesis (H0) in this test which means that there is enough evidence to claim that there are significant differences in color changes between the Eulerian amplified videos and the normal videos. In other words, the color changes do appear to be significantly different between these two groups of videos.

For the second hypothesis (Differences between Thermal and Normal Videos), we cannot reject the null hypothesis (H0) in this test (p-value >= 0.05), which implies that there is insufficient evidence to claim that there are significant differences in color changes between thermal camera videos and normal videos. In this case, the color changes in thermal and normal images do not appear to be statistically different.

This may be due to the resolution of the thermal camera and artifacts that may have been generated during video acquisition in the laboratory. This then triggers artifacts for the amplification which is very sensitive to them (light, noise, surrounding movements).

### 4.3 Discussion of findings and potential implications

After the statistical, visual and average analysis of the color values applied to the videos, both optical and thermal, amplified and non-amplified, we observed a series of results on the differences and similarities between the videos and their colors. We observed a series of results on the differences and similarities between the videos and the colors of the videos.

Two-sample t student tests were used to study the characteristics and make a comparison between the amplified and normal videos and the results show that there is a significant difference in color changes between these two groups. Therefore, we can assume that the Eulerian video amplification technique does favor the perception and magnification of colors in the videos.

On the other hand, in the comparison between the optical and thermal videos with the two-sample t student tests, no significant differences in color changes were observed between these categories so we deduce that there are no significant variations in chromatic perception. This may be due to the fact that thermal differences are usually related to other visual properties and not chromatic which could justify this result.

The ANOVA analysis examines the interactions between the amplifications and the type of camera used either optically or thermally to record the videos in relation to the color changes studied. And after the results we observed that there is no significant interaction between these factors therefore we assume that the Eulerian amplification techniques are not influenced by the type of camera used. That is to say, that the amplifications in thermal cameras do not provide better results, which may be due to the resolution of the camera and the context in which the videos were recorded, even improving this resolution and the taking of videos by putting a canvas behind the subjects to reduce the background and avoid other objects or movements that alter the magnification.

# 5. REALISTIC CONSTRAINTS AND CONCLUSIONS

## 5.1 Realistic Constraints

In terms of societal impact:

-Improved health and well-being: the application of the findings of this study in the biomedical industry could improve the early detection and diagnosis of diseases, which would directly impact people's health and well-being by providing more effective treatments and opportunities for early intervention and prevention.

- Fairer access to healthcare: the implementation of video analytics-based technologies could help make healthcare more accessible to rural or underserved populations by enabling telemedicine and remote screening, helping to treat diseases early that would otherwise progress to advanced stages making them difficult to treat.

- Awareness and education: Advances in medical imaging analysis could increase public awareness of the importance of early detection and accurate diagnosis by promoting greater health education. The public must be made to understand that prevention and early diagnosis are the best tools for taking care of health.

On the economic impact:

- Development of new markets: successful application of the findings made could generate new studies and markets for medical devices and advanced imaging technologies, which could drive economic growth in the medical and technology industries.

-Innovation and competitiveness: Companies and organizations that adopt the findings of this study and further research them for application in innovative products and services could increase their competitiveness in the marketplace.

-Cost reduction in the healthcare system: early detection and accurate treatments would reduce long-term costs in the healthcare system by avoiding more invasive or prolonged treatments, which occur when diseases are diagnosed at more advanced stages where greater treatment effort/cost is involved.

Environmental impact:

-Reduction in the use of resources: improved detection and diagnosis by imaging would mean reducing the need for certain unnecessary and repetitive medical procedures, which in turn would lead on the one hand to a reduction in the use of medical resources and, on the other, avoid the generation of healthcare waste.

-Innovation in sustainable technologies: if video analytics could be integrated into existing medical devices and imaging technologies, this would drive innovation towards more efficient and sustainable technologies.

-Reduction of the need for medical travel: the novelty of telemedicine would help reduce the carbon footprint by avoiding medical and patient travel.

Cost analysis:

We will evaluate now the costs associated with the research and development of our project. We will consider labor costs, design costs and the costs of the parts used in the project.

Let's consider a reasonable salary for a researcher and developer in our field. Suppose we spend 40 hours per week for 6 months on the project. The total cost would be twelve thousand euros gross, based on a monthly salary of two thousand euros gross. In addition, we must take into account the cost of the design, in which about four thousand euros would be used for design tools, software and various resources used in the progress of the project. And finally, the cost of the project devices, the thermal cameras, the cell phones used, the supports and other materials and parts for the experimental part, in which there would be a cost of approximately nine thousand euros. With all this we can assume that the total oste of the project would be approximately about twenty-five thousand euros.

Norms:

In order to comply with all regulations both Turkish and European, we will take into account the IEEE standards, making sure that all technological equipment and electrical systems comply with the standards. In addition to complying with the IET safety and design guidelines, along with the safety and EMC standards set by the

European Union. Finally, we will not forget about the Turkish national regulations and standards on design and safety in force.

Health and safety:

There is a risk of possible electric shock when working in a laboratory with different electrical components, so it is necessary for the whole research team to be aware of the rules and protocol to be followed in such risk areas.

## 5.2 Future Work and Recommendations

There are several formulas and recommendations for future work that could improve the impact and scope of this project such as:

-Take into account a possible exploration and study of more advanced algorithms and techniques for color analysis and pattern recognition. This could include machine learning models for more accurate detection of color changes.

-Expand the project to enable real-time monitoring of color changes in dynamic environments. This could involve system integration with IoT devices for continuous data collection and analysis.

-Seek collaboration with medical professionals to integrate color change detection technology with medical imaging processes in its innovative healthcare diagnostic application.

-Develop a user-friendly interface for visualizing and interpreting color change data. If appropriate, optimize algorithms and processes to work efficiently on specific hardware, such as embedded systems or handheld devices.

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## CURRICULUM VITAE

| | |
|---|---|
| **Name Surname** | **: Lucia Catania Payo** |
| **Place and Date of Birth** | **: Valencia, Spain 15/06/2000** |
| **E-Mail** | **: catania23 @ itu.edu.tr** |
| **EDUCATION** | |
| **Undergraduate:** | **: Universidad Politécnica de Valencia, Biomedical Engineering (2018-2023)** |
| **High School:** | **: Sagrado Corazon Hermanos Maristas de Valencia (2013-2018)** |