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Image Processing for Drones PARROT

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RESUMÉ [ENGLISH]

Traffic signs are an important part of any roadway. They are designed to regulate the flow of vehicles, giving specific information about the road or warning against unexpected road circumstances.

With the recent process of inclusion of drones to the national airspace in many countries, and considering the existent expansion of applications in this area, we propose a new Signpost System for Micro Aerial Robots, human readable, easy to analyze and robust enough as to be understood under many different lighting conditions in indoor environments.

On the other side, we propose a new and fast algorithm able to utilize the information provided by this signpost system effectively and efficiently, in order to give the aerial robot a good understanding of the environment, in order to choose between different paths to accomplish simple but specific missions.

In order to achieve this, we shall be interested mainly in the fusion of the information obtained by means of two cameras, in order to be more efficient in the perception and the understanding of the surroundings, and arrive from an initial point to a established destination.

Finally, and with the aim to have a well understanding of the actual developments and possibilities in the field of computer vision systems for MAVs and Aerial Robots, we started this study with an state-of-the-art study considering the different types of devices, the technical developments in this area, and a legal, economical and social overview of the drones.

To achieve this, it has been chosen the platform provided by AR.Drone, a low cost hardware environment that could eventually make easier the access to this technology. On the other hand, it is important to mention that it is a non-autonomous device, and this algorithm will provide autonomy to fulfill the desired tasks and be an aerial robot.

RESUMÉ [FRANÇAIS]

Les panneaux de signalisation sont une partie importante de toute voie. Ils sont conçus pour régler le flux de véhicules, donnant des informations spécifiques sur la route ou avertissant contre des circonstances inattendues de route.
Avec le processus actuel d'inclusion de drones à l'espace aérien national dans beaucoup de pays, et l'expansion réelle d'applications dans ce domaine, il est proposé un nouveau système de signalisation pour des Micro Robots Aériens, facilement lisible pour l'homme, facile à analyser et assez robuste pour être compris dans différents conditions d'éclairage à l'intérieur des environnements.
D'autre part, nous proposons un algorithme, nouveau et rapide, capable d'utiliser les informations fournies par ce système de Signalisation efficacement, pour donner au robot aérien une bonne compréhension de l'environnement, pour choisir entre des chemins différents et accomplir des missions spécifiques simples.
Pour réaliser ceci, nous nous intéressons principalement à la fusion des informations obtenues au moyen de deux caméras, pour être plus efficaces dans la perception et la compréhension de l'environnement et, par exemple, pour pouvoir éviter des obstacles ou aller en haut et en bas de un escalier.
Finalement et dans le but de bien comprendre les développements réels et des possibilités dans le domaine des systèmes de vision informatiques pour MAVS et des Robots Aériens, nous avons commencé cette étude par un état de l'art considérant les types différents de machines volantes, les développements techniques dans ce domaine et une vue d'ensemble légal, économique et sociale des drones.

Pour réaliser ceci, il a été choisi la plate-forme fournie par AR.DRONE, un environnement qui, grâce à son bas coût, pourrait faciliter l'accès à cette technologie. D'autre part, il est important de mentionner que c'est un dispositif non autonome et notre algorithme fournira l'autonomie pour accomplir les tâches désirées et être un robot aérien.

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1. INTRODUCTION

An aircraft is a vehicle capable of flying by gaining support from the air. The definition of Aircraft by the European Union [EU1149-2011] include any machine that is sustained in the atmosphere from reactions with the air, other than the ones that the air produce against the earth's surface. More specifically, the support is usually provided by an aerodynamic force called lift, which is produced from the motion of a body in a fluid.

Despite the unmanned character of drones, they need a distant pilot, who rather than being seated in the aircraft itself is located in a control centre normally referred to as a Ground Control Station. In other words, the designation Drone only covers the air vehicle. To designate the whole set a drone works with, it is referred to as system of drones, or a UAS, an acronym for Unmanned Aerial Systems.

Conversely, a robot, is a mechanical device that can perform tasks without continuous human guidance i.e. Unlike the human controlled machines, as a system of drones is, they can themselves start and conclude a task without human intervention.

So in function of the nature of working and the level of autonomy, we can have even a system of drones or also a System of Aerial Robots, even if the aircraft itself can be the same. In other words, how it works determines the kind of machine it is.

Despite dealing with the same device, its internal way of working to fulfill its mission and dependency with human intervention is what determines what it really is. Next, it will be discussed the components of a System of Drones.

System of Aerial Robots

Describing the components of a UAV system or a System of Aerial Robots, brings out the main feature of drones. That is, the main key feature of drones is their remote command functionality. They consist of:

- One or more aerial vehicles or UAVs, equipped with detection sensors;
- One or more ground data collect stations; or even general control stations (to give general tasks to make in function of needs).
- One wireless link between the aerial vehicle and the ground portion.

Another key feature is their re-usability, because, apart from missiles, which normally are used to accomplish just one single task, drones and aerial robots are reusable: They come back.

A third characteristic of aerial robots, which makes the difference with a System of Drones, is their autonomy, that is to say, the ability of the operational decision making to respond to any random event during the mission. And that allows its operation out of line of sight, in high-altitudes and other locations where a person on the ground cannot readily see them. Nevertheless, the operation of UAS out of sight, is regulated in several countries (see Section: Legal Aspect).

Regarding its name, the industry and the regulators have now adopted the acronym UAS for the whole system set of aircraft that follow the commands from a base, rather than UAV or drone, as the preferred term for Unmanned Aircraft or Aerial Systems as UAS encompasses all aspects of deploying these aircraft and not just the platform itself. Concerning the denomination System of Aerial Robots, it encompasses the case where the autonomy plays a main role in its functionality.[UAVSORG12]

2. STATE OF THE ART

2.1 UAV CLASSIFICATION

There are a wide variety of drone shapes, sizes, configurations, and features. Over a period of about twenty years UAV's have evolved worldwide into stable platforms capable of a wide range of mission profiles. In order to understand what the drones are, and what are their main characteristics, we will analyze some of their classifications. Possibles for both Unmanned Aerial Vehicles and Aerial Robots. The emphasys will be made on the Micro Air Vehicles.

2.1.1 MAVs

Even if the drones have been used since 1950, It was not until the early 1990's that technology advanced enough to make the MAVs economically and technologically reliable.

Figure 1: Wasp Micro Air Vehicle (MAV) developed by AeroVironment under a DARPA project.

The Micro Drones or MAVs, which stands for Micro Air Vehicle or Micro Autonomous Vehicle, represent a new generation of drones, and they were conceived to achieve missions which the bigger drones were incapable to achieve. These vehicles offer clear advantages in terms of reduced weight, unusual shape and increased mission performance.

There is not yet a unified classification on what the size and weight of a Micro Drone are, but basically they consist of an UAV with the size restriction of being enough small to be man-portable, from insect-sized aircraft to some kg of weight. [Onera09]

The MAVs small size sometimes can make teleoperation impractical because a ground station pilot could not see it clearly beyond 100 meters. The first solution to this problem was teleoperation using an onboard camera. However, nowadays some researches have focused on fully autonomous Micro Aerial Robots flights.

One of the main contributors to MAVs research was DARPA (Defense Advanced Research Projects Agency), an agency of the United States department of defense. In Europe, a French contributor in this field was the French Defence Aerospace Research Agency ONERA. The smallest models proposed, as the one shown in Figure 1, did not achieve to have an endurance of more than 20minutes.

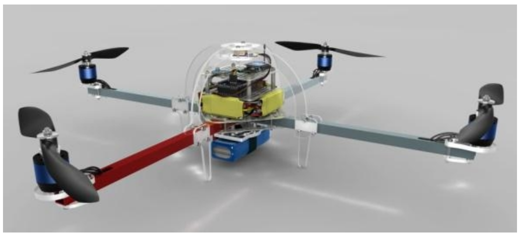

Figure 2: Arducopter Multirotor MAV, a creation of the DIY Drones community.

DARPA was the first in speaking about Nano UAVs or NAVs, which consisted in a development of a 10 gram UAV finished in 2011, an artificial hummingbird.

Nowadays, Smaller concept MAVs are still under active development, specially because the reduction in size gives agility advantages [Kushleyev12]. However, only larger MAVs have more endurance and range. Moreover, due to this reason, industry has focused mainly on larger MAVs (see Figure 2). [DARPA12]

Advantages

Currently, the advantages of using a micro Unmanned Air Vehicle, are that:

Compared to an aircraft, the micro drones are capable of taking versatile duties, especially when human intervention is hard or dangerous e.g. hazardous zone, disaster relief support or military operations, reducing thus the risk exposure of the operator of the aircraft. In addition, their size is just limited by the technology of equipments and its autonomy.

In addition, Aerial Robots can perform without human supervision wide range reconnaissance, traffic monitoring and any aerial surveillance accurately and repeatedly, informing to the base just alerts or relevant information.

Objective and Applications

The main purpose of drones is essentially to deliver a message or packet or to collect data. That is, a unmanned aerial system can be seen either as a transport machine or as a sort of mobile sensor to collect any special parameter in very flexible and changing environments.

Nowadays, due to the actual state of a policy framework in most of developed countries, its main client and applications are used for militaries, where their largest use is in observation and aerial surveillance. However, UAS and specially sUAS are also used in a small but a growing number of civil applications, such as firefighting or nonmilitary security work, such as surveillance of pipelines. UAVs are often preferred for missions that are too "dull, dirty, or dangerous" for manned aircraft. Some applications may include Flying over inhospitable areas, such as the Antarctic ice fields to collect data for predictive climate models. On the other side, the NASA centers have started to send UAVs to fly into stormy skies to communicate near-real-time data directly to the Ground Control Centre and help in hurricane formation researches.

A third kind of use has been muted for the future due to the actual endurance limitations: Performing the role of communication bridge between two communication systems. As an example, this use can be done to providing temporary cell or mobile phone coverage.

Concluding, the collection of data is currently the most important and promising application of a UAS even for military or civil applications. At present several new applications are being implemented. For example, a new application that is growing considerably and getting closer to the final user is the use of drones for entertainment, as the case of Parrot AR.Drone.[DraganFly11]

The following classification methods concern a way to understand the different technologies applied nowadays to sUAS, even if they are similar in some aspects to manned aircrafts.

2.1.2 By Weight

Given a lack of common standards, there are several different classifications based on the weight of UAVs. For example, in Europe, the EUROCAE makes the following classification:

- (Micro 0 - 1 kg)
- Mini 1-14 Kg
- Small 15-199 kg
- Medium 200-1999kg
- Heavy above 2000kg

The Micro classification is not defined in Eurocae, since its regulation does not concern those weights. As it will be shown below, there are different policies concerning the different weights of UAVs.

2.1.3 By method of propulsion

The method of propulsion concerns the way through which an UAV counters the force of gravity. We will analyze the methods of propulsion that use the dynamic lift of an airfoil.[UAVMarket11].

Rotary Wing Platforms

A rotorcraft or rotary wing aircraft is a heavier-than-air flying machine that uses lift generated by wings, called rotor blades, that revolve around a mast.

A rotorcraft system offers numerous logistical advantages, and the possibility to hover, gives a higher control to the vehicle, and allows it to make more precise mission, such as for example to follow corridor routes for mapping transmission lines, railways, highways, pipelines and any other linear asset.

Unlike fixed wing UAVs, for many Rotary Wing configurations, external payloads can be tethered to the bottom of the airframe; and since the payload does not need to be inside the vehicle, it allows to carry a wider kind of payloads in size or shape.

Since there are several kinds of Rotary wing Platforms, they can be characterized by:

Figure 3: Quadrirotor MAV. Developed under the open source project Mikrokopter.

Number of blades

Several rotor blades can mounted to a single rotor. So, a rotary wing is characterized by the number of blades. Typically this is between two and six per driveshaft.

Number of rotors

A rotorcraft may have more than one rotor. Various rotor configurations are used:

One rotor. Powered rotors require compensation for the torque reaction causing yaw.

Two rotors. These typically rotate in opposite directions cancelling the torque reaction so that no tail rotor or other yaw stabilizer is needed. These rotors can be laid out as

- Tandem - One in front of the other.
- Transverse - Side by side.
- Coaxial - One rotor disc above the other, with concentric drive shafts.
- Intermeshing rotors - Twin rotors at an acute angle from each other, whose nearly-vertical drive shafts are geared together to synchronize their rotor blades so that they intermesh, also called a synchropter.

Four rotors. Also referred to as quadrotors/quadcopters, they typically have two rotors turning clockwise and two counter-clockwise.

Hexacopters, Octocopters (multirotors): These designs have matched sets of rotors turning in opposite directions.

Fixed Wing Platforms

A fixed wing UAV is an Unmanned Aircraft capable of flight using forward motion that generates lift as the wing moves through the air.

A fixed-wing platform is the most rapid means by which to conduct a wide-area survey. Typically flying up to speeds of 120 kts or 200km/h, it is possible to cover very fast a survey area while simultaneously acquiring highly accurate data.

With fixed wing UAVs, payloads can also be attached to the airframe, but aerodynamics of the aircraft with the payload must be assessed. For such situations, payloads are often enclosed in aerodynamic pods for transport.

Figure 4: Launching a sUAS in a Antarctic project. (SUMO Small Unmanned Aerial Observer).

Flapping wings - Ornithopter

An ornithopter (from Greek ornithos "bird" and pteron "wing") is an aircraft that flies by flapping its wings.

Alike the rotary wing platforms, in an ornithopter, the driving airfoils do not rotate. Instead, they have an oscillating motion. This imitates nature, because no animals have any rotating parts. Designers seek to imitate the flapping-wing flight of birds, bats, and insects.[Ornithopter11]

Figure 5: Flapping wings NAV (Artificial Hummingbird) developed by DARPA.

Flapping wings potentially offer improved efficiency, better maneuverability, and reduced noise compared with the rotary-driven airplanes and helicopters. The resemblance to a real bird can also be useful, e.g., for spying or for keeping birds away from airport runways.

The Unmanned Flapping Wings Vehicles are generally built on the same scale as the flying creatures in which they are inspired, and their uses are mainly oriented to Research and Development.

Since their size is relatively small, one common feature is its reduced endurance, generally up to 20minutes.

Their hardware is made strong and crash resistant, but made of lightweight material, so as their weight does not exceed 25grams, like in the FlyTech Dragonfly UAV.

Other UAV types

Other UAV types are the Airships UAV and the Flexible wing UAVs. [UAVMarket11].

Airship or dirigible is a type of aerostat or "lighter-than-air aircraft" that can be steered and propelled through the air using rudders and propellers or other thrust mechanisms.

Alternatively, Flexible Wing UAVs, basically consists of a parafoil with a bigger engine, wheels and a control system, remotely operated or autonomous. The engine is placed in a harness suspended below a hollow fabric wing whose shape is formed by its suspension lines.

Both of them generally operate safely in low altitudes. In the case of Flexible wings UAVs, they provide a much longer endurance comparatively with a fixed wing UAV of similar price. Since the dynamic of flying is quite different from the fixed and rotary wing platforms, they allow the carry of payloads of various weight and size. That is, they offer an alternative in the cases that the situation allows lower speeds and bigger sizes.

2.1.4 By method of Take Off and Landing

CTOL - Fixed Wing UAVs

CTOL is an acronym for Conventional Take-Off and Landing, and it concerns the process whereby conventional aircraft take off and land.

A fixed wing air vehicle is capable of flight using wings that generate lift due to the vehicle's forward airspeed and the shape of the wings. The CTOL aircraft always needs some free area to take off and land.

In the case of UAVs, as they are generally much smaller than a conventional aircraft, the fixed wing UAVs usually takes off with some external help, i.e. the UAV may be launched by: Bungees, or even Slingshots and hands. See figure 3-4.

Once launched, the airborne is capable of autonomous navigation or a stabilized joystick control.

On the other hand, landing a fixed wing UAV, is not always easy. Winged aircraft have to maintain a fair amount of forward speed to keep from stalling out and plowing into the ground, and that makes precision landings hard to pull off, especially for UAVs that don't have room for accessories like landing gear, which are bulky, and heavy and generally inappropriate for a small UAV.

The first solution a controlled crash. Some Aircraft models, returns to a GPS waypoint near the ground, slows down to a stall, and then falls into the ground, breaking into pieces which can be easily reassembled. Other models, instead, can make an autonomous belly landing (using just its underside, or belly, as its primary landing device).

Figure 6: The IAI Heron landing with a parachute. (by Malat UAV division of Israel Aerospace Industries).

Another possibility, is with a parachute, which generally is activated at a user defined GPS location, having previously tested the wind speed and direction. However, as in the case of the landing gear, their inclusion in the UAV has weight and payload penalties. Also, the very nature of parachute flight means having low requirements in the final UAV position.

Finally, the other method is a capturing system. One example of this are the use of nets. Although there are much more complex systems, as the use of arresting cables, the basis idea can be seen with nets as they achieve to land an UAV when the situation requires to be landed in one exact spot with no room for error.

VTOL

VTOL is an acronym for vertical take-off and landing aircraft. This classification includes fixed-wing aircraft that can hover, take off and land vertically as well as rotary platforms. Vertical take-off and landing UAVs are those that are able to generate downward thrust and take off within very limited space. See Figures of quadrirotor (fig 3-1, 3-2 and 3-3) to notice some examples.

2.1.5 Other Classifications

Endurance and Range

Another useful classification method for UAVs is to categorize them by endurance and range. These two parameters are usually interrelated as obviously the longer a UAV can say airborne the larger its radius of operation is going to be. It is important to consider range and endurance because it enables the UAV designer to determine the type of U AV required depending upon how far the mission objective is from the launch site. Also it determines how regularly refueling is required and would effect how much time can be spent with the UAV performing its task and how much time it needs to spend grounded.

Maximum Altitude

The maximum operational altitude, or flight ceiling , is another performance measure by which UAVs can be classified. This is also useful for designers or choosing a UAV to purchase so the customer can select a UAV that meets their altitude needs. Some UAVs in military situations are required with low visibility to avoid being detected and destroyed by the enemy therefore high altitude is an important requirement. Also for imaging and reconnaissance a high altitude is required to obtain images of the maximum amount of terrain.

2.2 TECHNICAL ASPECT

Micro Aerial Robots and sUAS can enter areas and locations that manned vehicles cannot do without exceptional risks or higher costs, the autonomous use of micro-UAVs outdoors or in urban areas, the emphasis is on stabilization and control algorithms. However, their tasks are mainly limited by their autonomy, which does not allow a good endurance and range.

Conversely, small UAS and aerial robots have shown very good performances in indoor environments. In fact, thanks to its advantages of size and access they have become an important research focus in recent years. In fact, in these kind of environments less endurance may be more tolerable. Alike their use in outdoors environments, the stabilization and control are still important, but the most important task to accomplish is to arrive from an initial point to a destination. Thus, a reliable and effective technique for circulation is crucial to the success in accomplishing their tasks.

In this sense, many techniques have been developed, using different types of embedded sensors (radar, sonar, laser, optical flow). Nevertheless, with the fast development of machine vision system and advanced computer technology, a system that implements vision has many advantages compared to other systems that use different type of sensors. It includes low cost in introduction and maintenance, the better and larger amount of information extracted from a single image, and the fact of being a passive sensor with a small power consumption and a very light weight. All that made it become among the most commonly used sensors. The beginning of its use in the field of MAVs for autonomous flights back to the year 1992 [Black-Smith92], but it did not start with more sophisticated and autonomous flights until 2000 [Barrows00].

This study will focus on the technical issues and considerations in developing computer vision algorithms for micro UAVs, in unknown indoors environment.

2.2.1 Visual Subsystem

Generally a visual system is a set of one or more cameras, an onboard computer and a communicating system. Visual systems are generally designed to perform visual tasks involving Optical Flow measurement [Zingg10], Color Based algorithm [Azrad09], Support Vector Machine Classification [Bills11], Camera Calibration [Yannick09], Stereo vision to depth perception, for example. Most of implementations realize edge detection, corner detection, Hough Transform, a servoing method and Kalman Filtering. [Yu-Chi10].

Camera obtain images and videos, and the onboard computer process the information or also could send it for additional processing or to be processed completely in the ground control station. With the environment information obtained, like attitude and position, the MAV could make some decision making to achieve or get closer to the goal of the mission.

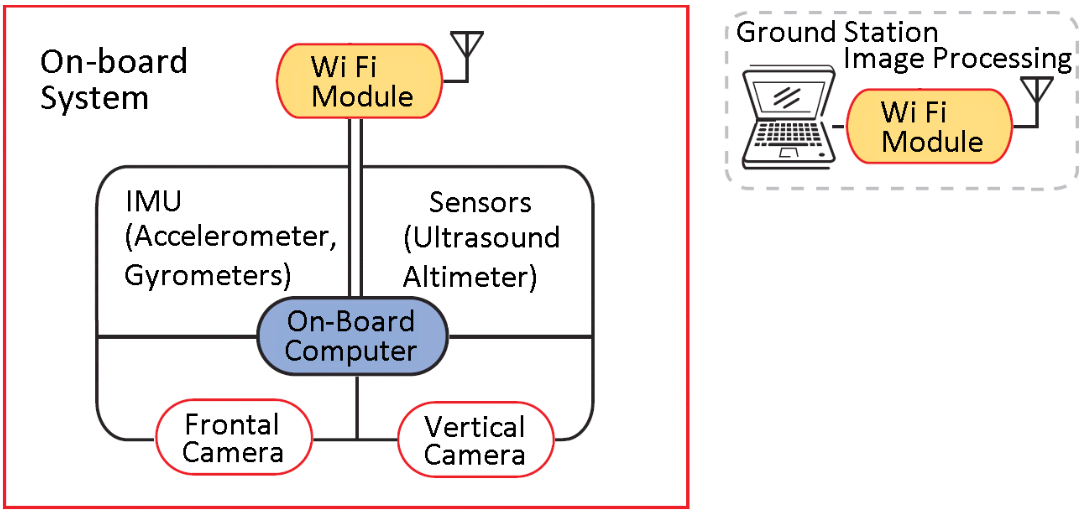

Figure 7: Vision System implemented in this project.

2.2.2 Camera Calibration

Since the camera is not a perfect representation of the environment, a camera calibration encompasses to determine the model used to do the representation of a scene. Camera calibration involves the estimation of both extrinsic and intrinsic camera parameters.

Intrinsic parameters are referred to be the geometric relationship between each 3D visible point (R = [X, Y, Z]) and its 2D (p = [x, y]) corresponding projection onto the image plane. The simplest way to model this relationship is with the pinhole camera model. From [Yannick09] it can be seen that the intrinsic parameters that sets the mapping 3D to 2D is defined by a matrix M as follows:

$$\lambda.\begin{pmatrix}x\\y\\1\end{pmatrix}=(M).\begin{pmatrix}X\\Y\\Z\\1\end{pmatrix}, \qquad M=\begin{pmatrix}f & \tau & o_x\\0 & n.f & o_y\\0 & 0 & 1\end{pmatrix} \quad \text{(eq. 1)}$$

where λ=Z is an homogeneous scaling factor, f is the focal lenght, o_X and o_Y set a pixel offset, n takes into account the aspect ratio and τ stands for a skew effect.

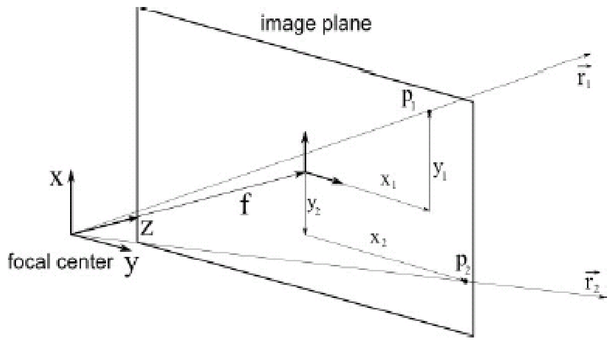

Figure 8: Correspondence between world (R1 and R2 points) and Image Plane (p1 and p2 points).

Extrinsic parameters, instead, indicate the external position and orientation of the camera in the 3D world. Position and orientation is defined by a 3x1 vector C and by a 3x3 rotation matrix R.

$$\begin{pmatrix}X'\\Y'\\Z'\\1\end{pmatrix}=\begin{pmatrix}[R] & [T]\\0 & 1\end{pmatrix}.\begin{pmatrix}X\\Y\\Z\\1\end{pmatrix} \quad \text{(eq. 2)}$$

(eq. 1) and (eq. 2) and the knowledge of the rotation and translation of the MAV allows change the coordinate system and to compensate effects of rotations and translation and obtain an holography matrix H that maps the pixels from two consecutive frames, differed by a time t_0. [Zhao12].

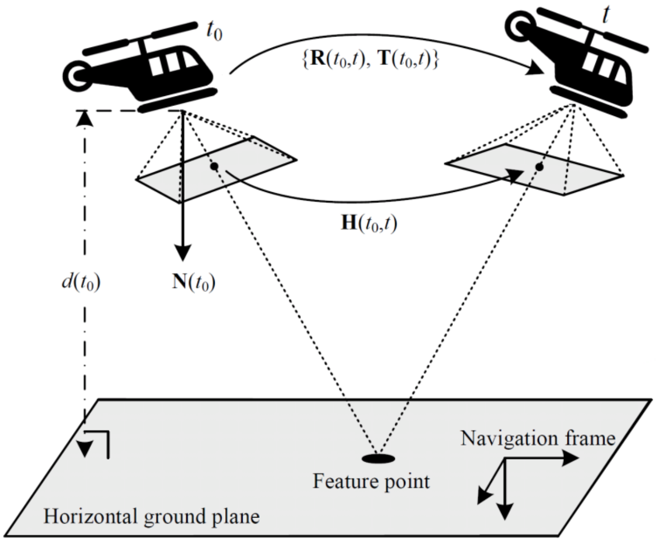

Figure 9: Angle Compensation.

2.2.3 Visual Servoing Methods

The Visual Servoing Methods are the techniques used to control the motion from the feedback obtained from vision sensors. The principal matter in the Visual servoing is how to integrate the information obtained into the control law. There are three methods of visual servoing: 3D, 2D and 2D1/2. [VisualServoing02].

3D visual servoing retrieves the three dimensional information about the scene. Known camera model is used to estimate the position and the orientation of the target with respect to the camera coordinate system. The positioning or tracking task is defined in the 3D space.

On the other side, inspired in several studies that shows that houseflies do not explicitly understand the 3D structure of their surroundings, other methods less computationally expensive have been developed.

2D visual servoing uses direct image measurements to identify the target or the desired path. Typical tasks like tracking and positioning are performed by reducing the image distance error between a set of current desired image features in the image plane. These methods suffer from high coupling dynamics between translation and rotational motion. Examples of this technique, are methods proposed by [Bills11] and [Azrad09].

2D1/2 visual servoing is based on the projective reconstruction of a target using feature points extracted from two images, without the need of the 3D position of the target points. Examples of 2D1/2 visual servoing methods are [Zingg10] and [Zhihai06].

2.2.4 Visual Navigation

Unlike Outdoors environments, where a GPS generally can provide pose and altitude estimation, in indoors environments the GPS may be very weak and even useless, since the GPS signal may have a precision un-adapted to an environment characteristics and would need a previous knowledge of the obstacles and walls in the building.

So, in order to get autonomous flights, the Aerial Robot must be capable of high level environment under-standing and decision making, i.e. to be able to define its position, attitude and obstacle detecting, avoid-ance and path planning, without outside intervention.

Autopilot

An autopilot is a system, often by means of hardware, used to guide the Aerial Robot without assistance from a human being or simply to know the position and dynamic parameters of Drone.

The autopilot provides a minimum set of flight sensors, which generally includes an IMU to maintain trajec-tory and stability of the UAV. It estimates: Attitude, angular position, angular velocity and acceleration from optional inertial sensors. [AutopilotSurvey10]. It generally is used to compensate the Optical Flow due to ro-tational and translational effects. The information provided by the autopilot is generally used also for com-pensating the measurements of optical flux, taking out undesired rotations, or even to compute the differ-ences between the O.F. measurement and the IMU, in order to provide obstacle detection or corridors navi-gation features [Zhihai06] [Zingg10].

2.2.5 Indoors Navigation

Several approaches have been implemented to autonomously navigate in indoor environments.

In **[Zingg10]** it is proposed an optical flow technique for safely maneuvering a MAV in unknown environ-ments avoiding collision with walls. It detects features in the image with Shi and Tomasi's corner finder [ShiTomasi94], it follows them with a Pyramidal Lucas Kanade flow de-tector.

Once computed the OF, the distance to the feature points is calculated as

$$D=\frac{v}{OF}\,.\sin(\propto)\ .\ \text{(eq 3).}$$

Depth estimation is obtained only from translational movement, so the rotations are compensated. Since $\sin(\propto ¿ 0)=0$, a drawback of this methods is that frontal objects cannot be detected.

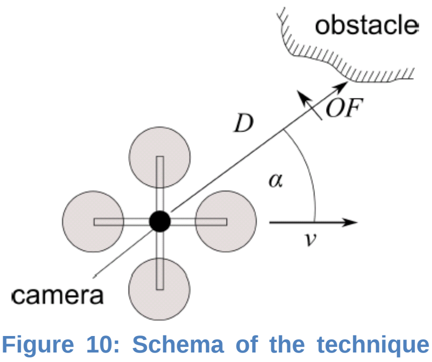

Figure 10: Schema of the technique presented in [Zingg10].

As law control method, they implemented an input variable obtained as the ratio between the difference and the sum of the average distances to left and right, as follows:

$$e_n=\frac{(\sim y_R)-(\sim y_L)}{(\sim y_R)+(\sim y_L)}\ \text{(eq 4).}$$

[Bills11] proposed an Autonomous MAV flight using single image perspective cues, where, given the images of the current environment, a classifier detects the environment type the MAV is in (corridor, room or stairs). This classifier extract the GIST descriptor of each image and the SVM for classifying indoor images into the three mentioned categories. After this process, a second classifier set confidence values to each image de-pending on scene parameters (as vanishing points for corridors, horizontal lines for stairs, etc).

After the fusion of these classifiers, the MAV follows different control law strategies. For corridors, it divide the image plane into a grid and detect vanishing points via Hough transform. For staircase, it detects horizontal lines and focus to be on the center of those lines. In corners and Unknown Environments, the MAV keep moving forward until proximity to a wall and turn to the most open area. All detectors have threshold values that are also used to the "confidence" values for the classifier.

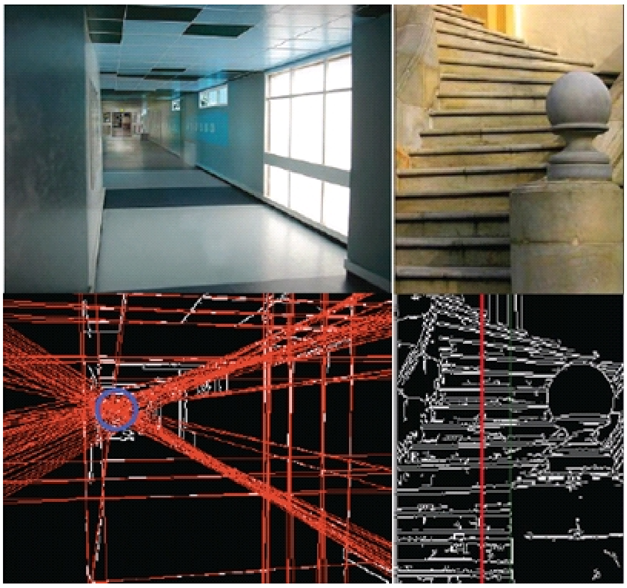

Figure 11: Images from the algorithms for corridors and stairs. [Bills11]

[Azrad09] Proposed a color-based and optic flow target detection and tracking algorithm. The first one, also called Integral Image Based algorithm, needs the target object to be selected. Once done, a normalized histogram of the object is calculated and the colors are quantized into bins. A probability distribution of the tracked object is done by replacing the value of the histogram into each pixel.

The tracking of the object is done by the fusion of a search area that changes dynamically and detects the target by the color based algorithm applied into the search area. A pyramidal Lucas Kanade Algorithm will set the center of the search area and if if the target go outside the field of view it will set the displacement needed to track the object again. The information of the target's position on the screen is the input of a kalman filter, which after determines the changes in the MAVs direction.

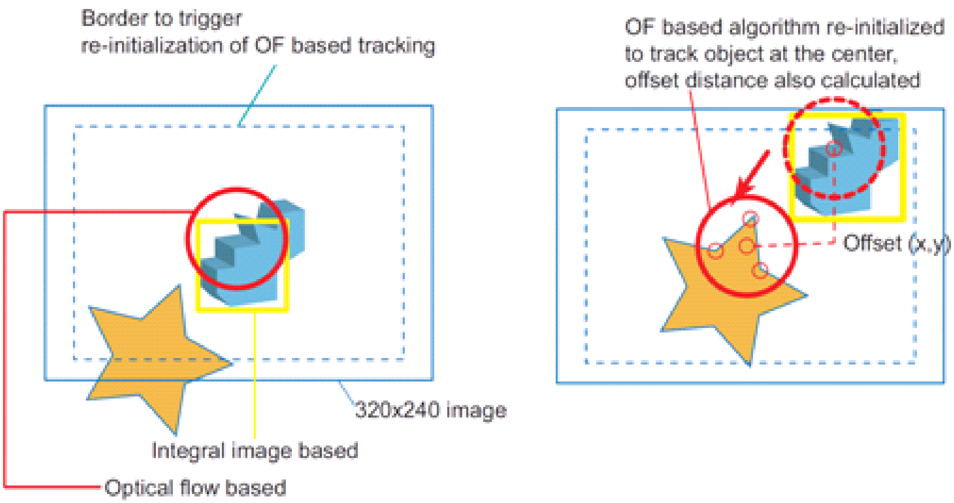

Figure 12: Proposed Optic Flow and Color-Based Algorithm in [Azrad09].

[Zhihai06] presented a Vision-based UAV flight control and obstacle avoidance, taking structural blocks from the image frames with the first coefficients with highest energy of the discrete cosine transform (DCT), which contain a significant amount of structural information. It defines a new distance measure to compare blocks from different frames, as a pondered sum of two different distance metrics:

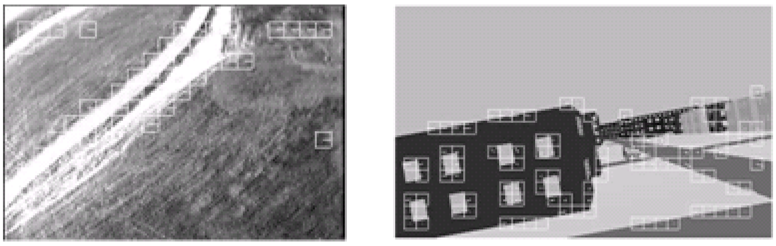

Figure 13: Structural Blocks in the Method presented in [Zhihai06]

In one side, the SAD difference, (Sum of Absolute Differences), which is invariant only under translational motion in the image frames.

$$d_0(A,B)=\sum_{i,j}(a_{ij}-b_{ij})$$

In the other side the difference of a feature called intensity profile is obtained, which is invariant under camera rotation and zoom.

$$m(O_B,r)=\frac{1}{|C(O_B,r)|}\times\oint I_t(x,y).dx.dy$$

$$d_1(A,B)=min_{\lambda}|m(O_A,\lambda.r)-m(O_A,\lambda.r)|$$

The invariability under rotation and zoom is obtained thanks to the dependency of just the sum of intensity and the scaling factor lambda (λ) .

In order to match blocks from different frames the algorithm search for best candidates, and taking into account noise, the blocks are mapped to the an average of best candidates, followed by calculation of a reliability measure.

According to the camera view geometry proposed by [Hartley_04], it is obtained the Angular Velocity for each block. Once obtained the depth Z for each block in the scene, it is made an error estimation by least mean squared method.

2.3 LEGAL ASPECT

United States

There are two ways to legally fly UAVs in the National Airspace. The main authority in this area is the Federal Aviation Administration (FAA) and the Aviation Rulemaking Committee (ARC). The two main ways to legally fly UAVs are:

- Get a Certificate of Authorization (COA) or the Experimental Airworthiness Certificate (EAC) (that is, aircraft specifically designed or modified for research, experimental or scientific purposes and likely to be produced in very limited numbers).
- Fly under exemptions granted to non-commercial ("recreational") fliers who adhere to certain restrictions.

However, concerning specifically the Policy on sUAS, since April 2008, the FAA chartered the ARC to examine operational and safety issues and make recommendations for proceeding with regulating sUAS. The ARC issued recommendations in 2009, which are restrictive: All drone's drivers must be trained.

Although, it allows to fly drones without prior authorization when flying outside populated areas, with the consideration of also certain restricted areas. It requires that the machine does not travel more than 100 meters away from the pilot.

On February 14, 2012, congress established a deadline on allowing small UAS to fly in the airspace by mid-2014, with the safe integration of all civil UAS by 30 Sept. 2015.

France

France has just adopted on April 2012 a regulation for the use of UAVs in civilian airspace, so far prohibited.

The Regulation is also restrictive. And the basis of the law are shared with the recommendations chartered by the ARC in United States.

Europe

There is no common law in Europe. However, some countries already have set a policy in its own territory and most of them are participating in the definition of common regulations.

The concerned authority in this field is the European Aviation Safety Agency (EASA) and makes provision for Implementing Rules dealing with airworthiness certification, a previous step to the inclusion in the airspace system. However, such regulations will not contemplate unmanned aircraft having less than 150 kg, which means that it will not regulate sUAS.

2.4 ECONOMIC ASPECT

The development of UAS started in the 50's. UAS have been used by armed forces for decades. Recent conflicts and peace-keeping operations around the world have demonstrated their operational capacities and led to a quasi-exponential increase of military applications. [Mentor12]

They have been the most dynamic growth sector of the world aerospace industry this decade, in the market study conceived by [Forecast11], it is estimated that UAV spending will almost double over the next decade from current worldwide UAV expenditures of $5.9 billion annually to $11.3 billion, totaling just over $94 billion in the next ten years, continuing as one of the prime areas of growth for defense and aerospace companies.

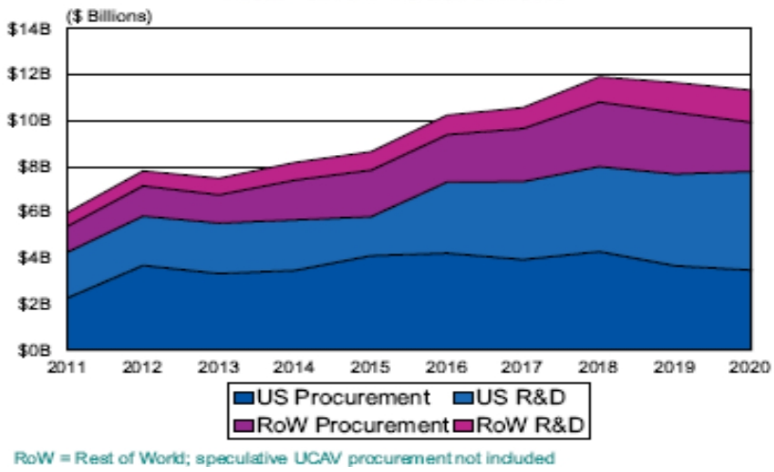

Figure 14: World UAV Forecast. R&D and Procurement.[Forecast11]

As shown in figure 3-14, global UAS procurement and R&D expenditures reached $6 billion in the year 2011, with about 40% spent on R&D. With respectively 66% and 10% of the worldwide UAS sales, the U.S. and Israel dominate the sector. Asia-Pacific represents the second largest market, followed very closely by Europe, whose countries, all together, does not represent more than 10 % . It is estimated that the worldwide UAS market will double over the next decade to represent an annual procurement and R&D market of $11.3 billion in 2020 with European and Asian manufacturers falling behind. Overall, it is estimated that 35,000 UAS will be produced worldwide in the next 10 years .

The U.S. is expected to account for 77 percent of worldwide research, development, test, and evaluation (RDT&E) spending on UAV technology over the next decade. The U.S. also accounts for roughly 69 percent of procurement.

Europe

The European market should experience the same growth trend but at lower scale. If Europe's ambition is maintained at current levels, the United States together with Israel will remain, in the foreseeable future, the dominant players in a growing UAS market.

Nevertheless, once a common European regulation is established, it is expected to start a totally new service industry offering operations and aerial work to commercial and state customers. This service industry is expected to generate revenues even bigger than the manufacturing industry itself. [EuropCommission12]

2.5 Social Aspect

While drones are expanding the use of force beyond a traditional battle-space and changing the very concept of war itself, there is still no comprehensive, consistent set of ideas governing their use.

The United States, which has recently used them as war tools, risks achieving near-term tactical benefits because they could incur in potentially significant longer-term costs to global public opinion. Actually, there is even disagreement on the justifications for the use of drones. [NYTimes_Opinion]

Several blogs and communities, think that using some governments would not limit the use of such powerful spying tool to only war purposes. Which could mean watching civilians in cities. [Blog_Opinion]

In that way, and concerning the domestic deployment of drones and the public acceptance, some studies have been issued by non-profit organizations, specially in United States, aiming to develop a set of recommendations for the use of unmanned aircrafts as aerial surveillance systems. [ProtectingPrivacy]. This tension and uncertainty concerning this policy is represented by the following comic published on the New York Times Journal [NYTimes_Comic].

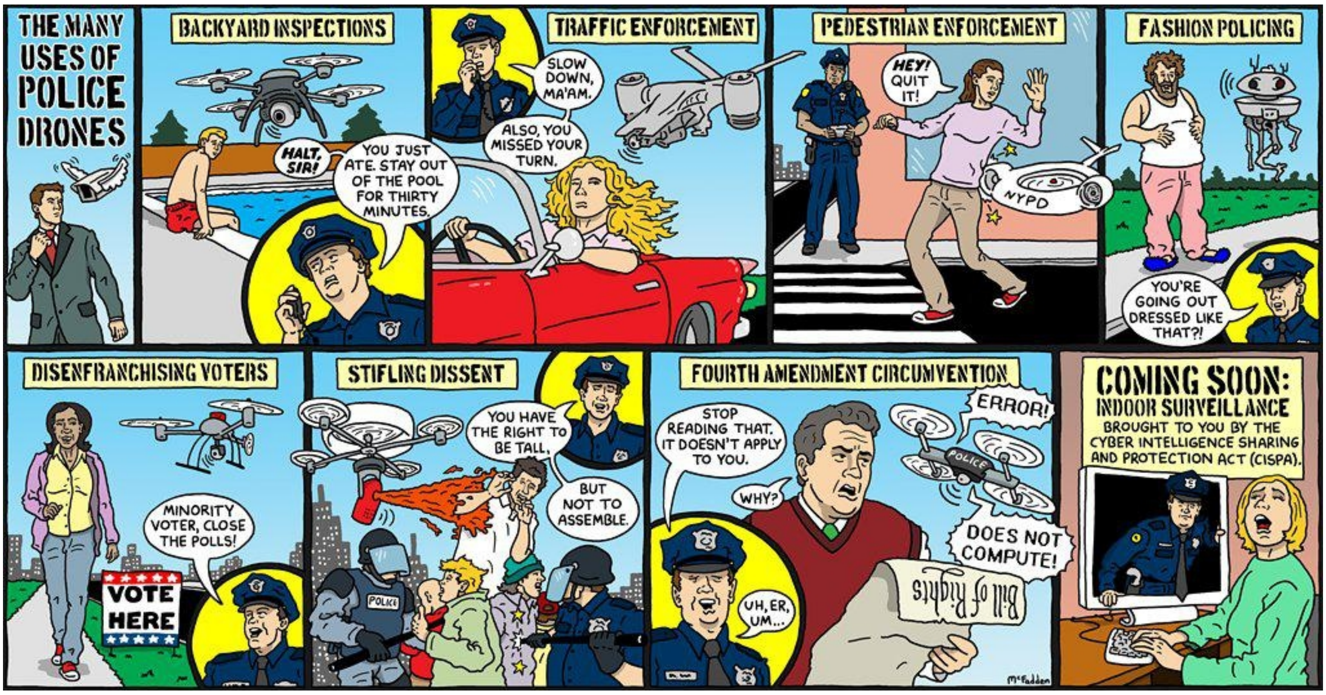

Figure 15: New York Times Journal Comic showing the public opinion on Drones as a mobile surveillance machines.

3. Technichal Characteristics

3.1 Working Environment

3.1.1 General Layout

As seen previously, the working environment consist of a Parrot AR.Drone connected via Wi-Fi 802.11g with a notebook Dell Latitude D830, equipped with a : Intel® Core™ 2 Duo processor T7250 (2.00GHz); 160GB Hard Disk; 3GB DDR 2 667MHz Memory RAM; a video card Intel® Graphics Media Accelerator X3100 (256MB shared); and the communicating interface is done by a card Intel®Pro/Wireless 4965 WiFi 802.11a/g.

All the information from sensors, the IMU and cameras flow are sent to the notebook, the image processing is done, and the control information parameters are sent back to the drone.

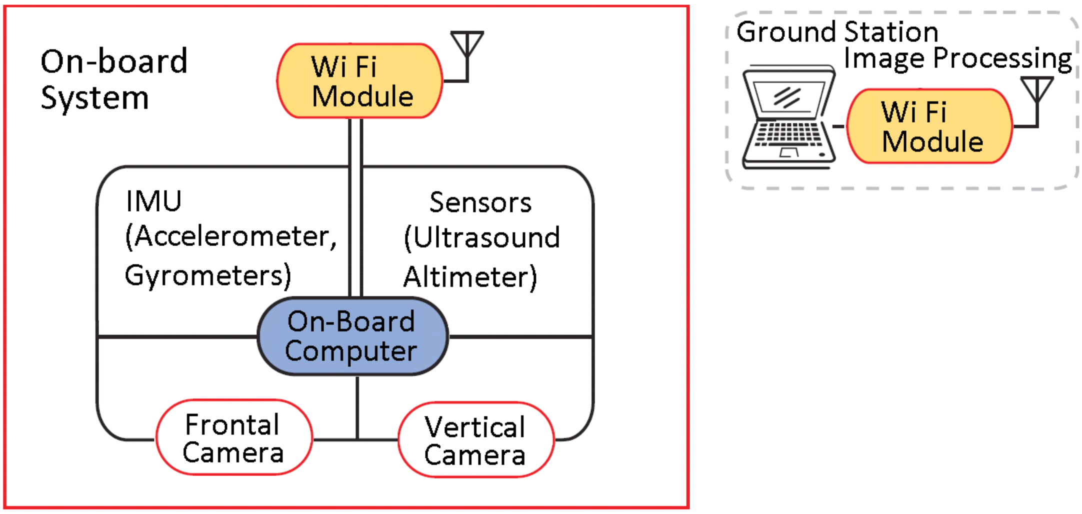

Figure 16: Vision System implemented in this project.

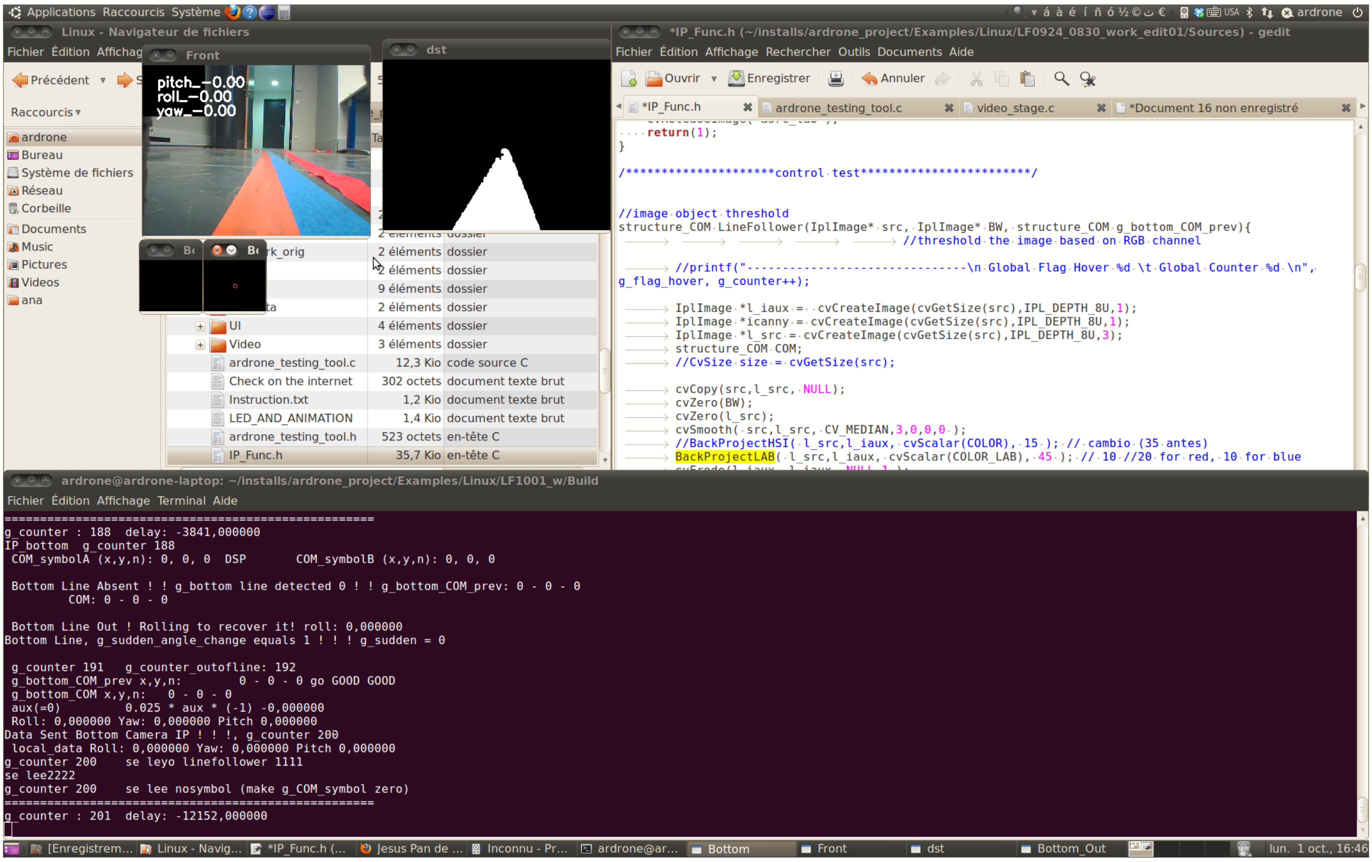

Figure 17: Working Environment in a common Test Fly

3.1.2 Parrot AR.Drone Characteristics

The AR.Drone is a drone type quadrotor helicopter, designed by the French company Parrot, to be used in Augmented Reality games, hence the AR of its name.

It is a device that can fly with a device under iOS (iPhone, iPod touch, iPad), Android or Symbian (Nokia) via a Wi-Fi 802.11g, and so it is limited to the radius of a wifi connection, a roughly 150pieds (~ 45m).

Figure 18: AR.Drone Parrot front view.

Though the AR.Drone is originally designed for recreation, it is provided with the same sofisticated components an unmanned vehicle has: an accelerometer of three axes; two gyroscopes; a frontal camera for piloting, and a vertical one for stabilization, an ultrasound altimeter, an embarked unit of processing under Linux and a b/g Wi-Fi module. For more information, see the full specifications in Appendix B, section I.

3.2 Development Platform

AR Drone API is an open API platform with shared source code released under the terms of the AR.Drone License. [SDK].

The AR.Drone Software development kit (SDK) allows third party developers to develop and distribute new games based on AR.Drone product for Wifi, motion sensing mobile devices like game consoles, the Apple iPhone, iPod touch, the Sony PSP, personal computers or Android phones. For the development of new applications, the main parts of this SDK are:

- the AR.Drone Library (ARDroneLIB), which provides the APIs needed to easily communicate and configure an AR.Drone product;
- the AR.Drone Tool (ARDroneTool) library, which provides a fully functional drone client where developers only have to insert their custom application specific code;
- the AR.Drone Control Engine library which provides an intuitive control interface developed by Parrot for remotely controlling the AR.Drone product from an iPhone;

The AR.Drone onboard sensors can assist in all maneuvers, such as take-off, hovering, trimming and landing. Those basic maneuvers are automatic, but all the flight control parameters obtained from on-board sensors can be tuned:

- altitude limit
- yaw speed limit
- vertical speed limit
- AR.Drone tilt angle limit
- host tilt angle limit

3.2.1 Layered architecture

Here is an overview of the layered architecture of a host application built upon the AR.Drone SDK.

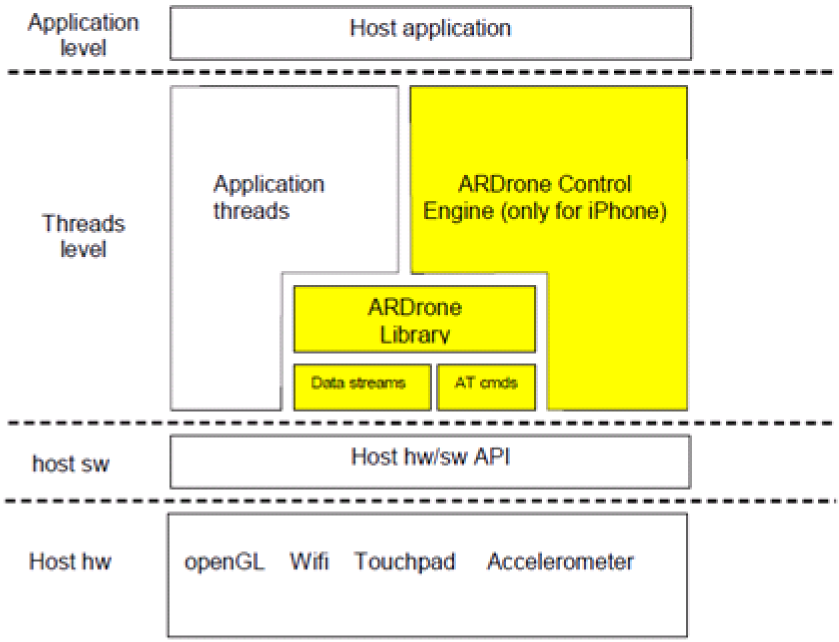

Figure 19: SDK Layered Architecture. [SDK]

The AR.Drone Library is currently provided as an open-source library with high level APIs to access the drone.

3.2.2 Wifi Network and Connection - AR.Drone Library

The AR.Drone can be controlled from any client device supporting the Wifi ad-hoc mode. The following process is followed

Part of the AR.Drone Library is the ARDroneTool . is a library which implements in an efficient way the four following communicating services :

Controlling and configuring the drone is done by sending AT commands on UDP port 5556. which collects commands sent by all the other threads, and send them in an ordered manner with correct sequence numbers.

Information about the drone (like its status, its position, speed, engine rotation speed, etc.), called navdata, are sent by the drone to its client on UDP port 5554. thread which automatically receives the navdata stream, decodes it, and provides the client application with ready-to-use navigation data through a callback function.

A video management thread VLIB, which automatically receives the video stream and provides the client application with ready-to-use video data through a callback function. This is sent by the AR.Drone to the client device on port 5555.

A fourth communication channel, called control port, can be established on TCP port 5559 to transfer critical data. This control thread handles requests from other threads for sending reliable commands from the drone, and automatically checks for the drone acknowledgements.

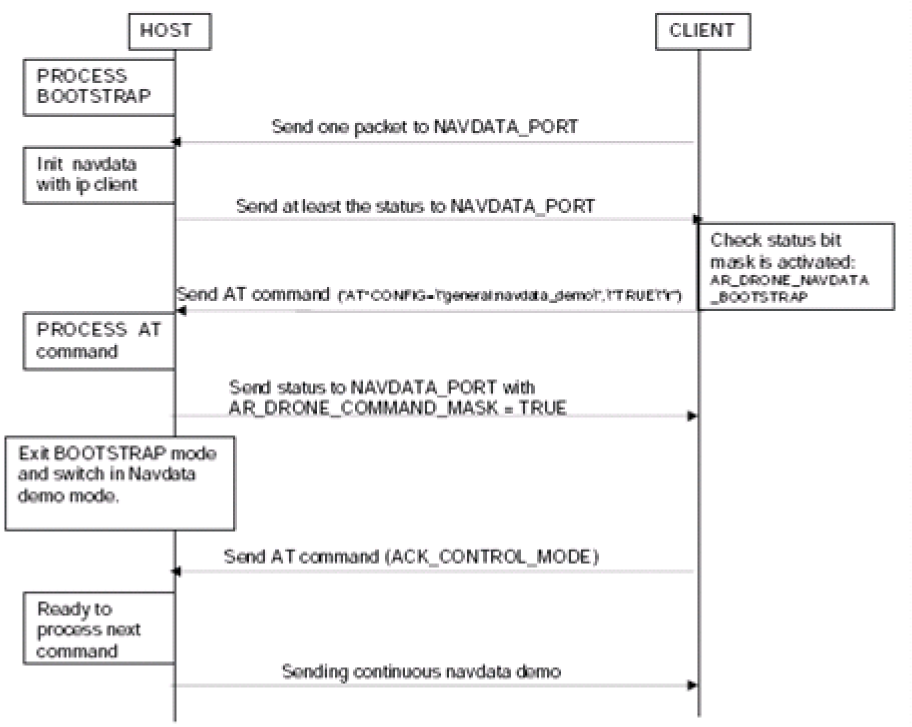

Figure 20: Navdata stream Initiation. [SDK]

3.3 Degrees Of Freedom

In a general rigid body, the position of the whole set is represented by the position of its center of mass or a reference point and its angular position, which is referred as the imaginary rotation that is needed to move the object from a reference placement to its current location. For a three dimensional rotation it is represented by 3 parameters, which added to the parameters to state the position of the center makes a total of 6 degrees of freedom.

Like every rigid body, the kinematics of the drone is expressed in the same way: It is defined by the translational velocity and the angular velocity.

Thus, an aerial robot is a system navigating in six degrees of freedom as a rigid body does. For determining its rotation It has been widely adopted the one proposed by Leonhard Euler, also called Euler Angles, in which one rotation is used to fix the orientation of two axes (e.g. X and Y) and the two others to fix the orientation of the vertical axis (Z). In the field of aviation, these three angles are normally called "Yaw, Pitch and Roll" and are represented by the φ (phi), θ (theta), and ψ (psi) Greek letters, respectively.

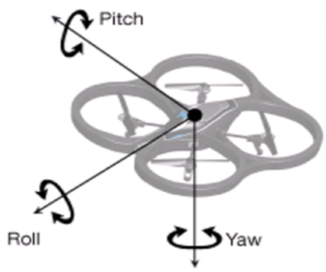

Figure 21: Degrees of Freedom, Orientation.

This degrees of freedom, are very important to take into account because rotations and translations of the UAV may cause undesired additional optical flow, which may affect as a sort of noise for the correctly measuring the environment parameters. Thus a compensation of rotation and translation, is sometimes necessary.

They are often measured by an autopilot, or more specifically by an Inertial Measurement Unit or IMU, which is an electronic device that measures and reports on a craft's velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes, sometimes also magnetometers.

3.4 Physical Control and Consequences of Size

The hardware platform consists basically of a Quadrotor Helicopter, so it has four rotors. If these rotors are spun at the same speed, the robot hovers, e.g. It keeps flying at the same height.

If the speed of each of these rotors is increased, then the robot flies upwards, it accelerates and goes towards the sky.

Of course, if the robot is tilted, inclined to the horizontal, the lift that made it goes upward, would have an horizontal component, and then it would accelerate in this direction.

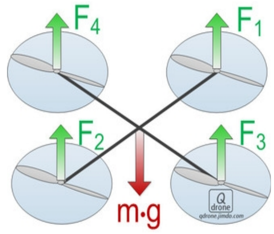

Figure 22: Balance of Power while hovering

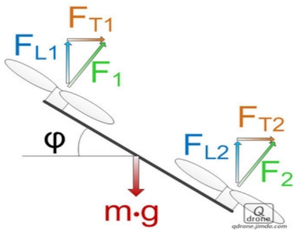

Figure 23: Force Decomposition for Tilting.

To get it to tilt, one way of doing it, is making rotor one and four spin faster and rotor two and three do it slower. So, as shown in figure there would be a moment that causes this robot to tilt, and consequently to roll to one side (in Fig 3, to roll to right, that is the direction of Ft1).

The particular part is the yaw angle. If every rotor would turn in the same direction, the quadcopter would start turning around the z axis (like an helicopter without a rear rotor). Therefore rotation directions are configured as following: Contiguous rotors turn in opposite direction. With this configuration we are able to neutralize the momentum.

And then, if opposite pairs of rotors are spun faster than the other pair, then the robot yaws about the vertical axis. So an on-board processor essentially looks at what motions need to be executed and combines these motions and figures out what commands to send to the motors 600 times a second. [TEDConf] [Qdrone12].

Finally, concerning its size (diameter ~50cm) and weight (~400g), one advantage of that is it allows low power consumption: it consumes about 15 watts of power. On the other side, another of the advantages of this design is, when things are scaled the robot naturally becomes agile.

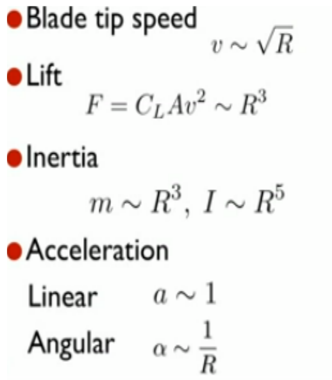

Figure 24: Physic Parameters in dependence with Radius.[Kushleyev12]

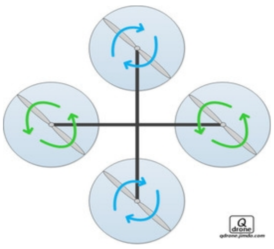
Figure 25: Rotors Rotation Direction

Let R be the characteristic length parameter of the robot. In the figure are shown several physical parameters that change as R is reduced. So the inertia, which governs angular motion, scales as a fifth power of R. So as a result, the angular acceleration, denoted by Greek letter alpha here, goes as one over R. It is inversely proportional to R. The smaller you make it the more quickly you can turn.

One disadvantages of that is, since the robot became agile, in the control aspect it can be understood as if its control become more difficult. [Kushleyev12].

3.5 IMPLEMENTATIONS

3.5.1 Motivations

Given the state of the art for image processing for UAVs, we considered the development of a signpost system for UAVs will be an important contribution to the community.

Taking into account the recent introduction of related regulations in France in mid 2012, and the existence of recommendations for the use of sUAS made by committees both in Europe and U.S. raises an eventual market opening for drones for civil and commercial purposes. Moreover, this market opening would allow the use of drones for data collect, data processing, and loads or individuals transporting with commercial purposes.

Technically, there are no similar developments of a signpost system for micro aerial robots. And in the same way the existing means of transport have a specific signpost system to regulate circulation areas and incorporate them into society, a new signaling system initially adapted to the use of micro drones can make great contributions in the area, allowing its sustained and organized growth.

On the other side, there are just some publications about a two perpendicular cameras stereo vision system, as the one show in [Bills11].

3.5.2 Implementation

Currently, there is an existing algorithm, it consists of 7 different threads:

- Image processing from the front camera,
- Image processing from the bottom camera,
- Communication thread (sending of new control data and session data configuration),
- Manual control of the drone,
- And other threads from the SDK (reception of video management, ardrone control, and update of on board sensors data).

Each thread refers to an independent process that must be executed simultaneously with the others.

That is to say, since several parts of the code are working simultaneously, more than one thread could need to access a shared resource, such as shared memory or a global variable, at the same time other thread is doing it. In order to avoid this problem, a concurrency control method have been implemented. [Mutex].

The purpose of this concurrency control method is to maintain the consistency of components operating concurrently while interacting, i.e. guaranty the mutual exclusion of the different processes, and thus the consistency and correctness of the whole system. Introducing concurrency control into a system means applying operation constraints which typically result in some performance reduction, without reducing it below reasonable. [Concurrency].

A technique of Two-phase locking - 2PL was implemented in the SDK. This implies that before the use of shared data in this software, shared data must be locked to prevent any other attempt to change it. Once the locked has been successful, the changes can be made, and the data unlocked. The mutual exclusion was implemented to accessing global variables and shared resources. [Mutex_tech].

Video Stream Usage

There are two cameras on the UAV. The incoming video has a resolution of 320x240px at 15 frames per second.

Althought the full resolution indicated in specifications is VGA (640x480px), the stream resolution is fixed to 320x240 (QVGA) for bandwidth, on the other side, with the current video codec, streaming both cameras at the same time would add too much latency and wifi traffic to be correctly useable.

So, since there are two image frames, the incoming video is formatted in a PiP stream (Picture in Picture streaming video). That is, the stream is combined with the images from both cameras, so that we get 320x240px horizontal images with 88x72px vertical image in the top left corner.

The Image Processing thread for the bottom camera, is in charge of following the line and detect symbols.

Conversely, the image processing for the frontal camera complements the information from the bottom camera images to orient the yaw of the drone.

Following, it will be analyzed individually the fundamental code blocs of the working algorithm. These sections cover the Color Detection Algorithm, the Center of mass of detected objects, the line following and control stabilization system, a new algorithm (that has not been tested yet on the drone) that replaces the line following algorithm and works with tag points, and also the line representation for the yaw update of the drone. The symbol detection algorithms and Signpost System proposed will be analyzed at the end of this section.

The algorithm Diagram Block for the bottom image processing and front image processing thread can be seen on Figures 41 and 42.

Color Detection

In this project, the detection of a colored line was necessary to indicate the robot the path to follow. In order to accomplish the path detection, the first approach of the algorithm was made following a red colored line of 8cm height. The detection was made in an HSV color space. The algorithm measured color differences between each pixel's frame received and a color reference value, with an empirical metric which used hue and saturation differences, as follows:

$$D_{HSV}=\left|\left(H_{PX}-H_{REF}\right)\right|\cdot 2+\left|\left(S_{PX}-S_{REF}\right)\right|/4$$

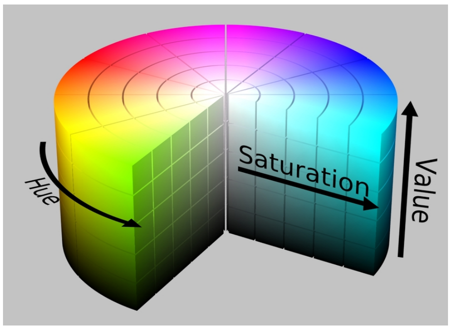

Figure 26: HSV Color Space 3D representation.

With that algorithm we experienced some problems related to lighting environments. When the camera tried to detect the line in a lighting environment, it lost the line. Analyzing the pictures frames, It has been noticed that the saturation decreased noticeably, even if the hue parameter was inside the desired interval.

Analyzing the HSV and HSL color spaces, it has been observed that they do not separate uniformly the saturation in different colors. The value at which this maximum chroma occurs depends on the hue - e.g. very high for yellow, low for violet and blue. In this project, for example, that implies that a red line in an illuminated room would have a much more different saturation than a blue one, and in some cases could not be detected. Also, the threshold for detecting a blue line under different saturation levels, would carry to detect noise according to the environment.

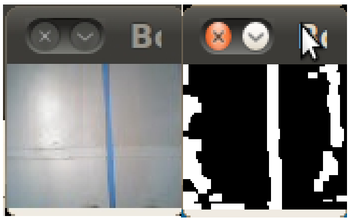

Figure 27: Problems in color detection in HSV.

Even if in the HSV metric the saturation differences where attenuated by a scaling factor, HSV metric had some problems, what used to happen was that even if the Hue parameters fit properly, but in high light conditions the saturation was several affected. Also because the background has also low saturation and carried to false detections.

The cause was in the definition in the HSL and HSV color spaces, since the saturation is described as *relative chroma* because the model defines saturation as the ratio between the chroma and that hue's maximum possible chroma. [JobloveGreenberg78]. Even that, the saturation defined in this color spaces can be aproximated as the ratio between chroma and its own brightness.

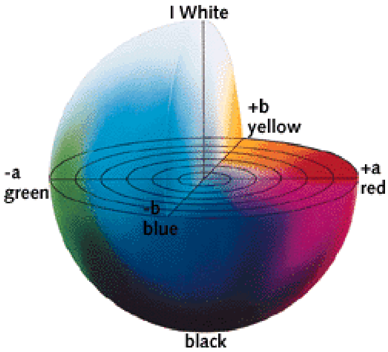

Figure 28: CIELab Color Space

An Experiment was made, taking photos to different colors at different heights. The first photo was used to calibrate the detection of the color, and the second to verify the results in another perspective, with expected luminance changes, but keeping the same parameters from the previous image.

Another color measure was necessary, a chroma based color-space was chosen. So, it has been proposed to test the CIELab color space [Soendoro11], because besides CIELab is particularly designed for use defining color tolerance, since the distance between any colors is proportional to the visual perception color difference [Cielab], it also works with chromacity, wich worked also empirically better with luminescence changes, as it will shown as follows.

Concerning the metric employed in CIELab, the color distance formula provided by CIEDE is employed. [Sharma05].

Since variations are proportionally to color perception, the first approach is to take an euclidean distance.

$$D_{CIEDE}=\sqrt{\left(a_{PX}-a_{REF}\right)^2+\left(b_{PX}-b_{REF}\right)^2}$$

However, since the algorithm should resist different lighting environments, the L differences has been omitted in this formula.

Here are some results obtained:

Pixel: x 177 y 160
Pix Click Color RGB: 34.000000 - 47.000000 - 91.000000
Pix Click Color Lab: 53.000000 - 138.000000 - 100.000000
Pix Click Color HSV: 113.000000 - 160.000000 - 91.000000
The values for the thresholds are: CIELab = 10, HSV=34.

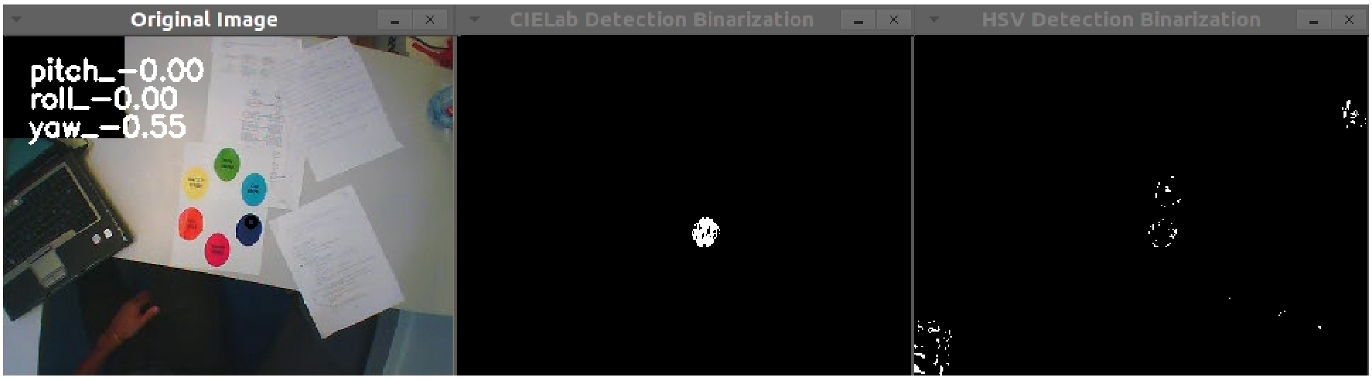

Figure 29: Image Experiment 1. Detecting Blue Color at 30cm height.

In the first image, for the HSV it is possible to notice that HSV has not a good difference between cyan and blue. Even in the bottom left side, there are blue pixels with low saturation, that are detected as blue.

It is possible to see in the next image, that other blue colors are detected. That's not wrong, since there is no post-processing in these images. But there are some interesting differences in results. The HSV algorithm has a lot of dispersion in its new result at 70cm from the table, while the CIELab algorithm gives similarities just with the colors that for a human vision are blue. Alike the HSV metric, CIELab metric doesn't detect cyan objects as blue even if there is a lot of cyan color in the image (monitor, the other circle and a paper next to the table).

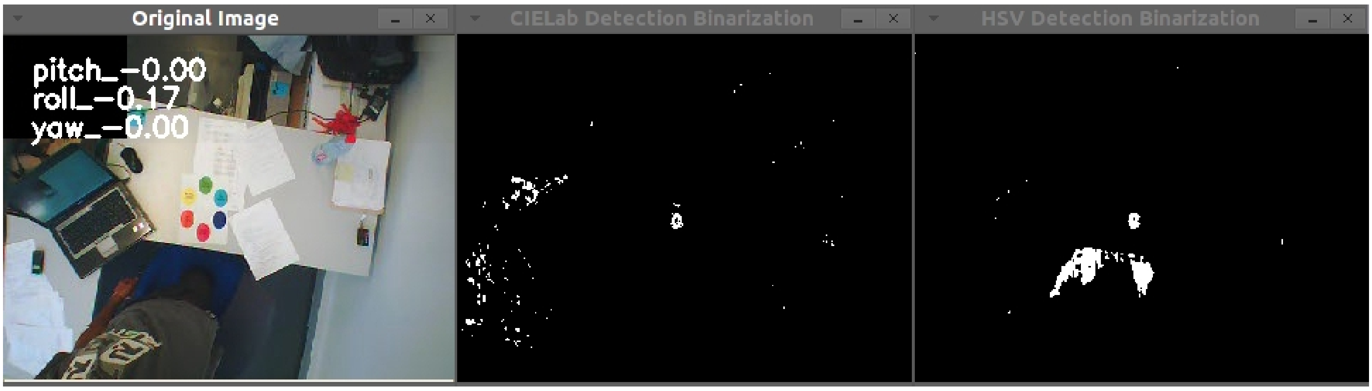

Figure 30: Image Experiment 1. Detecting Blue Color at 70cm height.

HSV metric Problems in detecting colors with less variation in chroma, as the blue. And also, we can see up to this moment that having a color space similar to human perception gives expected results.

With the green color, instead, to obtain similar results in the first image, the color thresholds were set, and it has been observed that HSV metric had some miss detections, which were just isolated pixels.

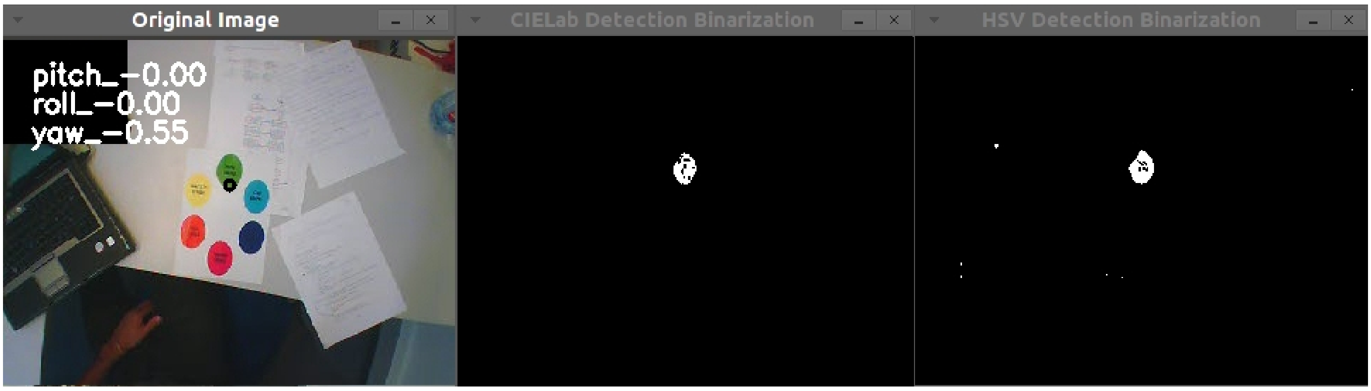

Figure 31: Image Experiment 2. Detecting Green Color at 30cm height.

Pixel: x 162 y 129
Pix Click Color RGB: 94.000000 - 140.000000 - 50.000000
Pix Click Color Lab: 136.000000 - 97.000000 - 170.000000
Pix Click Color HSV: 45.000000 - 164.000000 - 140.000000

With the same color detected, it has been made a detection in another image at 70cm height. The results are below:

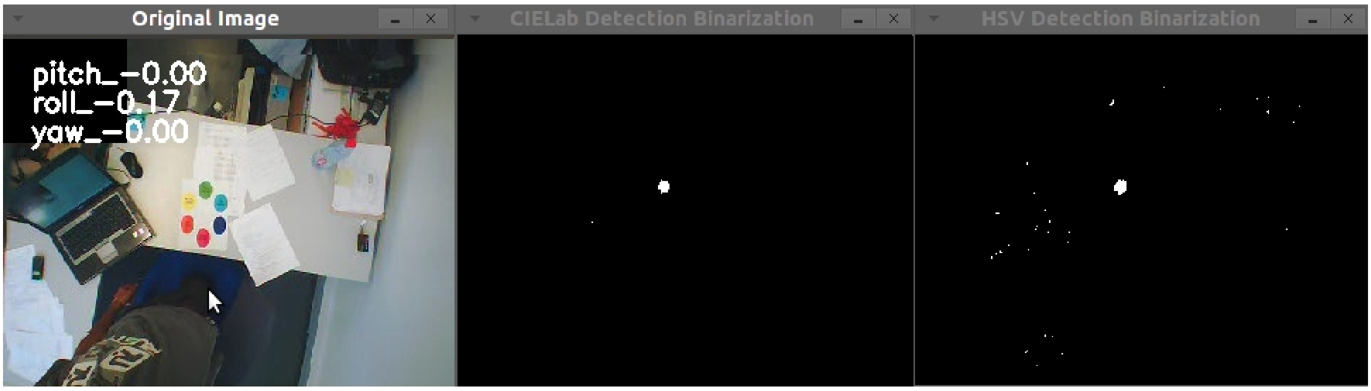

Figure 32: Image Experiment 2. Detecting Green Color at 70cm height.

With the green color, it has been observed that the detection quality with CIELab is much better and stable, even if the results given by HSV metric can be as good with an morphologic opening (erode – dilate). The green has a maximum chroma higher than blue, and the results are also better.

As a last example, the red color was detected.

For this case, instead, the thresholds for CIELab metric = 11, HSV metric = 15. That is, a lower threshold was necessary for the HSV.

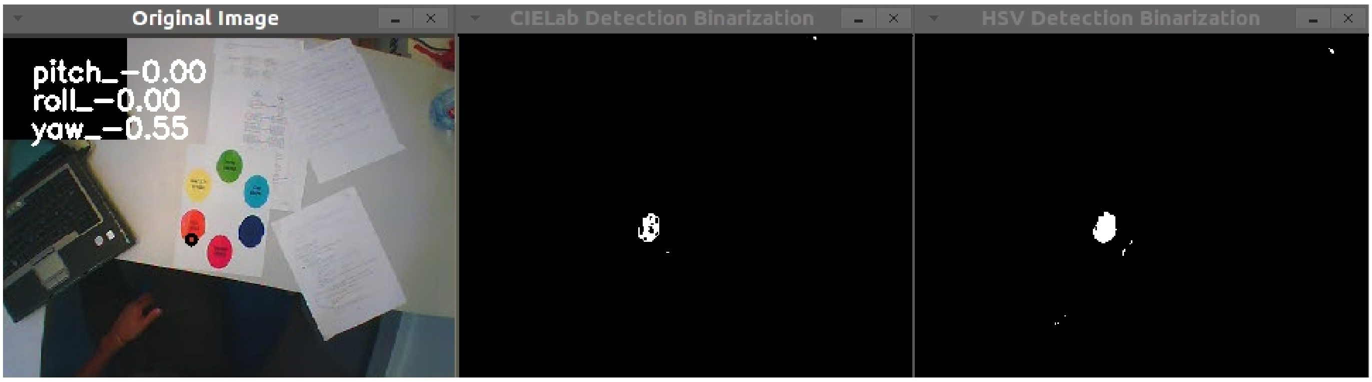

Figure 33: Image Experiment 3. Detecting Red Color at 30cm height.

Pixel: x 133 y 171
Pix Click Color RGB: 215.000000 - 52.000000 - 35.000000
Pix Click Color Lab: 123.000000 - 190.000000 - 176.000000
Pix Click Color HSV: 3.000000 - 213.000000 - 215.000000

As can be shown, for similar results in the original image, in the second image the results were better in the CIELab metric.

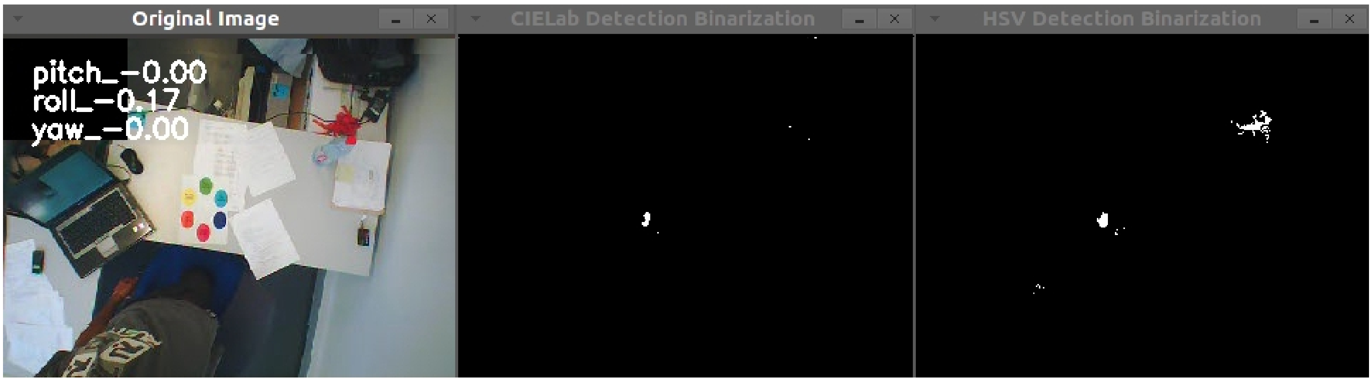

Figure 34: Image Experiment 3. Detecting Red Color at 70cm height.

Another appreciation, is that CIELab is effectively homogeneous with color differences, since for different colors a relative similar threshold was used.

As an explanation relative to the saturation and chroma relationship, if the CIELab color space is expressed in cylindric coordinates, as the HSV is, the CIELCh color space will be obtained, where C stands for Chromacity, and it is possible to estimate the saturation of a color with the following formula:

$$S_{ab} \approx \frac{C_{ab}}{L} = \frac{\sqrt{a^2+b^2}}{L}$$

In this way, it can be shown that the Saturation is dependent on Luminance. In other words, though CIELAB is not perfect and also have trouble adapting to unusual lighting conditions, is to be dramatically more perceptually relevant than RGB, HSL, HSV, or XYZ.

However, the results with CIELab has shown an improvement, specially with differenciating the desired color with false detections.

Figure 35: Line Detection with CIELab Algorithm

Once the line detected, there are two main processes:

- The calculation of the center of mass of the line.
- The calculation of the hough transform, in order to update the YAW angles.

Center of Mass of line

Since the centering of the robot above the line must be enough robust in order to avoid fragments of the line lost, the best proposed solution was to obtain the center of mass of the binarized image.

The concept of the center of mass is used here in the sense that an average of the pixel positions is taken (the values considered are all of the same weight, 255 or white), and factored by their distances from the image reference point.

On the other side, in order to avoid noise detection, the detected image components are filtered by a previous calculation of connectedness in order to get the biggest and separated fragment of line detected, and after evaluate the center of that object.

Control Stabilization System - Derivative-based Roll Control System

As the algorithm was developed and increased in size, it became necessary to improve the algorithm and the aspects of control and stabilization of the drone, since in the applications developed under the SDK, the control system is slightly less stable than when using the applications provided by drone parrot.

Since the purpose of the robot is to follow that line, the initial method proposed was a linear method, where the roll angle was proportional to the distance to the path line. It has been observed that this method produced a very unstable fly where sometimes the corner was not possible to be detected and the drone got lost.

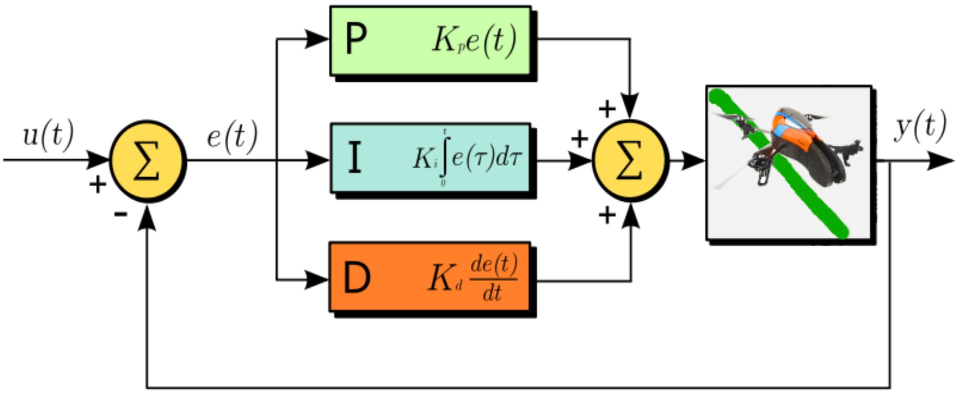

Figure 36: General Schema of the Proposed Control System.

In order to solve that, a PID controller block system was proposed. [PID12]

The variable (e) represents the tracking error, the difference between the desired input value (R, the center of the image as ideal position for the line) and the actual output (Y, the position of the center of the line). This error signal (e) will be sent to the PID controller, and the controller computes both the derivative and the integral of this error signal. The signal (u) just past the controller is now equal to the proportional gain (Kp) times the magnitude of the error plus the integral gain (Ki) times the integral of the error plus the derivative gain (Kd) times the derivative of the error.

This signal (u), will be sent to the plant, and the new output (Y) will be obtained. This new output (Y) will be sent back to the sensor again to find the new error signal (e). The controller takes this new error signal and computes its derivative and its integral again. This process goes on and on.

Analizing the problem of stability from this point of view, the problem that occurred was just the overshot of the signal y(t) in the process of stabilization.

If we consider just as approach the force diagram of the drone roll as a simple mass with a spring and damper without friction, we have that:

$$M.\ddot{x}+b.\dot{x}+k.x=F(x)$$

And the proposed system gives:

$$K_{P.}\ddot{x}+K_{D.}\dot{x}+K_{I.}x=PID(x)$$

In order to show the behavior of the system $\frac{PID(x)}{F(x)}$, it is possible to show that while Kp contributes to reduce the rise time, it also increases the overshot of the response, that is, it makes the position to exceed its target (the line).

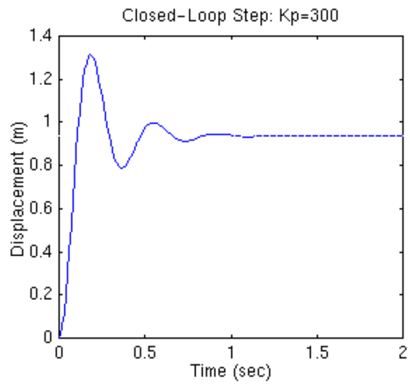

Figure 37: Response for a representative system with a Proportional Control System.

Conversely, the derivative controller reduce both the overshot and the settling time, also increasing a bit the rise time and the steady-state error. In other words, it just increases the steady-state error, which cannot be noticed easily and does not affect the stability of the drone.

So, after testing a proportional derivative system with better results, it has been proposed a proportional-derivative control system. This system gives much more importance to the changes in position rather than positioning itself, since the derivative tends to eliminate the overshot, which was the most problematic effect in this case.

Parameter	RISE TIME	OVER-SHOOT	SETTLING TIME	S-S ERROR
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	No Change

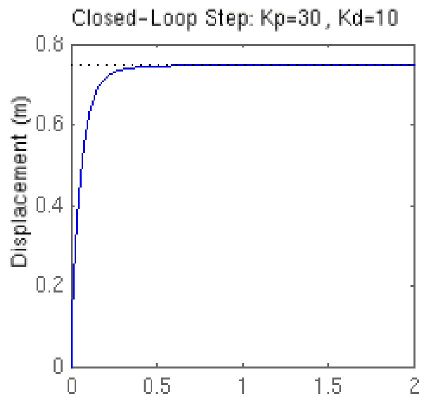

Figure 38: Response for a representative system with a Proportional Derivative Control System. The Overshot is eliminated.

The last parameter to consider, was the integral controller, which also reduces the rise time and increases the overshot as the proportional controller does.

Finally the system was implemented was a proportional derivative controller, which also has a non-linear behavior for the case where the line is on the border of the received image. Also, it has memory on the last position of the line, in case of lost the line it is able to recover it.

Hough Transform for line representation - Yaw Update

Once detected the line and made the preprocessing, the detected line is processed with a canny edge detector, and two border lines are supposed to be obtained.

The hough transform obtains the model for both lines, and it is taken an average of both values.

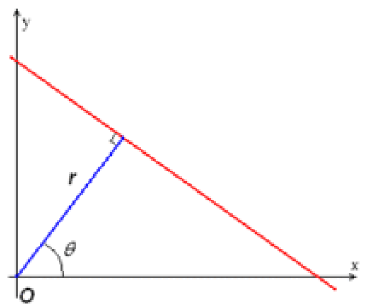

Figure 39: Line representation in the (rho, theta) parameter space

This feature extractions is made in order to achieve the task of yaw correction.

Since this procedure obtains object candidates as local maxima, the result has to be filtered with a threshold parameter in order to detect just the actual line the robot is following. As well, since the procedure is carried out in the parameter space (rho, theta), the parameter used is the angle theta to get the desired yaw update, just by a linear transformation.

Front line Yaw adjustment

Since the algorithm for the line following was made based with the purpose to small changes in yaw, an algorithm to determine the end of the turnings and to look for the lane in case of lost is needed.

That is the case of the algorithm in the front camera: It looks constantly for a line, with a color-based detector, and in case of a detection.

Since the facing camera algorithm must be robust enough to differentiate the path line from, for example a wall with that color, it calculates the connected components on the image, and takes the components which start at the bottom of the image and whose height do not exceed a determined limit.

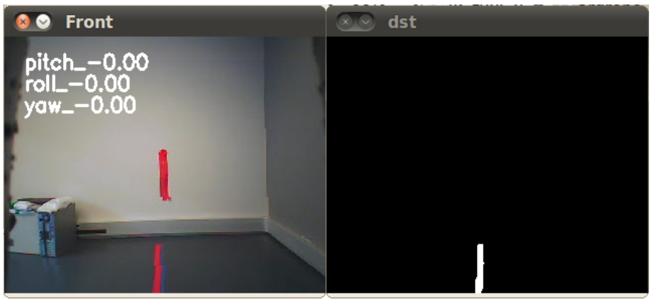

Figure 40: Front Camera Algorithm Connected Components Test.

Proposed and Tested Color Gradient-Based detection Algorithm

Since the use of a line is intrusive, difficult to install and expensive for long trajectories, it has been observed that even if some improvements in the color-based detection had been made, it had still several problems in light changing environments.

On the other side, a fast algorithm to detect the path is needed, but color was somewhat difficult to detect in some illumination conditions. So, it is proposed a new algorithm that draws on properties of color gradients, which are invariant to a wide range of illumination conditions, without needing to implement full color constancy [Coughlan05].

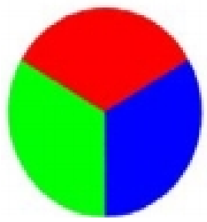

Figure 41: Proposed Tag for a new tracking algorithm.

It is intended to be used for the same purpose as the line has, but with the distinctive feature that can vastly simplify visual search for the path in environments with changes in lighting. However, some form of color constancy is needed to cope with unknown lighting conditions.

In other words, it is proposed an algorithm that follow tag points, where each tag is a three color circle as shown in figure.

The proposed algorithm has four sequential tests to determine the image pixels that do lie on a colour target. Given any candidate target center with pixel coordinates (x,y), three points p1, p2 and p3 are computed with fixed offsets relative to (x,y), corresponding to nearby, equidistant locations in the red, green and blue patches, respectively.

Previously it has been shown that CIELab color space best fits a color detection, since its representation is closer to human color perception. However, now it is being tested color gradients. And the first test was simply in the RGB color space, in order to test its robustess. Besides, the ranges for CIELab values a and b changes in function of L, what means that no direct gradient can be taken (the value of the gradient will be a funcion of Luminosity).

The four tests are the following inequalities used in the tag detection:

- R1 > R2 + T,
- G1 + T < G2,
- G2 > G3 + T and
- R1 > R3 + T.

Here the subscripts refer to the RGB intensity channels (ranging from 0-255) at points p1, p2 and p3, and T is a threshold (empirically chosen to be 20).

Once the detection tag process made, the next step is to form a line with the points obtained. To do that, it has been considered that each point was a solution of the equation of a line. With that consideration, the least squares method was implemented.

That is if $(x_{1,}y_1)$ and $(x_{2,}y_2)$ is a detected tag, it is known that:

$$y'_1=a\cdot x'_1+b$$

$$y'_2=a\cdot x'_2+b$$

Where (x'_1, y'_1) and (x'_2, y'_2) represent the closest points to (x_1, y_1) and (x_2, y_2) that minimizes

$$e = \sum |a \cdot x_i + b - y_i| \quad .$$

Previous to solve the system, it is checked that the angle of the line wont be 90º and the a --> infinity obtained and used as the update for the way angle.

The center of the line is extracted and used in the same way as the center of mass of the line was used.

However, a calibration must be made, since it has not been made work in real time.

Proposed Sign Post Systems

Regarding the current development status of the algorithm, it has been developed two basic guides to make a decision, some of them are: Turn Left, Right, Go Upstairs, Downstairs, presence of an Elevator, Door closed, Go up and down, Speed down, and speed up.

One signpost system it has been developed upon the actual development of the Tramway Sign System for some countries in Europe. It is the simplest to recognize signpost system that can be implemented, but its drawback it was that it is not human readable.

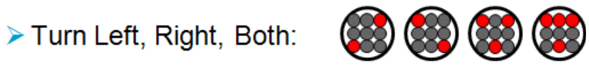

Figure 42: Signs for turning based in the Tramway Sign System.

So, in order to develop a new signpost system, it has been developed a new signpost system, by means of the following pictograms.

Figure 43: Proposed Sign System for turning based human-readable pictograms

Where the shape has also been changed into a quadrirotor in top view, in order to differentiate them also from other sign systems (the route system for example).

The proposed sign system was developed in order to be detected by to the color and shape, and recognized by the shape of the sign. However, since the resolution of the bottom camera (88x72px) made necessary to increase the border of the sign to unpractical sizes, the system has been changed to the following.

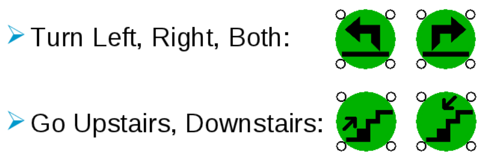

Figure 44: Proposed Sign System for turning v2

The differences in the stairs and Turning were made in order to increase the features that differentiate opposite symbols.

Symbol Detection

A sign recognition system usually involves two main steps [delaEscalera03] [LopezFuentes07]:

- A detection of potential signs in the image, based on the common shape and/or color design of sought traffic signs, and
- A classification of the selected regions of interest (ROIs) for identifying the exact type of sign, or rejecting the ROI.

So, the goal is to develop a Sign Recognition System quick to execute, algorithmically simple and strong enough to detect and classify the signs in real time. It must allow a basic decision making and give a good knowledge of the (indoors) environment the drone is in.

Several methods have been developed, but having the limitation of a low resolution in the bottom facing camera, the first approach implemented was a color based detector and classification.

i- Color-based

Initially, since the control and calibration of parameters was the main purpose to achieve, a simplification of the original signpost was made:

- Turn Left, Right, Both:
- Go Upstairs, Downstairs:

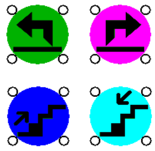

Figure 45: Color-based Sign System.

In this step, several problems have been founded in to achieve this, some of them concerned to the control system, that were progressively solved, but also some concerned the sensors that needed an external calibration.

However, this step has been successfully achieved with the drawback of a color based detection, which is not robust enough without a calibration for each environment.

ii- SURF classifier implementation

A SURF classifier, which is currently under development has been proposed to symbol recognition step. However, considering the actual limitations in matter of resolution, as shown in next point, it has not been possible to finish the implementation and calibration steps.

iii- Bottom Camera Resolution

Considering the case where the flight height is about 1 meter, which is a low altitude between the possible range in an indoor environment, the bottom camera is provided with a 64° Diagonal Field Of View lens, which means that

$$\alpha = 2 \cdot \arctan\left(\frac{d}{2 \cdot f}\right) = \arctan\left(\frac{D/2}{S1}\right)$$

Where D is the diagonal of an Object that fills the whole image at a distance S1.

So, the field of view covered at 1 meter height is:

$$D = 2 \cdot \tan(64^o) = 1{,}25\, m$$

Which correspond to a size of:

$$D_{pixels} = \sqrt{88\text{px}^2 + 72\text{px}^2} = 113\text{pixels}$$

Finally, a symbol of 20cm width has 18pixels size as maximum, since the height of flying is thought to be more.

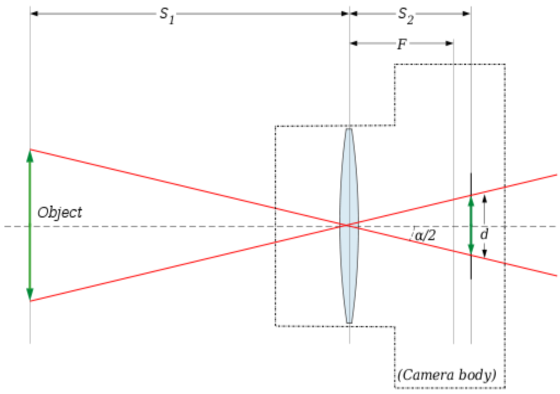

Figure 46: Image Capture basic parameters

This small size, made difficult the tasks of recognition. However this size limitation is now improved in new version from parrot.

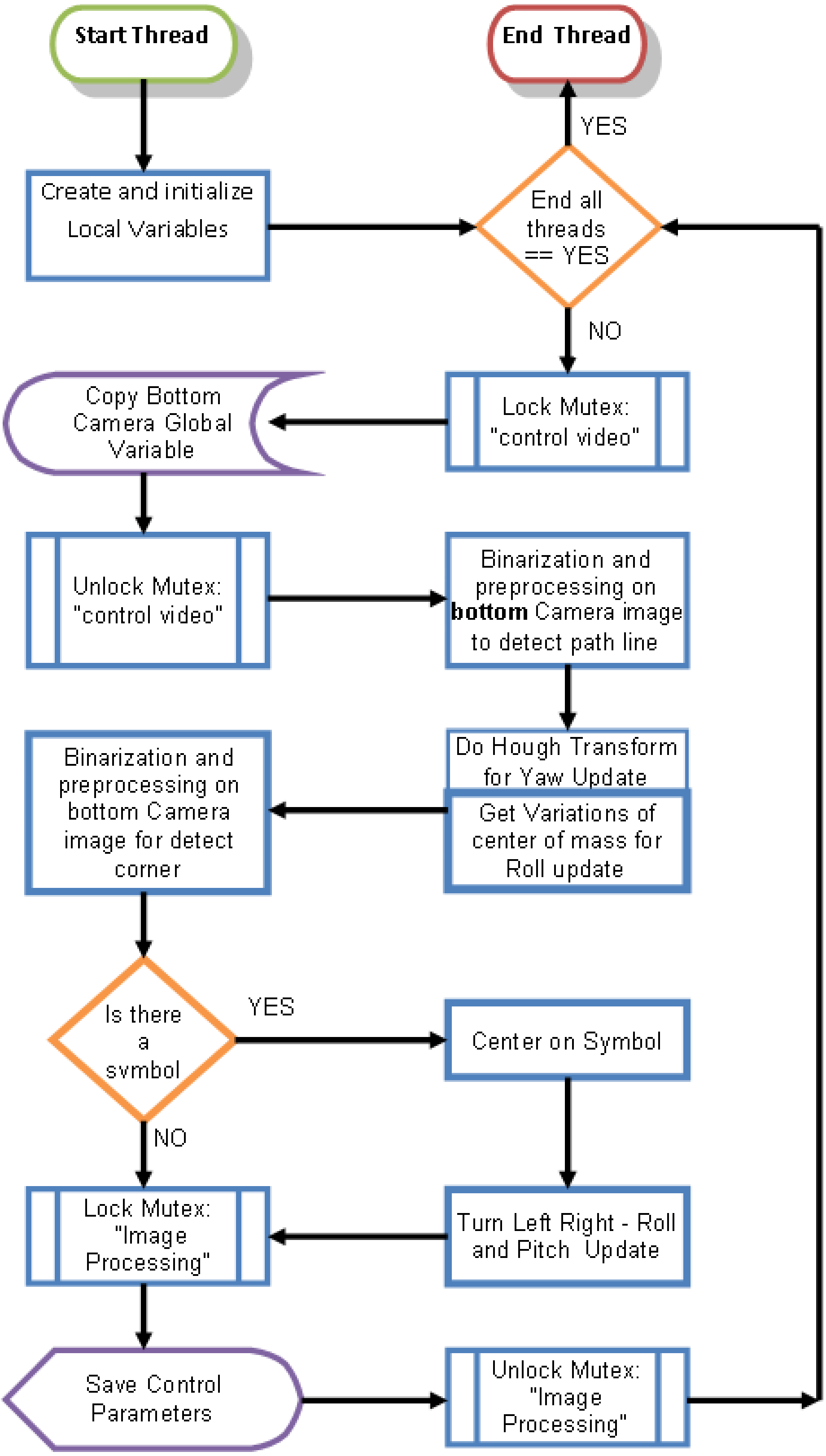

Figure 47: Bottom Image Processing Thread.

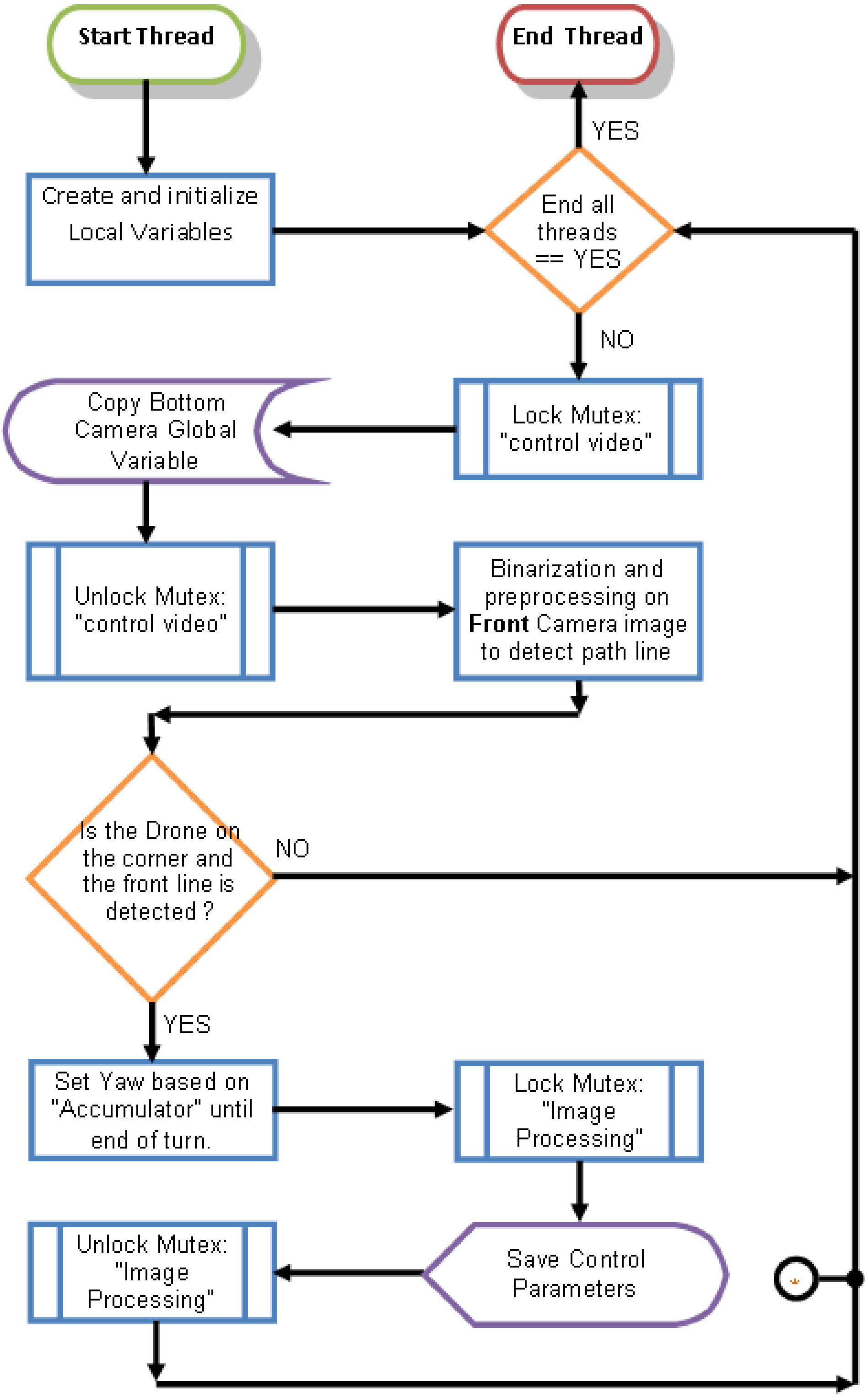

Figure 48: Front camera Image Processing Thread.

4. WEBSITE

It has been developed a website under HTML 4.0, which is indicated in the following pictures.
It has the following sections:

- Home, as main page.
- News, to get to know the latest developments and demos on the drone.
- FAQs, which gives a general knowledge for an uninformed person,
- Community, with 20 academic and professional Labs that works with Micro Aerial Robots all over the world.
- And an About Us.

The access will be possible from www.drone4u.eurecom.fr.

Figure 49A: Projects Website.

Figure 49B: Projects Website.

5. Conclusion

It has been shown that the drones, which performed as war weapons and for recognition purposes in the military field, are also able to perform tasks in the civil field, with very interesting performances and possibilities.

Even that, drones for the general public can perform tasks as aerial robots, and fulfill basic tasks with the aim of achieving much more longer and complex missions in near future.

A color-based system for detecting the line is proposed, where the performances are better than using other color-spaces and also easier to calibrate for several different colors, since the color differences are proportional to eye perception.

The detected image is filtered and used just with the biggest line segment, when a PD control system is proposed to keep the drone in the path and avoid overshot in the line positioning of the drone. Future work can include taking into account the rotor of the optical-flow measured in the frontal camera in order to compensate the values obtained from the detected line. However, with proper calibration in the PD control system the drone has good performances in indoors environments.

A new algorithm, color gradients-based, that follow tag points is also proposed, since the use of lines is more intrusive and difficult to maintain. As it is color gradient based, it is more robust and invariant to a wider range of illumination conditions. It creates a virtual line with the least squares method, when two or more tag points are detected, minimizing distances to the line from each of the detected tags.

A color-based algorithm for sign detection and recognition is proposed, as a consequence of the low resolution in bottom camera, in replacement of a SURF classifier, which had no good performances in tests made.

The needs of more endurance is essential for a better accomplishment of longer tasks autonomously, without human intervention.

The quality of some sensors, as the bottom camera is something that need to be improved in future versions of the Parrot AR.Drone. On the other hand, an IDE-compatible SDK would make easier the development.

A website for the project was developed, which will give an eventual opening to the academic community but also oriented to the general public, in order to get the project closer to the users in a near future.

6. Perspectives

It has been proposed to develop an intelligent system, based on source-destination and paths information, which can determine the way to take following also the set of rules imposed by the signpost system that is on the way.

Another research line, is to work on the communication between drones, since it makes the possibilities bigger and allow to make drone swarms achieve missions where the payload or the autonomy would not permit to correctly fulfill the desired tasks.

The Current perspectives of these developments are several, much of them concern the assistance in the civil field. Examples of eventual applications are: assistance in street accidents, guidance for visitors in public establishments and surveillance of swimming areas. Other general possible applications in the civil field are: Aerial Photography and Videos, Mobile Network Access, Face Recognition with Surveillance, Guiding and Delivery Services. However, the possibilities are almost endless.

7. Glossary

UAV stands for Unmanned Aerial Vehicle, thought it could mean Unmanned Autonomous Vehicle or Unmanned Airborne Vehicle too. UAV is generally other designation for Drone, that is, an aircraft intended to navigate in the air without an onboard pilot.

UAS, which stands for Unmanned Aircraft or Aerial Systems, is the preferred term by the industry and the regulators, rather than UAV or drone, as UAS encompasses all aspects of deploying these aircraft and not just the platform itself. An UAS encompasses the unmanned aircraft and its associated elements related to flight operation, such as Control Stations, Data communications links, Support equipment, payloads, flight termination systems, and launch and recovery equipment

sUAS, instead, stands for Small Unmanned Aircraft or Aerial Systems, which is the term adopted for describing an UAS whose UAV is size limited. See micro Drone.

MAV, which stands for Micro Air Vehicle or Micro Autonomous Vehicle, is another designation for micro Drone.

Aerial Robot: Since the unmanned vehicles requires a distant operator, the aerial vehicles that can autonomously achieve certain tasks are differentiated from the other denominations with the “Robot“designation, which makes reference to the ability to response to random situations.

µUAV: Another name for MAV.

HSV: A Color Space, which represents the color information with the Hue, Saturation and Value Parameters.

HSL: A Color Space which represents the color information with the Hue, Saturation and Lightness Parameters.

CIELab: A Lab color space is a color-opponent space with dimension L for lightness and a and b for the color-opponent dimensions, based on nonlinearly compressed CIE XYZ color space coordinates.

IMU: Stands for Inertial Measurement Unit. It is an electronic device that measures and reports on a craft's velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes, sometimes also magnetometers.

PiP Stream: Picture in Picture streaming video. That is, a video stream which is actually made from two different streams. Generally, one of them is in a corner in a much more reduced size, compared to the bigger image frame.

SDK: stands for Software Development Kit, and it refers to the development platform that the application works on.

IDE: Integrated Developing Environment. An IDE normally consists of a source code editor, build automation tools and a debugger.

VGA: Video Graphics Array (VGA) refers specifically to the display hardware first introduced with the IBM PS/2 line of computers in 1987, but through its widespread adoption has also come to mean either the 640×480px resolution itself.

QVGA: Quarter VGA, that is, a video frame whose size is a quarter of a VGA video frame: 320x240px.

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Open Source Projects

Some Open Source Projects mentioned throughout this report or whose MAVs are in pictures:

The PaparazzI Project | The Free Autopilot
http://paparazzi.enac.fr/wiki/Main_Page

DIY Drones
http://diydrones.com/

Autopilot | Do it yourself UAV
http://autopilot.sourceforge.net/index.html

Open Pilot | Open source UAV autopilot
http://www.openpilot.org/

Mikrocopter
http://www.mikrokopter.de/ucwiki/

Qdrone Project
http://qdrone.jimdo.com/project/

9. ANNEXES

9.1 ANNEXE A: PRÉSENTATION DE L'ENTREPRISE [FRENCH]

9.1.1 Présentation de l'établissement d'accueil

Eurécom est une école d'ingénieurs dans le domaine des technologies de l'information et un centre de recherche en systèmes de communication, placée à Sophia-Antipolis, département des Alpes-Maritimes, France. Eurécom a été crée en 1991 par l'École Nationale Supérieure des Télécommunications (E.N.S.T. Paris) et l'École Polytechnique Fédérale de Laussanne (E.P.F.L), mais actuellement est conformé par les membres académiques suivants :

Les écoles de l'institut Télécom (Membres Fondateurs) :

- Télécom Paristech ;
- Télécom Bretagne ;
- Télécom SudParis.

Les Universités Européennes membre du groupement Eurécom :

- E.P.F.L. ;
- Politecnico di Torino ;
- Technische Universität München (TUM) ;
- Norwegian University of Science and Technology (NTNU) ;
- Université Nationale du Vietnam Ho Chi Minh ville (VNU) ;
- Et Aussi des autres écoles partenaires :
- École Polytechnique Fédérale de Zurich ;
- TU Darmstadt ;
- Univ. Stuttgart ;
- ETSET, Barcelone ;
- NYU, Brooklyn.

9.1.2 Environnement Professionnel du Stage

Aspect Organisationnelle

L'activité de recherche d'Eurécom est un élément structurant, elle est organisée autour de trois thèmes principaux, qui seront abordés dans la section suivante. Toutefois, l'organisation de chacun des départements de recherche et enseignement, est conçue de la façon suivante :

Figure 50: Organisation de chaque département.

Le GIE Eurécom (Groupe d'Intérêt Économique) combine une coopération proche avec l'industrie et la recherche dans une dimension internationale. Il donne la formation finale pour des ingénieurs des principales institutions d'enseignement supérieur en Europe, et chaque année il reçoit une centaine d'étudiants. Son gros lien avec l'étranger est représenté par un parcours entièrement en anglais, et aussi, par la plupart des stages (90%) qui sont réalisés à l'étranger.

Aspect Scientifique

À niveau de la recherche, il y a trois départements, l'un pour chacun des trois axes de recherche principaux :

- Communications Mobiles (Département CM);
- Communications Multimédia (Département MM);
- Réseaux et Sécurité (Département CE).

Le stage s'est déroulé dans le «Groupe de traitement de Images Multimédia» (MIG de l'anglais Multimedia Image Processing Group), qui appartient au département de Communications Multimédia. Le groupe consiste en environ 10 membres (postdocs/Ph. D./interns) et il est conduit par le prof. Dr. Jean-Luc DUGELAY. Le but des principaux thèmes de recherche est d'étudier les technologies fondamentales afin d'améliorer le traitement et l'usage des informations des images multimédia, pour les applications de sécurité suivantes :

- Tatouage Numérique ;
- Stéganographie ;
- Image Forensique ;
- Biométrie ;
- Vidéo Surveillance ;
- Drones.

Le MIG participe et a participé dans plusieurs projets nationaux (ANR Mistral, FAR 3D, Biobimo, VIdeo ID, Oseo Biorafale) et aussi internationaux (Similar, Ecrypt, Actibio, Video Sense, Tabula Rasa), tous rélationés au domaine des traitements de signaux multimédia pour des applications de Sûreté, Sécurité et Forensiques.

Aspect Économique

Avec un budget 2011 de 10,6M€, le GIE Eurécom est appuyé aussi par ses membres, qui sont les principaux partenaires d'Eurécom dans les projets de recherche, proposent des stages et des projets et contribuent à l'administration du GIE. Les principaux partenaires sont : Swisscom, SFR, Orange, ST Ericsson, BMW Group research & technology, Cisco, Symantec, Monaco Télécom, SAP.

Aspect Social

Eurécom est doté d'un staff d'environ 140 membres, dont près de 23 sont enseignants-chercheurs associés, 15 sont ingénieurs et techniciens, près de 72 sont doctorants, et 30 personnes appartiennent au secteur d'administration. De plus, Eurécom reçoit chaque année près de 130 étudiants, qui avec le staff d'administration font un ensemble de 270 membres, avec une forte présence des nationalités Française, Italienne et Espagnole, il y a aussi 25 nationalités représentées, comme par exemple: Allemande, Anglaise, Argentine, Chilienne, Chinois, Colombienne, Grecque, Mexicaine, Suisse et Vietnamienne. En matière de quantité, un peu près la moitié des étudiants et la plupart des enseignants (70%) sont étrangers.

Aspect Citoyenne et Géographique

À niveau géographique, Eurécom est situé à la Côte d'Azur. Donc, encadré au nord par les Alpes du Sud, et au sud par la Côte d'Azur, il est bénéficié d'importants atouts naturels. De plus, proche des principales villes de la métropole Nice Côte d'Azur, et aussi bénéficié de certains équipements culturels.

Plus spécifiquement, Eurécom est localisé dans le 1ère technopôle européenne (Sophia Antipolis), qui constitue un environnement approprié pour atteindre ses objectifs en matière d'enseignement et de recherche. Eurécom utilise trois bâtiments sur le site du CICA (Centre International de Communication Avancée), mais, il se déplacera cette année à un campus partagé avec l'INRIA, le CNRS et l'université de Sophia Antipolis-Nice dans un nouveau bâtiment.

9.2 ANNEX B: TECHNICAL ANNEXES

I - AR.DRONE PARROT TECHNICAL SPECIFICATIONS

Version 1 - Released 18/08/2010 UK and September 2010 in the USA.

EMBEDDED COMPUTER SYSTEM

ARM9 468 MHz Processor.
Microchip PIC24HJ16GP304 40MHZ 16-bit microprocessor.
DDR 128 Mbyte at 200MHz
ROCm Atheros AR6102G-BM2D b/g Wi-Fi module.
USB high speed
Linux OS

INERTIAL GUIDANCE SYSTEMS WITH MEMS

The AR.Drone features a 6 DOF, MEMS-based, miniaturized inertial measurement unit. It provides the software with pitch, roll and yaw measurements. The MEMS gyroscope is done by the Invensense IDG-500 Integrated Dual-Axis Gyroscope.

- 3 axis accelerometer
- 2 axis gyrometer
- 1 axis yaw precision gyrometer

SPECIFICATIONS

Running speed:
5 m/s; 18 km/h; 16.4 ft per second; 11.2 miles per hour
Weight:

- 380 g with outdoor hull (0.8 pounds)
- 420 g with indoor hull (0.9 pounds)

Flying time**:** About 12 minutes

DIMENSIONS

With Hull: 52,5x51,5cm.
Without Hull: 45x29cm.

SAFETY SYSTEM

Expanded Polypropylene hull for indoor flight
Automatic locking of propellers in the event of contact
Control interface with emergency button to stop the motors

AERONAUTIC STRUCTURE

High-efficiency propellers.
Carbon-fiber tube structure.

MOTORS AND ENERGY

4 brushless motors, (35,000 rpm, power: 15W) 28,000 RPM while the AR.Drone is hovering, and as fast as 41,400 during full acceleration.
UL2054 Lithium polymer battery (3 cells, 11,1V, 1000 mAh)
Discharge capacity: 10C
Battery charging time: 90 minutes

FRONT CAMERA:

93° wide-angle diagonal lens camera, CMOS sensor.
Camera resolution 640x480 pixels (VGA).

VERTICAL CAMERA:

64° diagonal lens, CMOS sensor.
Video frequency: 60 fps.

ULTRASOUND ALTIMETER

Emission frequency: - 40kHz.
Range 6 meters (19.7 ft).

9.3 ANNEX C: MOTIVATIONS AND PERSONAL ACCOMPLISHMENTS

From the beginning, the technical diversity that this project was implying was a great motivation. This project involved a mix of several interesting aspects : Real-time Computing, Control Systems, Image Processing and all that applied in a field in a very promising field as the micro-air-vehicles is. Besides, the idea of being in a prestigious academic environment would offer a propitious context for the learning.

This project has given me a valuable experience in the development environment ANSI C, which is a language widely used in low level applications as in the field of the Electronic Engineering, my initial formation. I also believe that these fields converge on the embedded systems, which is a growing interest field long time ago.

On the other side, my personal motivations to come in France were the fact of getting into a new culture and have a international experience, nowadays very important in the formation of an engineer, and even more in a prestigious school as Télécom Bretagne is.

Nevertheless, once in France I noticed that even if this culture ends being pretty similar to mine's, the small changes are the ones that make big differences. I experienced how it implied to adapt myself to new customs and ways of confronting the world.

Also, I felt how the physical distance from my origins, allowed me to understand the new persons I have met and the cultures I have seen, in a different way. I think it also allowed me to reinterpret the environment where I had been living, and to acquire a valuable knowledge of myself.

I am really thankful for the opportunity that it has given to me, and I would really like to thank also my tutor Jean-Luc Dugelay, Ludovic Apvrille, and my Trainee Adviser, Gouenou Coatrieux. Also I am really thankful for the presence of the jury and for their time reading this report.

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