

**FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO**

# **Title of the Dissertation**

**Name of the Author**

WORKING VERSION



Mestrado Integrado em Engenharia Informática e Computação

Supervisor: Name of the Supervisor

June 18, 2017



# **Title of the Dissertation**

**Name of the Author**

Mestrado Integrado em Engenharia Informática e Computação

June 18, 2017



# Abstract

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# Resumo

O Resumo fornece ao leitor um sumário do conteúdo da dissertação. Deverá ser breve mas conter detalhe suficiente e, uma vez que é a porta de entrada para a dissertação, deverá dar ao leitor uma boa impressão inicial.

Este texto inicial da dissertação é escrito no fim e resume numa página, sem referências externas, o tema e o contexto do trabalho, a motivação e os objectivos, as metodologias e técnicas empregues, os principais resultados alcançados e as conclusões.

Este documento ilustra o formato a usar em dissertações na Faculdade de Engenharia da Universidade do Porto. São dados exemplos de margens, cabeçalhos, títulos, paginação, estilos de índices, etc. São ainda dados exemplos de formatação de citações, figuras e tabelas, equações, referências cruzadas, lista de referências e índices. É usado texto descartável, *Loren Ipsum*, para preencher a dissertação por forma a ilustrar os formatos.

Seguem-se umas notas breves mas muito importantes sobre a versão provisória e a versão final do documento. A versão provisória, depois de verificada pelo orientador e de corrigida em contexto pelo autor, deve ser publicada na página pessoal de cada estudante/dissertação, juntamente com os dois resumos, em português e em inglês; deve manter a marca da água, assim como a numeração de linhas conforme aqui se demonstra.

A versão definitiva, a produzir somente após a defesa, em versão impressa (dois exemplares com capas próprias FEUP) e em versão eletrónica (6 CDs com "rodela" própria FEUP), deve ser limpa da marca de água e da numeração de linhas e deve conter a identificação, na primeira página, dos elementos do júri respetivo. Deve ainda, se for o caso, ser corrigida de acordo com as instruções recebidas dos elementos júri.

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# 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 CCompiler-oriented Language
Loren	Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed vehicula lorem commodo dui
WWW	<i>World Wide Web</i>



# Todo list

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## ABBREVIATIONS

# Chapter 1

## Introdução

*O primeiro capítulo da dissertação deve servir para apresentar o enquadramento e a motivação do trabalho e para identificar e definir os problemas que a dissertação aborda. Deve resumir as metodologias utilizadas no trabalho e termina apresentando um breve resumo de cada um dos capítulos posteriores.*

### 1.1 Contexto/Enquadramento

*Esta secção descreve a área em que o trabalho se insere, podendo referir um eventual projeto de que faz parte e apresentar uma breve descrição da empresa onde o trabalho decorreu.*

### 1.2 Projeto

*Na continuação da secção anterior, e apenas no caso de ser um Projeto e não uma Dissertação, esta secção apresenta resumidamente o projeto.*

### 1.3 Motivation and Goals

*Apresenta a motivação e enumera os objetivos do trabalho terminando com um resumo das metodologias para a prossecução dos objetivos.*

### 1.4 Estrutura da Dissertação

Para além da introdução, esta dissertação contém mais x capítulos. No capítulo 2, é descrito o estado da arte e são apresentados trabalhos relacionados. No capítulo 3, ipsum dolor sit amet, consectetur adipiscing elit. No capítulo 4 praesent sit amet sem. No capítulo 5 posuere, ante non tristique consectetur, dui elit scelerisque augue, eu vehicula nibh nisi ac est.

## Introdução



## Chapter 2

# Revisão Bibliográfica

*Neste capítulo é descrito o estado da arte e são apresentados trabalhos relacionados para mostrar o que existe no mesmo domínio e quais os problemas em aberto. Deve deixar claro que existe uma oportunidade de desenvolvimento que cobre alguma falha concreta . O capítulo deve também efetuar uma revisão tecnológica às principais ferramentas utilizáveis no âmbito do projeto, justificando futuras escolhas.*

Resenha utilização computer vision em trafego e em transportes Concluir com os desafios da armis (drive, que quer aplicaro computer vision para automatizar determinados aspetos) Sequência de funcionalidades que respondem ao desafio da Armis(segmentação,deteção,...) Uma secção para cada um

Tese Gustavo Lira / Pedro Loureiro

### 2.1 History of Computer Vision

Computer vision appeared as an area of investigation around the mid 60's at the MIT by Professor Larry Roberts, whose PhD. thesis focused on methods to extract 3D information from a 2D image [Hua96] in order to reconstruct entire scenes from the geometry gathered. This area is now considered by the ACM as a branch of artificial intelligence according to the 2012 ACM Computing Classification System [ACM12]. From this point onward scientists began applying the techniques developed in multiple fields.

The use of computer vision in manufacturing industry was among the first to be explored, as there were already multiple robots working in the assembly lines of the factories that needed to be improved, as noted by Stout in 1980 [Sto80]. These robots were becoming outdated due to the lack of interaction with the environment. This meant that for a robot to work with a part in an assembly line it needed to be placed in a pre-determined position, and any deviation could mean that the line needed to be stopped. Michael Baird relates in [LB78] a computer vision system developed to inspect circuit chips rotation in a welding base. Computer vision was also used as

a tool to automatically analyse weather satellite images [BT73] and multidimensional medical images [Aya98], with applications being developed in these areas being now common in our daily life.

Regarding intelligent transport systems (ITSs), the use of computer vision to aid in the analysis of traffic has been increasing in the last years due to the decreasing costs of hardware, both cameras, storage and processing power, as well as the knowledge to extract useful data from the video gathered. One of the first works applying computer vision to analyse traffic was published in 1984 [DW84]

Since the dawn of computer vision in the early 90's as an area of artificial intelligence, according to the [ACM12], that

## 2.2 Segmentation

Image segmentation is the process through which an image is separated into its different regions according to the desired output, usually objects of interest. These regions are composed by pixels that have a common characteristic [SS01]

## 2.3 Secção Exemplo

*Scalable Vector Graphics* é uma linguagem em formato XML que descreve gráficos de duas dimensões. Este formato padronizado pela W3C (*World Wide Web Consortium*) é livre de patentes ou direitos de autor e está totalmente documentado, à semelhança de outros W3C standards citekn:svgdoc.

Sendo uma linguagem XML, o SVG herda uma série de vantagens: a possibilidade de transformar SVG usando técnicas como XSLT, de embeber SVG em qualquer documento XML usando *namespaces* ou até de estilizar SVG recorrendo a CSS (*Cascade Style Sheets*). De uma forma geral, pode dizer-se que SVGs interagem bem com as atuais tecnologias ligadas ao XML e à Web, tal como referido em citekn:svgibm,kn:svgw3c.

## 2.4 Resumo ou Conclusões

No final do capítulo deverá ser apresentado um resumo com as principais conclusões que se podem tirar.

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## Chapter 3

# Computer Vision applied to Traffic Analysis - An Overview

Este capítulo deve começar por fazer uma apresentação detalhada do problema a resolver<sup>1</sup> podendo mesmo, caso se justifique, constituir-se um capítulo com essa finalidade.

Deve depois dedicar-se à apresentação da solução sem detalhes de implementação. Dependendo do trabalho, pode ser uma descrição mais teórica, mais “arquitetural”, etc.

### 3.1 Secção Exemplo

Neste capítulo apresentam-se exemplos de formatação de figuras e tabelas, equações e referências cruzadas.

Apresenta-se de seguida um exemplo de equação, completamente fora do contexto:

$$CIF_1 : \quad F_0^j(a) = \frac{1}{2\pi i} \oint_{\gamma} \frac{F_0^j(z)}{z-a} dz \quad (3.1)$$

$$CIF_2 : \quad F_1^j(a) = \frac{1}{2\pi i} \oint_{\gamma} \frac{F_0^j(x)}{x-a} dx \quad (3.2)$$

Na Equação 3.2 lorem ipsum dolor sit amet, consectetur adipiscing elit. Suspendisse tincidunt viverra elit. Donec tempus vulputate mauris. Donec arcu. Vestibulum condimentum porta justo. Curabitur ornare tincidunt lacus. Curabitur ac massa vel ante tincidunt placerat. Cras vehicula semper elit. Curabitur gravida, est a elementum suscipit, est eros ullamcorper quam, sed cursus velit velit tempor neque. Duis tempor condimentum ante.

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<sup>1</sup>Na introdução a apresentação do problema foi breve.

nunc, tincidunt vitae, dictum posuere, pulvinar nec, diam. In suscipit mauris a nunc. Pellentesque gravida. Morbi quam lacus, pretium eget, tincidunt vulputate, interdum sed, turpis. Curabitur quis est. Sed lectus lorem, congue vel, dignissim laoreet, blandit a, nisi. Aenean nunc ligula, tincidunt eu, hendrerit vel, suscipit non, erat. Aliquam gravida. Integer non pede. In laoreet augue id leo. Mauris placerat.

A arquitetura do visualizador assenta sobre os seguintes conceitos basecitek:ZPMD97:

- **Componentes** — Suspendisse auctor mattis augue *push*;
- **Praesent** — Sit amet sem maecenas eleifend facilisis leo;
- **Pellentesque** — Habitant morbi tristique senectus et netus.

### 3.1.1 Exemplo de Figura

É apresentado na Figura 3.1 um exemplo de figura flutuante.

[t]

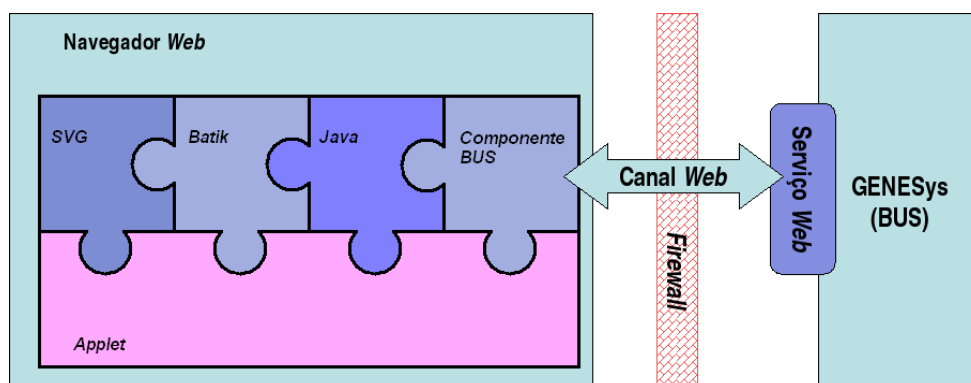


Figure 3.1: Arquitetura da Solução Proposta

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### 3.1.2 Exemplo de Tabela

É apresentado na Tabela 3.1 um exemplo de tabela flutuante e na Tabela 3.2 um exemplo de tabela flutuante, um pouco mais complicada.

Table 3.1: Uma Tabela Simples

Acrónimo	Significado
ADT	<i>Abstract Data Type</i>
ANDF	<i>Architecture-Neutral Distribution Format</i>
API	<i>Application Programming Interface</i>

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Table 3.2: Uma Tabela Mais Complicada

$k$	Iteração $k$ de $f(x_n)$			comentários
	$x_1^k$	$x_2^k$	$x_3^k$	
0	-0.3	0.6	0.7	-
1	0.47102965	0.04883157	-0.53345964	$\delta < \varepsilon$
2	0.49988691	0.00228830	-0.52246185	$\delta < \varepsilon$
3	0.49999976	0.00005380	-0.523656	$N$
4	0.5	0.00000307	-0.52359743	
$\vdots$	$\vdots$	$\ddots$	$\vdots$	
7	0.5	0.0	<b>-0.52359878</b>	$\delta < 10^{-8}$

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### 3.2 Secção Exemplo

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### 3.3 Resumo e Conclusões

Resumir e apresentar as conclusões que se podem tirar no fim deste capítulo.

## Chapter 4

# Implementation

*Este capítulo pode ser dedicado à apresentação de detalhes de nível mais baixo relacionados com o enquadramento e implementação das soluções preconizadas no capítulo anterior. Note-se no entanto que detalhes desnecessários à compreensão do trabalho devem ser remetidos para anexos. Dependendo do volume, a avaliação do trabalho pode ser incluída neste capítulo ou pode constituir um capítulo separado.*

Capitulo implementação Como resolver os desafios Estabilização BG Sub

As previously stated, the work done for this project consists of a module for the "Video Server" being developed by LIACC, that will perform all the required analytics of the video received. This chapter provides the details of the implementation of this module, developed during the dissertation semester between February and June 2017. Tasks performed involved designing an appropriate architecture, able to scale with the project, treating the images received from the video streams to detect events and extract information.

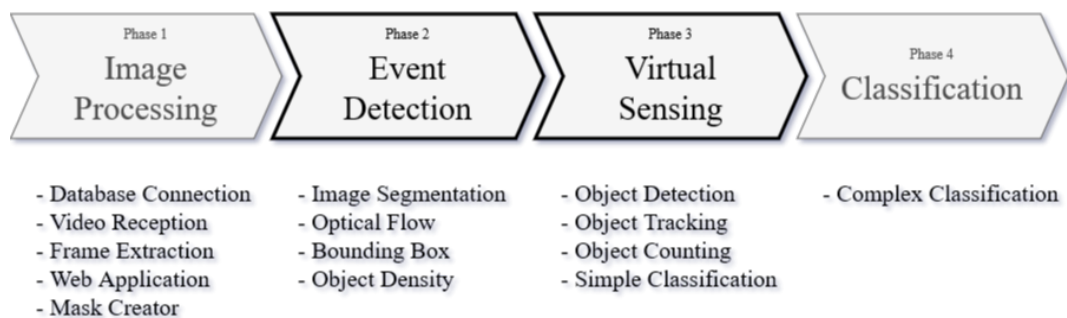


Figure 4.1: Project Planning

It is expected that this chapter provides some insight on how the theoretical backgrounds presented before were used during the project development, namely phase 2 and 3 of the presented project planning in 4.1. Phase 2 focused on the detection of relevant events to the traffic controller such as suspicious approximation to the camera, intrusion in prohibited areas, fallen objects on the

road and wrong way travelling, while phase 3 aimed to count and classify vehicles in both urban and high-way scenarios.

### 4.1 Technology

In order to build this project we needed both a library of already implemented computer vision algorithms as well as a simple way to retrieve frames from both video streams and files. This section describes what were the chosen technologies including a brief description and why it was chosen.

#### 4.1.1 OpenCV

OpenCV is a library composed of implementations of useful computer vision algorithms implementation, widely used across the industry and academy. It has interfaces for multiple programming languages, like C++, Java and Python, but is natively written in C++ in order to take advantage of low level performance enhancements, as performance is an important factor in real time computer vision applications [Ope17a].

The library contains over 2500 algorithms ranging from the more basic image processing such as filtering, morphology operators and geometric transformations to more complex ones that are able to, among others, compare images, track features and camera movements and recognize faces. Along with the image processing capabilities OpenCV also ships with interfaces to stereo cameras such as Kinect that allow users to retrieve a cloud of 3D points and a depth map from the captured image. This was the chosen library as there existed already previous work at LIACC using it, which could be leveraged for this project.

#### 4.1.2 JavaCV

JavaCV is a wrapper for OpenCV written in Java that works on top of the JavaCPP Presets, a project that provides Java interfaces for commonly used C++ libraries, such as OpenCV and FFmpeg, the ones we are using, as well as CUDA, ARToolKitPlus and others. It provides access to all the functionalities of OpenCV inside a Java environment, and was the chosen solution as there was already experience inside LIACC working with this technology.

Even though the code is written in Java and runs inside a Java Virtual Machine, the code from OpenCV is compiled from C/C++ and the memory of the objects created there is allocated in a separate thread. This made it impossible to rely on the garbage collector to do the memory management, and necessary to manually delete the native objects. Failure to address this issue causes the system to run out of memory and a subsequent program crash.

#### 4.1.3 FFmpeg

FFmpeg is a framework that performs encoding, decoding, transcoding, streaming and filter operations on videos in all the well known video formats, across a large number of platforms. It is used



## Implementation

```
1 // videopath can be either a stream path or a file path
2 FFmpegFrameGrabber _frameGrabber = FFmpegFrameGrabber.createDefault(videopath);
3 Frame currentFrame = null;
4
5 while( (currentFrame = _frameGrabber.grabImage()) != null) {
6     // Use grabbed frame
7 }
```

Listing 4.1: FFmpegFrameGrabber usage example

in the "Video Server" to read streams from any format and restream them all to the same format. In the Analytic module it is used to grab the frames from both the video files and the streams using the same code, as shown in [4.1](#).

## 4.2 Architecture

### 4.2.1 Implementation Architecture

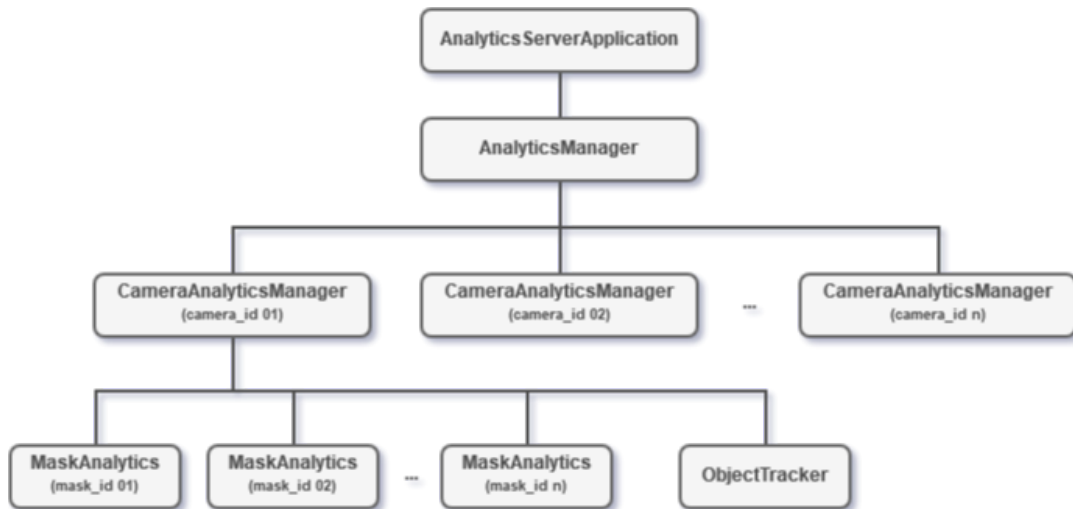


Figure 4.2: Manager Architecture

The analytics module was designed to comply with the following specifications, imposed by both our partner and to comply with the already developed modules.

- Run uninterruptedly waiting for requests to be made
- Process a large number of video inputs at the same time
- Receive input from streams or files
- Specify which analysis are to be run on a specific video

Mais re-  
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ments?

The application main thread runs an instance of the `AnalyticsManager` class that implements the `Java Runnable` interface. This thread will launch one `CameraAnalyticsManager` instance for each video to be analysed, be it from stream or from file, and keep track of each worker status, disposing of them when they finish, and launching new ones when a request is received. The `CameraAnalyticsManager` is then responsible to query the database in order to find out what are the analytics the user wants to retrieve from the video, information that is stored in the *camera* table of the database. This process then starts a frame grabber that will convert each frame of the video into its representation in OpenCV and feed it to each `Analyser` through a queue. This enables each one of these workers to run at his own pace and if one of them runs slower than the pace at which the frame grabber reads the images, it will simply queue them up and not slow down the remaining workers. The drawbacks of this solution are that it is theoretically possible to run out of memory to keep these frames, although this limit was not reached during the testing phase.

### 4.3 Segmentation

This section describes how the segmentation of the received images is performed, and how it returns a foreground mask representing the moving areas of the scene.

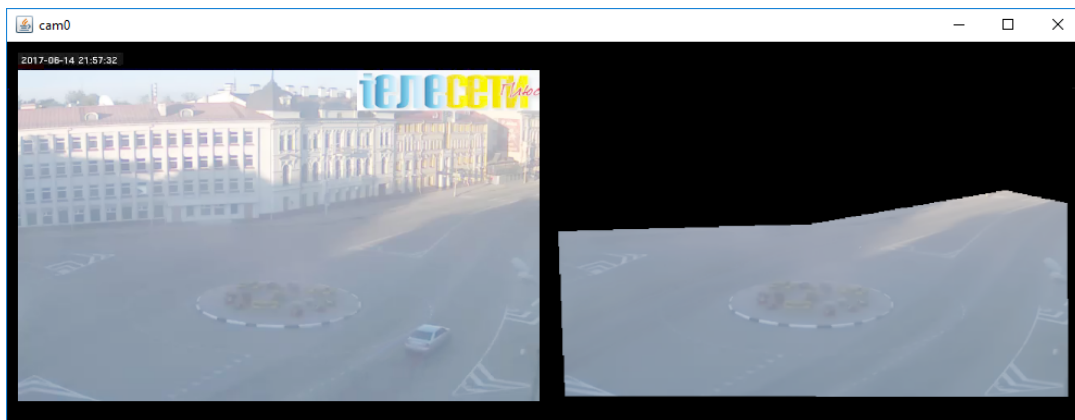


Figure 4.3: Background Subtraction - Background Model

Explain  
masking  
process

In figure 4.3 we can see the original frame on the left and the calculated background model of the scene on the right. To achieve this result, the first step is to mask the obtained frame in order to prevent uninteresting regions of the image from being processed the Background Subtractor. This solves an issue where moving or changing regions of the image outside our region of interest would create unwanted artefacts, for example moving trees due to the wind blowing, or the issue that occurred in this scene, where a car passing would be reflected in the windows of the building.

The next step of the Segmentation process is to feed the masked frames into a Background Subtraction algorithm that will use them to update its internal representation of the scene. This

## Implementation

project uses the OpenCV implementation of the Mixture of Gaussians algorithm that allows the user to tune:

- Number of past frames considered on the background calculation
- Threshold value from which a pixel is considered to be foreground, compared to the difference between its current value and the one from the background model
- Learning rate of the algorithm, how much each new frame influences the model

After updating the background model we can retrieve from the Background Subtractor its foreground mask, a rough representation that is calculated by subtracting the background model from the current image and thresholding it, thus returning only the pixels where the difference is significant enough.

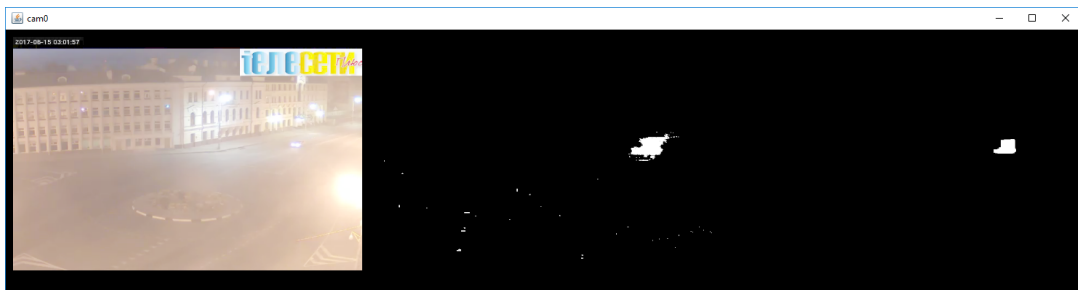


Figure 4.4: Background Subtraction - Foreground Mask

As we can see in the middle image of figure 4.4 the foreground mask from the Background Subtractor can have a lot of noise due to lighting conditions. To solve this issue two morphology filters are applied to the image, a squared erosion filter to remove the small speckles that appear in the mask, followed by a larger circular dilation filter to consolidate the positive regions of the mask, as the wind shield and windows of the vehicles are usually detected as background due to their dark colour and/or reflection of the environment.

## 4.4 Object Detection

This section describes how the information about the objects' size and position are retrieved from the binary mask returned from the segmentation process.

OpenCV provides BlobDetector [Ope17b], a family of functions that retrieve information of blobs in an image. It works by thresholding the image into multiple binary images using a range of threshold values, grouping the connected white pixels at each one of these images in binary blobs and then merging blobs that are close enough to each other into larger blobs. This method allows users to filter returned blobs based on 3 properties:

- Area - The area of the region

## Implementation

- Circularity - Ratio between the area of the smallest involving circle and the area of the region
- Convexity - Ratio between the area of the convex hull of the region and its area
- Inertia - Elongation of the region (0 for lines, 1 for circles)

This however does not work as intended for our input, an already binarized image where we just need to group the connected pixels. For this the project uses the OpenCV function *connected-ComponentsWithStats*, that retrieves the groups of connected pixels in a binary image along with their area, width, height and both the leftmost and topmost coordinate of the group's bounding box. From this data we can create an ImageObject instance that will represent a moving object in the scene, using the regions with a region size above a given threshold, in order to prevent detection of small objects or noise that got through the filtering process.

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## 4.5 Object Tracking

In order for the solution to correctly analyse the objects of the scene it needs to track them during their lifetime, in other words, establish a relation between the objects identified on a frame with the objects identified in the next frame. This is done iterating through each one of the new objects and finding which existing object is closer to him. If the distance between them is smaller than the size of the existing object then they are matched.

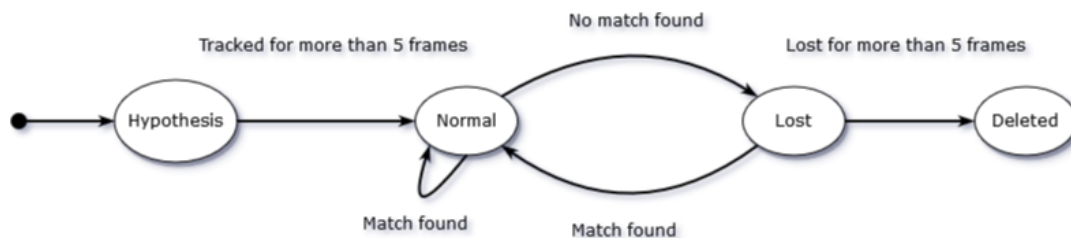


Figure 4.5: Object Life Cycle State Machine

Referenciar  
artigo  
da state  
machine

To enhance this mechanism a sub-set of the state machine presented which allows us to model the life cycle of an object. As seen in 4.5 an object starts as an Hypothesis, and cannot be used for analytics while in this state. After being tracked for 5 frames it then changes its state to Normal, where it stays until no match can be found, either from leaving the scene or due to problems with the input frame. An object in this state remains for a maximum of 5 frames, after which it is deleted or until a new object is found in the vicinities of it's last known position.

This technique relies on objects appearing close to their previous position in the next scene, and because the project was designed to run in high-way scenarios, where vehicles travel at high speeds, there was the need to improve it. The chosen solution was to follow a method used by Chris Dahms in his vehicle counting software [Dah17] that predicts an object next position by calculating an weighted average of the previous inter-position deltas and summing it to its current position as shown in 4.1.

## Implementation

$$NextPos = CurrentPos + \sum_{i=1}^5 (PosHist(i) - PosHist(i-1)) * (5-i) \quad (4.1)$$

In image 4.6 we can see the result of the tracking process on the right most image. Each detected object is circled in a colour representing its current state in the state machine, blue for normal and red for lost, and shows the trail represents its path across the scene.



Figure 4.6: Object Tracking

## 4.6 Object Classification

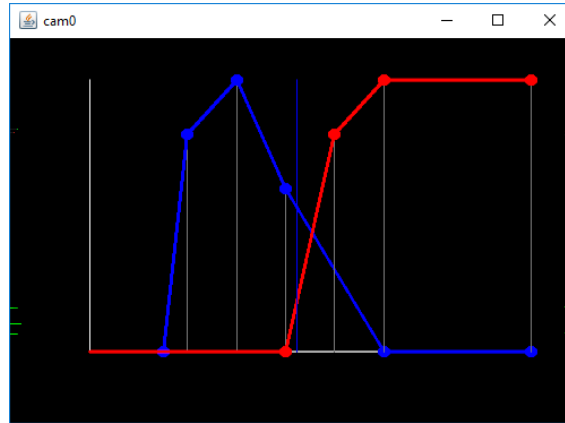


Figure 4.7: Object Classifier

In order to classify the objects present in the scene into light or heavy vehicles a fuzzy set is used. This set is calculated at run time based on a mask drawn by the user via the web interface that roughly approximates the size of a light vehicle. The area of that mask ( $A_{Light}$ ) is used as a base value to create the fuzzy set shown in figure 4.7. This set has 2 series, one for light vehicles, drawn in blue, and one for heavy vehicles, drawn in red.

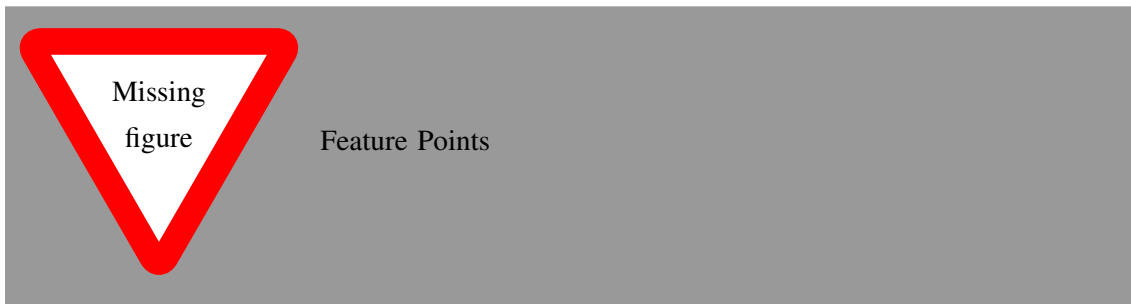
The blue series peaks at  $A_{Light}$ , where we have 100% certainty that a matched object is a light vehicle. The point immediate points are at  $2/3 * A_{Light}$ , where the trust is 80% and at  $4/3 * A_{Light}$

where it drops to 60%. Any object with area below  $1/2 * A_{Light}$  or above  $2 * A_{Light}$  are considered to have 0% chance to be light vehicles.

The red series peaks at  $2 * A_{Light}$ , and any object whose area is larger than this value is considered to be an heavy vehicle with 100% confidence. At the same time, any object whose area is smaller than  $4/3 * A_{Light}$  is never considered to be an heavy vehicle, from where the certainty rises to 80% at  $5/3 * A_{Light}$ .

When an object is counted in one of the virtual sensors its area is passed to this classifier where an interpolation is calculated for each series, returning the certainty with which it belongs to each one of the classes. Using these values the process can distinguish classifications with certainty below and above a user specified threshold to be treated separately.

### 4.7 Feature Point Tracking



The need to track feature points stems from the fact that without them we rely wholly on the background subtraction to process the image. Using feature points we can extract and track details of the vehicles that would otherwise be lost due to the process only working with a binary mask.

We can use these points to distinguish vehicles grouped in a single binary region, as they are characterized by This way, even if a vehicle stops for a long time and starts to be considered background we can use its tracked points to maintain the position of

### 4.8 Utility

Over the development of the project the rise needed to implement some functionalities to enhance the code flow and to help the visualization of the implemented algorithms. This section will describe the most relevant ones for the reader to analyse and implement in its own projects.

#### 4.8.1 Video Wall

#### 4.8.2 Image Processors

### 4.9 Summary

Although dealing with a framework with no proper documentation was a difficult challenge to overcome, the performance obtained from the native code was essential for the final result, as the

## Implementation

software is now able to track objects in a busy scene faster than the camera's capture rate, allowing us to process a video file in a shorter period of time than it's length. This was a request

## Implementation



## Chapter 5

# Conclusões e Trabalho Futuro

*Deve ser apresentado um resumo do trabalho realizado e apreciada a satisfação dos objetivos do trabalho, uma lista de contribuições principais do trabalho e as direções para trabalho futuro. A escrita deste capítulo deve ser orientada para a total compreensão do trabalho, tendo em atenção que, depois de ler o Resumo e a Introdução, a maioria dos leitores passará à leitura deste capítulo de conclusões e recomendações para trabalho futuro.*

Capitulo conclusão Continuação para tornar cada parte mais robustas (cada um pode ser uma tese)

This chapter presents an overview of the work done, as well as an evaluation of the state of completion achieved during the semester, followed by a list of the contributions and a foresight into the next steps of the project.

### 5.1 Satisfação dos Objetivos

### 5.2 Trabalho Futuro

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Contagem  
tempo em  
video

Analise  
cruzamen-  
tos

## Conclusões e Trabalho Futuro

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