



UNIVERSITY OF STUDY OF TRENTO
DEPARTMENT OF INDUSTRIAL ENGINEERING

Master of Science in Mechatronics Engineering

EMBEDDED SYSTEM

**Enhancing UAV capabilities with machine
learning on board**

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Chapter 1

Introduzione

1.1 Contesto applicativo

Ciao ragazzi :D questo è un template che potete utilizzare per scrivere la vostra tesi in \LaTeX (sì, il nome di questo linguaggio è tutto un programma...)

Cos'è \LaTeX ? Cercatevelo su Wikipedia¹!

A parte gli scherzi... è un linguaggio che vi permette (in poche parole) di creare documenti accademici (e non) con uno stile molto professionale. Gran parte del lavoro sporco (creazione dei capitoli, delle sezioni, dell'indice, della bibliografia, gestione dei margini, ecc...) viene interamente gestito da \LaTeX , le poche cose da configurare sono già state impostate in questo template... (quindi in poche parole avete già tutto pronto, stronzi!)

In questo pdf è spiegato un po' come far funzionare il tutto, ovvero:

- Dove scaricare l'IDE e come configurarlo
- Come scaricare il compilatore
- Come iniziare a personalizzare questo template

Cercherò di utilizzare più elementi \LaTeX possibile nello scrivere questa guida (tabelle, elenchi puntati, footnote, immagini...) così quando andrete a leggere il codice vi imparate pure qualcosa, caproni (<3)

1.2 Motivazioni e obiettivi

Il principale motivo che mi spinge a creare questo pdf è quello di risparmiarvi gran parte delle rotture che si trovano quando ci si avvicina al mondo \LaTeX ... insomma mi auguro

¹<http://it.wikipedia.org/wiki/LaTeX>

che questa guida vi permetta di avere un buon punto d’inizio.

Come già spiegato nella sezione precedente, \LaTeX offre tantissimi servizi utili ed uno stile professionale unico, cose che su altri programmi (come Microsoft Word) potete anche sognarvi.

Insomma... con \LaTeX potete presentare una tesi fatta come si deve :)

1.3 Risultati raggiunti

Nella Figura 1.1 potete ammirare quanto \LaTeX sia più figo di Microsoft Word, ooooooh...

Figure 1.1: Oooooooh che figo \LaTeX , ooooooooooh

1.4 Organizzazione della tesi

Vi spiego brevemente quali sono le parti di questo template:

Susanna.tex Questo è il file principale del template: contiene le impostazioni generali e la struttura della tesi. Ricordate di impostarlo come documento master ogni volta che iniziate a lavorare alla tesi (ovviamente potete rinominarlo, nabbazzi)

frontespizio.tex Sarebbe la copertina della tesi, nonché la prima pagina. Contiene nome dell’università, del dipartimento, nome della tesi bla bla bla... io ho scelto un argomento di Fisica molto importante <3

dedica.tex Una pagina dove scrivete a chi dedicate la tesi (Susanna <3)

introduzione.tex Il file che contiene questo capitolo introduttivo (vi consiglio di creare appunto un file .tex per ogni capitolo). Le 4 sezioni di questo capitolo (Contesto applicativo, Motivazioni e obiettivi, Risultati raggiunti e Organizzazione della tesi) sono le 4 sezioni standard da inserire nell’introduzione di una tesi, quindi vi consiglio di lasciarle così

start.tex Contiene l’unico capitolo utile di questo documento: spiega come scaricare l’occorrente e come configurare il tutto per lavorare con \LaTeX

conclusione.tex Contiene la conclusione (YOU DON’T SAY)

bibliografia.bib Contiene i dati relativi alle fonti che citerete nella tesi (ad esempio, ora sto citando un libro sugli algoritmi genetici [?], l’unico inserito nella bibliografia di questo template)

IEEEtran.bst È lo stile della bibliografia, non lo toccate

imgs Cartella contenente le immagini (YOU DON'T SAY AGAIN)

Chapter 2

Come fare le cose

In questo capitolo vediamo la roba smanettosa per iniziare a smanettare

2.1 Occorrente

Roba da scaricare e installare (Tabella 2.1).

Table 2.1: Tabella vergognosamente inutile

File	Piattaforma	Dimensioni
<i>TexMaker</i>	Windows	46.3 MB
<i>TexMaker</i>	Mac	40.7 MB
<i>MiKTeX</i>	Windows	154.1 MB
<i>MacTex</i>	Mac	2.3 GB
Template Susanna	Multiglobale-powa	4 MB (circa)

2.1.1 L'IDE

Allora... per prima cosa vi serve un IDE, ovvero un programma che vi funga da editor e compilatore (in realtà il compilatore si scarica a parte ma vabbè). Ce ne sono molti in giro ma io vi consiglio *TexMaker*¹ per due motivi:

1. È molto intuitivo è ben fatto
2. Esiste sia per Mac che per Windows

Non dovrete avere problemi con il download e l'installazione (vi state per laureare porca paletta, non devo spiegarvi pure questo).

2.1.2 Il compilatore

Per quanto riguarda il compilatore il discorso è un po' più complicato. Armatevi di pazienza e scaricate *MiKTeX*² se avete Windows oppure *MacTeX*³ se avete un Mac (mi dispiace ma non conosco un compilatore LaTeX per Linux... se lo trovate fatemelo sapere che aggiorno la guida). Entrambi questi programmi inglobano un ambiente di sviluppo \LaTeX costituito da diversi compilatori che il nostro IDE riconoscerà automaticamente.

P.S. Prima che cominciate a strapparvi i capelli, sì, *MacTeX* occupa più di 2 GB... questo perchè comprende tutti i pacchetti necessari per \LaTeX , mentre *MiKTeX* (che occupa solo 150 mb) li scarica volta per volta.

2.1.3 Il template

Trovate il sorgente di questo template ad un link dropbox non meglio specificato⁴

2.2 Configurazione dell'IDE

Oooh, ora che avete installato IDE e compilatore, lanciate l'IDE. Principalmente dovete fare tre cose una volta avviato:

1. Aprite il file *Susanna.tex* del template
2. Andate su Opzioni -> Definire il documento corrente come Master (questo serve per dire all'IDE che gli altri documenti sono inclusi in un documento master e che

¹<http://www.xmlmath.net/texmaker/>

²<http://miktex.org/download>

³<http://mirror.ctan.org/systems/mac/mactex/MacTeX.pkg>

⁴<https://www.dropbox.com/sh/1f06sd7eprongvl/dKsfID1Kwc>

quindi, al momento della compilazione, non devono essere trattati come documenti separati)

3. Andate nelle preferenze dell'IDE nella sezione Compilazione Rapida e personalizzate la compilazione tramite l'assistente-wizard. Essenzialmente dovete configurarla in modo da effettuare 3 compilazioni: PdfLatex, BibTex e di nuovo PdfLatex. Oltre a queste tre compilazioni aggiungete una quarta opzione ovvero la visualizzazione pdf.

Vi spiego meglio il punto 3... praticamente ci sono più compilatori diversi, che svolgono operazioni diverse... ma a noi interessano solo due compilatori, ovvero PdfLatex (che compila il codice \LaTeX in un documento pdf) e BibTex (che compila la bibliografia). Le compilazioni sono 3 e in quel preciso ordine perchè altrimenti la bibliografia non viene compilata bene (non chiedetemi perchè). Per evitare di dover eseguire manualmente le diverse compilazioni, *TexMaker* vi dà la possibilità di utilizzare la Compilazione Rapida che esegue automaticamente queste operazioni con un click. Configuratela come vi ho spiegato e non avrete problemi.

2.3 Siamo pronti

Abbiamo configurato l'IDE ed il (i) compilatore(i). Ora premendo sulla freccina della Compilazione Rapida (oppure premendo F1) potrete compilare il vostro codice \LaTeX in pdf. Fate una prova compilando il template (il pdf purtroppo, così come tutti gli scarti della compilazione, verranno generati nella stessa cartella del sorgente...).

E ora? Ora create i vostri capitoli copiando la struttura di *start.tex* e di *introduzione.tex* ed integrateli nel documento master :) se avete bisogno di ulteriori dettagli sulla sintassi \LaTeX vi consiglio di farvi un giro nella sezione Tex di *Stack Exchange*⁵: è tipo Yahoo Answers ma focalizzato ovviamente su \LaTeX .)

⁵<http://tex.stackexchange.com/>

Chapter 3

Heading on level 0 (chapter)

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3.1 Heading on level 1 (section)

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3.1.1 Heading on level 2 (subsection)

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3.2 Lists

3.2.1 Example for list (itemize)

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Example for list (4*itemize)

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3.2.2 Example for list (enumerate)

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Example for list (4*enumerate)

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Chapter 4

Hardware

THIS chapter describes the hardware used to realize out the project. Where the use of the Raspberry Pi single board computer designed to have high performance both in education and science coupled with 8 mega-pixel camera module CMOS sensor was an almost conditioned choice. Shows that scientific and engineering- grade imagery can be produced with the Raspberry Pi 3 and its V2.1 camera module. It also presents a brief introduction to thermography and its physical principles before introducing Lepton 2.5 thermal camera module, made by the company FLIR which is currently one of the top manufactures of thermal camera solutions.

4.1 Raspberry Pi 3

The Raspberry Pi is a high-performance single-board computer designed to experiment and solve real-world problems. This small computer supports a camera module that uses a Sony IMX219 8 mega-pixel CMOS sensor.

4.1.1 Specification

As of early 2016, over 8 million Raspberry Pi's had been sold, making it one of the most popular single-board computers on the market.[1]

The Raspberry Pi credit-card-sized computer supports several accessories, including a camera module containing the Sony IMX219 sensor. This computer and camera configuration is of particular interest since it can provide raw-data format imagery that can be used for a multitude of applications, including computer vision, biophotonics, medical testing, remote sensing, astronomy, improved image quality, high dynamic range (HDR) imaging, and security monitoring. The Raspberry Pi 3 is the third generation single board Raspberry Pi computer and became available to consumers in February 2016.

Some of the more significant Raspberry Pi attributes, including interfaces, are described in Table 4.1. The Raspberry Pi Foundation provides several operating systems for the Raspberry Pi 3, including Raspbian and a Debian-based Linux distribution, as well as third-party Ubuntu, Windows 10 IOT Core, RISC OS, and specialized distributions for download.[2]

Table 4.1: Raspberry Pi 3 computer attributes.

CPU 1.2 GHz 64-bit ARM Cortex-A53
1 GB of RAM LPDDR2 (900 MHz)
Wireless N and Blue-tooth 4.1 communication
Four USB ports
HDMI interface
Ethernet port
MicroSD card slot
40 GPIO pins
Camera interface
Composite video audio jack

4.2 Raspberry Pi, Camera Board V2

The camera is based on the Sony IMX219 silicon CMOS back-lit sensor and produces 8 mega-pixel images that are 3280×2464 pixels in size.

The IMX219 sensor operates in the visible spectral range from 400 to 700 nm).[3] Sensor specifications are detailed in Table 4.2.

Table 4.2: Sony IMX219 sensor chip specifications.

Sensor parameter	Specification
Image sensor type	Back-lit CMOS
Image size	Diagonal 4.60 mm (type 1/4.0)
Number of active pixels	$3280 \text{ (H)} \times 2464 \text{ (V)} \sim 8.08 \text{ mega-pixels}$
Chip size	$5.095 \text{ mm (H)} \times 4.930 \text{ mm(V)}$ (w/ Scribe)
Unit cell size (pixel)	$1.12 \text{ }\mu\text{m (H)} \times 1.12 \text{ }\mu\text{m(V)}$
Substrate material	Silicon
Bit depth	10-bit A/D converter on chip
Data output	CSI2 serial data output (selection of 4 lane/ 2 lane)
Communication	2-wire serial communication circuit on chip
Max full-frame frame rate	30 frames/s
Pixel rate	280 mega-pixel/s (all-pixels mode)
Data rate	Max. 755 Mbps/lane (at 4 lane), 912 Mbps / lane(at 2 lane)

4.2.1 Specification

The V2 camera module operates at a fixed focal length (3.04 mm) and single f -number (F2.0) typically focused from the near-field to infinity. Images can be captured at ISO settings between 100 and 800 in manually set increments of 100 and camera exposure times between 9 μ s and 6 s using a rolling shutter. Some of the more significant camera specifications are shown in Table 4.3. In addition to still photos, the Raspberry Pi Sony IMX219 sensor supports a cropped 1080p format at 30 frames per second (fps) and full-frame imaging video at up to 15 fps, but not in raw-data format. The entire camera board is small 25 mm \times 25 mm \times 9 mm and weighing about 3 g. It connects directly to the Raspberry Pi 3 through a 15 pin mobile industry processor interface (MIPI) camera serial interface and is shown alongside a Raspberry Pi 3 in Figure 4.1.[1, 4]

Table 4.3: Raspberry Pi camera.

Camera parameter	Specification
Lens focal length	3.04 mm
f -number	2.0
Instantaneous field of view	0.368 mrad
Full-frame field of view	59.17 $^{\circ}$ (H) \times 58.3 $^{\circ}$ (V)

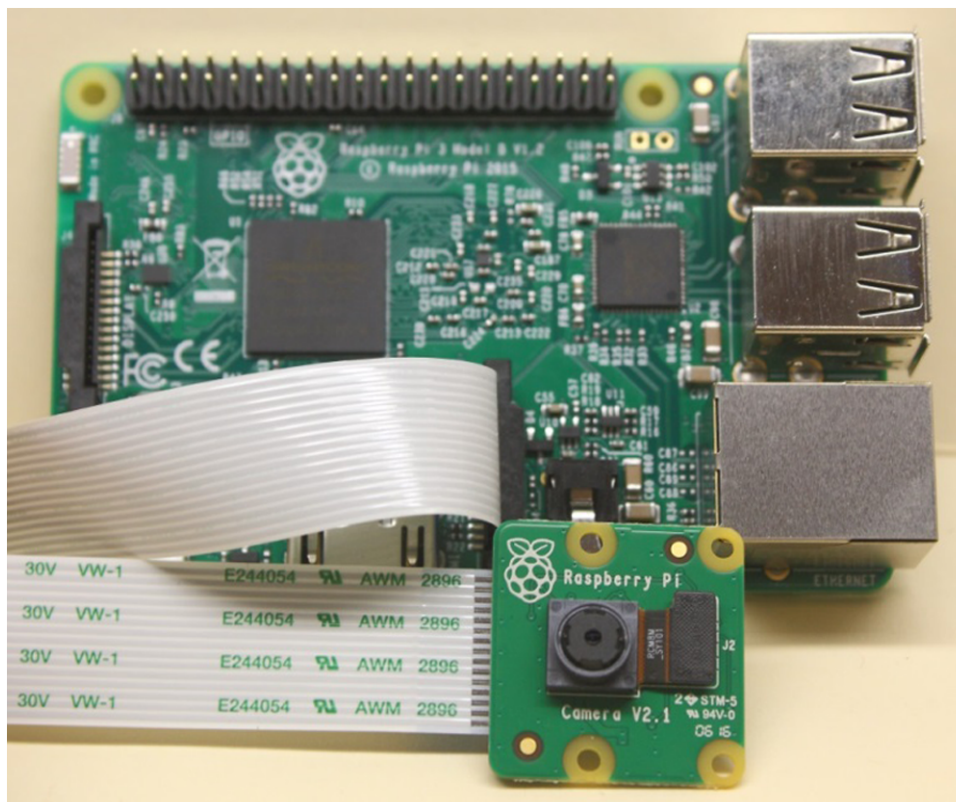


Figure 4.1: Raspberry Pi 3 and camera module V2.1.

4.3 Theory

Electromagnetic radiation is all around (and within, and throughout) us and is comprised of everything from gamma radiation on the high frequency end to radio waves on the low frequency end. While most imaging sensors detect radiation in the visible spectrum (wavelengths from 380 to 700 nm), long wave infra-red sensors detect radiation from 900 to 14000 nm. This is known as the infra-red spectrum, and it accounts for most of the thermal radiation emitted by objects near room temperature.

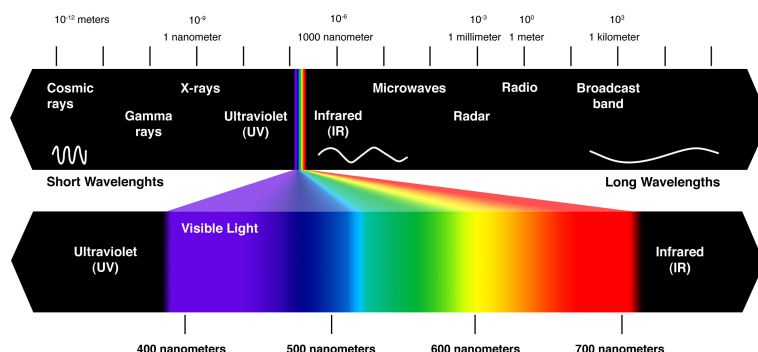


Figure 4.2: Composition of the spectrum of electromagnetic waves

4.4 Thermal Camera module Lepton 2.5

The thermal camera module we use in this project its made by FLIR, we will go through its technical specification, modes of capture and communication protocol for both video frame transfer and camera control. Information about the camera are extracted from official documentation.

4.4.1 Specification

Lepton is an infra-red camera system that integrates a fixed-focus lens assembly, an 80×60 long-wave infra-red (LWIR) micro-bolometer sensor array, and signal-processing electronics. Easy to integrate and operate, Lepton is intended for mobile devices as well as any application requiring very small footprint, very low power, and instant-on operation. Lepton can be operated in its default mode or configured into other modes through a command and control interface (CCI). The effective frame rate of the camera is only 8.6 Hz, however for our needs this is not a problem. The camera only requires low voltage supply and has small power consumption of around 140 mW. See table 4.4 for more specifications. For better manipulation with the camera module

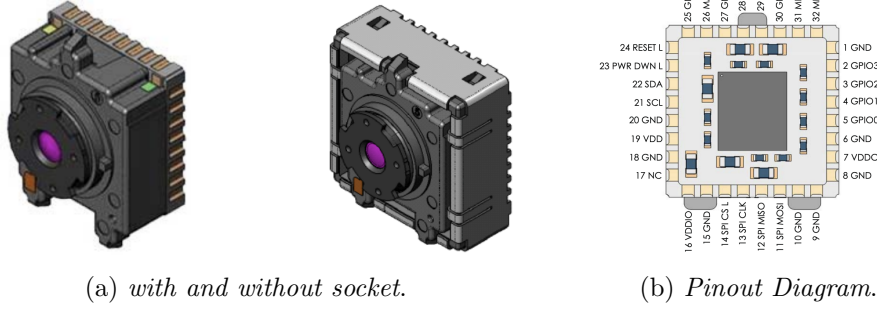


Figure 4.3: Lepton Camera

Table 4.4: Key Specifications

FLIR Lepton 2.5		
Resolution (h x w)	80×60	pixels
Spectral Range	8 to 14	μm
Horizontal Field of View	51	$^\circ$
Thermal Sensitivity	< 50	mK
Frame Rate	< 9	Hz
Control Interface	I ² C	
Video Interface	SPI	
Promised Time to Image	< 0.5	s
Integral Shutter	yes	
Radiometry	14-bit pixel value	
Operating Power	~ 150	mW

we use a breakout board (figure 4.4) with a housing for the Lepton camera module. The breakout board provides better physical accessibility, improves heat dissipation and increases input voltage supply range to 3–5 V, as it has its own regulated power supply. This power supply provides the camera module with three necessary voltages: 1.2, 2.8 and 2.5–3.1 V. The breakout board also supplies the camera with master clock signal.[5] The camera uses two interfaces for communication:

- SPI for transferring video frames from the camera to a SPI master device.
- I²C for receiving control commands from the I²C master device.

4.4.2 System Architecture

The lens assembly focuses infrared radiation from the scene onto an 80×60 array of thermal detectors with 17-micron pitch. Each detector element is a vanadium-oxide (VOx) microbolometer whose temperature fluctuates in response to incident flux. The

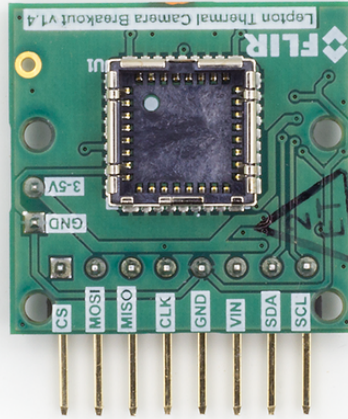


Figure 4.4: Breakout board.

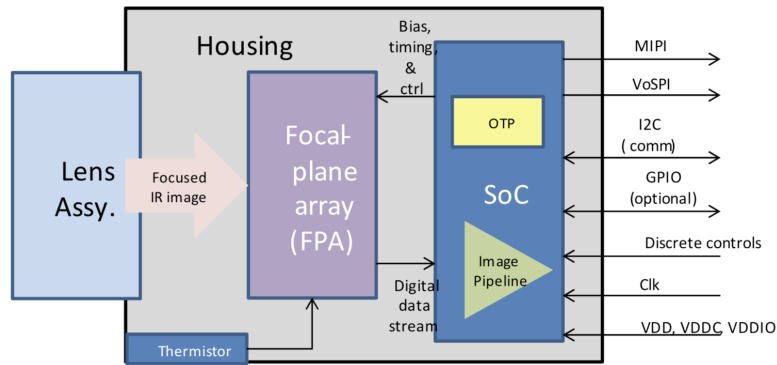


Figure 4.5: Lepton Architecture.

change in temperature causes a proportional change in each microbolometer's resistance. VOx provides a high temperature coefficient of resistance (TCR) and low $1/f$ noise, resulting in excellent thermal sensitivity and stable uniformity. The microbolometer array is grown monolithically on top of a readout integrated circuit (ROIC) to comprise the complete focal plane array (FPA). Once per frame, the ROIC senses the resistance of each detector by applying a bias voltage and integrating the resulting current for a finite period of time called the integration period. The serial stream from the FPA is received by a system on a chip (SoC) device, which provides signal processing and output formatting.

4.4.3 Video Pipeline

The video pipeline includes non-uniformity correction (NUC), defect replacement, spatial and temporal filtering, automatic gain correction (AGC), and colourization.

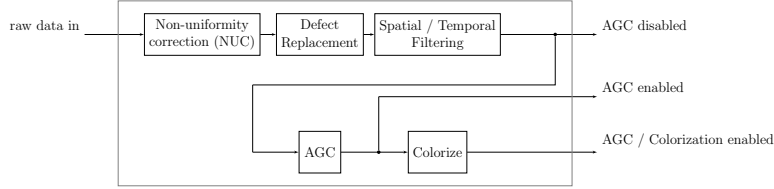


Figure 4.6: Lepton video pipeline block diagram.

The non-uniformity correction (NUC) block applies correction terms to ensure that the camera produces a uniform output for each pixel when imaging a uniform thermal scene. Factory-calibrated terms are applied to compensate for temperature effects, pixel response variations, and lens-illumination roll-off. To compensate for temporal drift, the NUC block also applies an offset term that can be periodically updated at runtime via a process called flat-field correction (FFC). The FFC process is further described in FFC States, (4.4.5).

The defect-replacement block substitutes for any pixels identified as defective during factory calibration or during runtime. The replacement algorithm assesses the values of neighboring pixels and calculates an optimum replacement value. The typical number of defective pixels is ≤ 1 .

Temporal Filtering the image pipeline includes a number of sophisticated image filters designed to enhance signal-to-noise ratio (SNR) by eliminating temporal noise and residual non-uniformity. The filtering suite includes a scene-based non-uniformity correction (SBNUC) algorithm which relies on motion within the scene to isolate fixed pattern noise (FPN) from image content.

The AGC algorithm for converting the full-resolution (14-bit) thermal image into a contrast-enhanced image suitable for display is a histogram-based non-linear mapping function. See (4.4.6).

The colorize block takes the contrast-enhanced thermal image as input and generates a 24-bit RGB color output.

4.4.4 Power States

Lepton currently provides five power states. As depicted in the state diagram shown in Figure 6, most of the transitions among the power states are the result of explicit action from the host. The automatic transition to and from the overtemp state is an exception. In the figure, transitions that require specific host-side action are shown in bold. Automatic transitions are not bolded.

- **Off:** When no voltage is applied, Lepton is in the off state. In the off state, no camera functions are available.
- **Uninitialized:** In the uninitialized state, all voltage forms are applied, but Lepton has not yet been booted and is in an indeterminate state. It is not recommended to leave Lepton in this state as power is not optimized; it should instead be booted to the on-state (and then transitioned back to standby if imaging is not required).
- **On:** In the on state, all functions and interfaces are fully available.
- **Standby:** In the standby state, all voltage forms are applied, but power consumption is approximately 4 mW. In the standby state, no functions are available, but it is possible to transition to the on state via the start-up sequence. The shutdown sequence is the recommended transition back to the standby state. It is also possible to transition between standby and on states via software commands, as further defined in the software IDD.
- **Overtemp:** The overtemp state is automatically entered when the Lepton senses that its temperature has exceeded approximately 80 °C. Upon entering the overtemp state, Lepton enables a “*shutdown imminent*” status bit in the telemetry line and starts a 10 s counter. If the temperature of the Lepton falls below 80 °C before the counter times out, the “*shutdown imminent*” bit is cleared and the system transitions back to the on state. If the counter does time out, Lepton automatically transitions to the standby state.

4.4.5 FFC States

Lepton is factory calibrated to produce an output image that is highly uniform, such as shown in Figure 4.7a, when viewing a uniform-temperature scene. However, drift effects over long periods of time degrade uniformity, resulting in imagery which appears more grainy (Figure 4.7b) and/or blotchy (Figure 4.7c). Operation over a wide temperature range (for example, powering on at $-10\text{ }^{\circ}\text{C}$ and heating to $65\text{ }^{\circ}\text{C}$) will also have a detrimental effect on image quality. For scenarios in which there is ample scene movement,

such as most handheld applications, Lepton is capable of automatically compensating for drift effects using an internal algorithm called scene-based non-uniformity correction (scene-based NUC or SBNUC). However, for use cases in which the scene is essentially stationary, such as fixed-mount applications, scene-based NUC is less effective. In those applications, it is recommended to periodically perform a flat-field correction (FFC). FFC is a process whereby the NUC terms applied by the camera’s signal processing engine are automatically recalibrated to produce the most optimal image quality. The sensor is briefly exposed to a uniform thermal scene, and the camera updates the NUC terms to ensure uniform output. The entire FFC process takes less than a second.

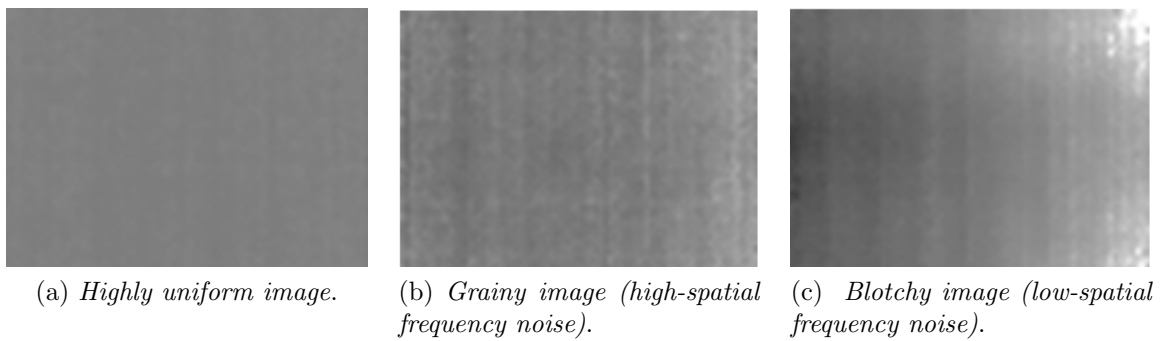


Figure 4.7: Examples of Good Uniformity, Graininess, and Blotchiness

The current FFC state is provided through the telemetry line. There are three FFC states, as illustrated in Figure 4.8:

1. FFC not commanded (default): In this state, Lepton applies by default a set of factory-generated FFC terms.
2. FFC in progress: Lepton enters this state when FFC is commanded. The default FFC duration is nominally 23 frames.
3. FFC complete: Lepton automatically enters this state whenever FFC is completed. Lepton also provides an “FFC desired” flag in the telemetry line. The “FFC desired” flag is asserted at start-up, when a specified period (default = 3 minutes) has elapsed since the last FFC, or when the sensor temperature has changed by a specified value (default = 3 °C) since the last FFC. The “FFC desired” flag is intended to indicate to the host to command an FFC at the next possible opportunity.

4.4.6 AGC Modes

There are two AGC modes:

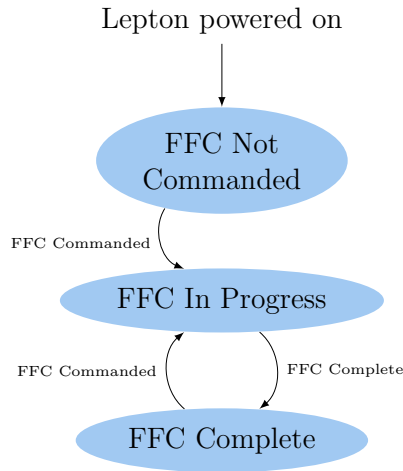


Figure 4.8: FFC States.

- AGC disabled (default)
- AGC enabled

AGC is a process whereby the large dynamic range of the infrared sensor is collapsed to a range more appropriate for a display system. For Lepton, this is a 14-bit to 8-bit conversion. In its most simplistic form, AGC can be a linear mapping from 14-bit to 8-bit; however, a simple linear AGC is generally incapable of providing pleasing imagery in all imaging conditions. For example, when a scene includes both cold and hot regions (for example, a hot object in front of a cold background as illustrated in 4.10, linear AGC can produce an output image in which most pixels are mapped to either full black or full white with very little use of the gray shades (8-bit values) in between. Because of this limitation of linear AGC, a more sophisticated algorithm is preferred. Similar to most AGC algorithms that optimize the use of gray shades, Lepton’s is histogram-based. Essentially a histogram counts the number of pixels in each frame that have a given 14-bit value. Figure 4.9 the concept for a 3x3 pixel area.

Classic histogram equalization uses the cumulative histogram as a mapping function between 14-bit and 8-bit. The intent is to devote the most gray shades to those portions of the input range occupied by the most pixels. For example, an image consisting of 60% sky devotes 60% of the available gray shades to the sky, leaving only 40% for the remainder of the image. By comparison, linear AGC “wastes” gray shades when there are gaps in the histogram, whereas classic histogram equalization allocates no gray shades to the gaps. This behavior is in principle an efficient use of the available gray shades, but there are a few drawbacks:

- The resulting contrast between an object and a much colder (or hotter) background can be rendered poor by the fact the algorithm “collapses” the separation between

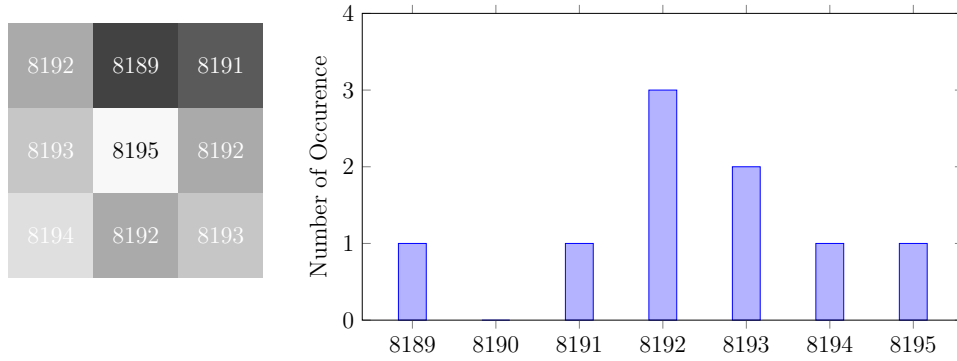


Figure 4.9: Illustration of a Histogram for a 3×3 Pixel Area.

such that the object is only one step gray shade above the background. This phenomenon is illustrated in 4.10.

- Too much emphasis can be placed on background clutter, particularly when a mostly isothermal background comprises a large fraction of the total image area. This is also illustrated in 4.10. The Lepton AGC algorithm is a modified version of classic histogram equalization that mitigates these shortcomings. One such modification is a parameter called “clip limit high”. It clips the maximum population of any single bin, limiting the influence of heavily populated bins on the mapping function. Another parameter utilized by the Lepton algorithm is called “clip limit low”. It adds a constant value to every non-zero bin in the histogram, resulting in additional contrast between portions of the histogram separated by gaps. Figure 4.10 is an example showing the benefit of the Lepton clip parameters.

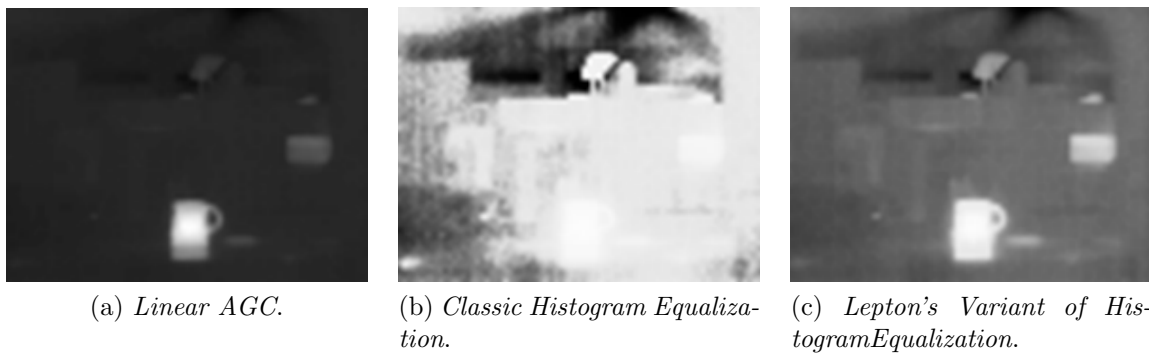


Figure 4.10: Comparison of Linear AGC and Classic/Lepton Variant of Histogram Equalization

A high value of clip limit high results in a mapping more like classic histogram equalization, whereas a low value results in mapping more like linear AGC. For clip limit low, the opposite is true: a high value results in a mapping more like linear AGC, whereas a low

value results in a mapping more like classic histogram equalization. The default values of both parameters produce a good compromise between the two; however, because optimum AGC is highly subjective and often application dependent, customers are encouraged to experiment to find settings most appropriate for the target application. By default, the histogram used to generate Lepton's 14-bit to 8-bit mapping function is collected from the full array. In some applications, it is desirable to have the AGC algorithm ignore a portion of the scene when collecting the histogram. For example, in some applications it may be beneficial to optimize the display to a region of interest (ROI) in the central portion of the image. When the AGC ROI is set to a subset of the full image, any scene content located outside of the ROI is not included in the histogram and therefore does not affect the mapping function (note: this does not mean the portion outside of the ROI is not displayed or that AGC is not applied there, only that those portions outside the AGC ROI do not influence the mapping function).[6]

Chapter 5

Software

IN this chapter we will discuss the software used to control the cameras presented in the chapter. This software was designed to have a minimum number of dependencies and was specifically optimized to exploit the hardware already presented.

5.1 Introduction

In this era, a large amount of structured and unstructured data became available. **Machine Learning (ML)** has evolved as a branch of artificial intelligence: it envisages the development of self-learning algorithms, which are capable of acquiring knowledge from data with the aim of making predictions. Instead of requiring a human presence who manually enact the rules and build models for the analysis of large amounts of data, machine learning offers a more efficient alternative to capture the knowledge in the data. Machine learning aims to gradually improve the performance of forecasting models and to make data driven decisions. In this section we will examine the three different types of machine learning: *supervised learning*, *unsupervised learning* and *reinforcement learning*. Where we will show the fundamental differences between these types of learning.[7]

5.1.1 Supervised learning

The main purpose of supervised learning is to derive a model from training data, which allows us to make predictions for data that are not available or future. Here, the term “supervision” refers to the fact that the output signal labels of the sample sets are already known. A supervised learning task, which is based on discrete class labels, is also called a classification task, in figure 5.1 it is possible to observe a process diagram. Another supervised learning subcategory is regression, whose resulting signal is a continuous value. Classification is a sub-category of supervised learning, which has the goal to provide class

category labels for new instances, based on observations made in the past.

These labels are discrete, unordered values that can be considered as belonging to a group of instances. However, the set of class labels does not necessarily have to be a binary nature. The predictive model identified by a supervised learning algorithm can consider each class label that is present in the learning dataset of a new instance, which is not labelled. A typical example of *multi-class classification* is the recognition of hand-written text.[7]

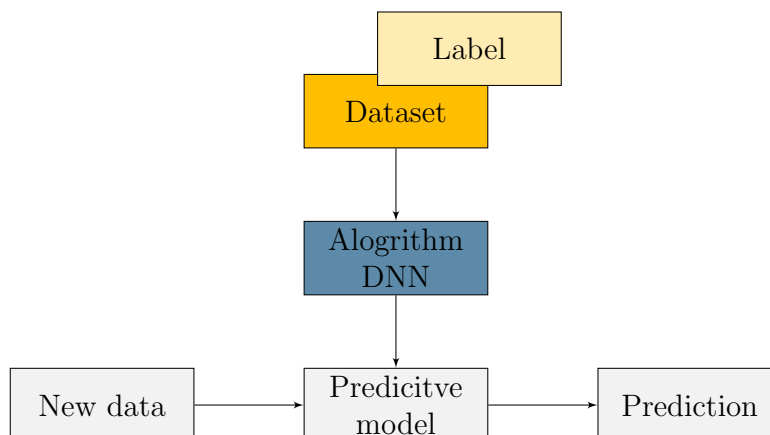


Figure 5.1: supervised learning scheme

5.1.2 Reinforcement learnig

Another type of machine learning is reinforcement learning. Here, the goal is to develop a system (*agent*) for people to improve their performance. In order to do so, that system is based on interactions with the environment. Since information relating to the current state of the environment include also a *reward* signal, we can consider strengthening learning as an example of supervised learning. However, this feedback is not the correct label or the true value of truth, but it represents the quality of the measurement of the performance measured by the reward function. Through interaction with the environment, an agent can then use reinforcement learning to learn a series of actions, which maximize this reward through a trial-and-error exploratory approach or deliberative planning.[7]

5.1.3 Unsupervised learning

In supervised learning, we know in advance the correct answer when we describe our model, while in reinforcement learning we define a measure, or reward, for the specific actions performed by the agent. In unsupervised learning, on the other hand, we are dealing with unlabelled data or data from the unknown structure. Using unsupervised learning

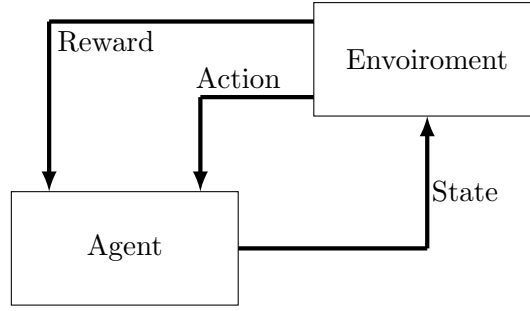


Figure 5.2: reinforcement learning scheme

techniques, we are able to observe the structure of our data, to extract meaningful information from them without being able to rely on the guide nor a variable known relative result, nor a reward function. Clustering is an exploratory technique of data analysis that allows us to organize a series of information within meaningful groups (*cluster*) without having any previous knowledge of memberships in such groups. Each cluster that can be derived during the analysis defines a group of objects that share a certain degree of similarity, but which are more dissimilar than the objects present in the other clusters, which is why clustering is sometimes called “*unsupervised classification*”. Clustering is an excellent technique for structuring information to identify meaningful relationships in the data.[7] the software created is based on the paradigm of object-oriented programming. It

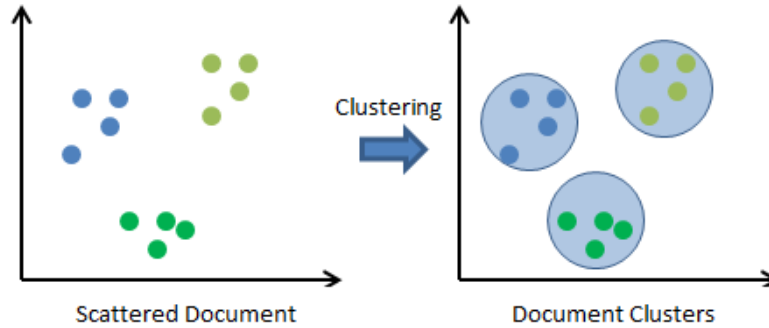


Figure 5.3: example of clustering

is a question of keeping the dependence on other libraries and frameworks to a minimum, trying to guarantee the portability of the source code on platforms with different hardware. The language chosen is C++ with an intuitive use of the Qt framework thus once again guaranteed portability, as well as the graphical interface and high data performance the feature of compiled languages. The software thus created inside presents the graphic structures of Qwidget, the libraries to manage the Raspberry Pi camera seen in chapter 4 and the FLIR Lepton SDK.

Once started, the application runs the main screen that can be divided into three

main areas: the preview section, the fusion section, the sidebar of the commands. In the first section two widgets are shown that show the video streams captured by the two cameras in separate threads, this thanks to the extensive use of the “**signal & slot**”¹ made available by Qt. In the sidebar of the controls, there are the operations that allow you to change the color palette of the thermal image, capture an image, select a particular blending method for the two video streams and see them combined in the central section. The central section, as anticipated, shows the superimposition of the thermal map on the RGB image captured by the traditional photo camera.

¹Signals and slots are used for communication between objects. The signals and slots mechanism is a central feature of Qt and probably the part that differs most from the features provided by other frameworks. Signals and slots are made possible by Qt’s meta-object system.[8]

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