Use of Drones for Surveillance and Reconnaissance of Military Areas

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Abstract. This research is intended to contribute to the design of control algorithms for static cameras and drones. These were modelled on the quadcopter Parrot Bebop 2 by using the communication software Robot Operating System ROS to provide data and recognize different drone stages (landed, on flight, and its maneuvers: yaw, throttle, roll, pitch). The controller was developed after conducting several tests regarding the ideal distance for effective drone operations which include image processing for target detection or tracking in real time. This study also analyzes the benefits on the implementation of this technology in the Ecuadorian Armed Forces for surveillance and reconnaissance operations. Based on the results, it can be concluded that the use of drones in aspects of national security would have a positive impact because it allows to reduce costs as well as to optimize human resources in military operations.

Keywords: Drones · Images · Detection · Surveillance · Reconnaissance

1 Introduction

The globalization and the technological advance in different academic areas has not been the exception in the aeronautical field. Unmanned Aerial Vehicles (UAVs) are a clear example of continuous development, they are more commonly known as drones, "aircrafts able to fly without having a pilot on board, consisting on an aerial platform handled from the ground with the capacity to obtain and transmit information immediately through the use of sensors" [1]. These devices can be reused and are capable to perform a controlled flight hold by a combustion engine. Moreover, "UAVs are considered as tactical, autonomous and are connected to a ground control station (GCS); in addition, drones are able to perform surveillance and reconnaissance tasks as well as sending live information" [2].

Nowadays, these technological devices are used for commercial, military, and personal purposes. "At the moment, the most frequent uses are: aerial photography, cinematography, monitoring, surveillance, inspection of facilities, search and rescue missions, emergency management, and land mapping" [3]. It has been observed an increased number of drone users in fields such as geology, wealth management,

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hydrology and security and border control. Likewise, there are different types of UAVs, classified as: fixed wing & rotary wing drones. "Fixed wing drones are mostly used by militaries for intelligence, reconnaissance and attack missions due to their superiority in terms of autonomy, scope, service ceiling, speed and loading capacity" [4].

As stated in the previous paragraph, drones are also used during military operations; Armed Forces of various countries such as the United States have included these technological devices for several years; for example, in 1983, UVAs were employed by the American militaries in Lebanon. After the terrorist attack occurred on September 11th of 2000, the United States increased the production of drones as well as their use in the Pakistani confrontation. "The US Government led by President Barack Obama systematically intensified drone attacks in Pakistan due to their effectiveness in Afghanistan. It can be concluded that the main American war strategy in Pakistan was based on the use of unmanned aerial vehicles" [5]. UAVs were employed in numerous operations and "the idea of using drones MQ1-1 and MQ-9 in surprised attacks against military leaders without having great losses was generalized" [6].

Moreover, the use of these technological aircrafts, have started to take place in South America, especially in Colombia, which is a country that has been battling for more than 50 years an internal conflict. In order to combat this situation, most public institutions have incorporated UAVs for reconnaissance, surveillance, photography and communication missions; this decision have brought favorable results against armed illegal groups [7].

Apart from that, Ecuador has also entered in the use of this technology, particularly the Armed Forces, which have conducted several researches in this field. An example, presented by the Ecuadorian Air Force, is the design and implementation of a pre-flight automated system for the "UVA-1 prototype Phoenix which is able to perform operations like landing, taking off, and autopilot. It can also transmit real time data through the use of a video camera with an electro-optical system; this feature contributes to the mission of surveillance and reconnaissance which is a responsibility of the nation's Defense area [8]. The Geographic Military Institute, which belongs to the Ecuadorian Army, is in charge of the nation's mapping service, and acquired a drone to "conduct research studies related to the geography and mapping of a specific zone in the Antarctica called Pedro Vicente Maldonado Station…" [9].

Based on what has been previously explained, it can be deducted that the use of drones in surveillance and reconnaissance missions is feasible, however, this technology is not applied with the frequency it should be by the Armed Forces. Some Ecuadorian universities have also centered new academic programs in this field by offering degrees in various areas associated to technology. Students who get their majors in these careers possess the necessary knowledge to design a software capable of controlling UAVs. The fact of having the opportunity to apply drones for military operations as well as the contribution of professionals in technological fields, are the main reasons of this research. It is aimed at the designing of control algorithms for static cameras and drones, which were modelled in Parrot Bebop 2 quadcopter, for efficient real-time people and objects detection.

This article has been structured in four sections: the first part is the introduction; the second, describes the process of capturing images; the third, presents the analysis and procedures for tracking implementation, additionally, it is briefly examined the applicability of drones for military operations. Finally, the research conclusions are presented in the last part of this work.

2 The Use of Computer Vision for Image Processing

The methodology applied for modelling the algorithms, used for the communication system as well as for the detection and tracking of the drone Parrot Bebop 2, is the Pre-Experimental design based on the design "One group Pre-test, Post-test". Several tests were done to determine the distance needed for proper robot operation. Visual Servoing (VS), also known as Vision-Based Robot Control, is the technique used during this research to monitor movements and actions of the drone [10]. A camera is employed to provide data related to the location of an object in relation to the collected image in order to control the robot's movements [11].

Through image-based visual servoing (IBVS) technique, the error is estimated among current and desired characteristics in the image plan; characteristics might be the coordinates of visual characteristics, lines, or regional moments [11].

For a precise recognition of the target that will be tracked, through a quadcopter type Dron Bebop 2, the following stages are considered: image acquisition, image preprocessing, noise reduction, segmentation, characteristics extraction, and recognition & interpretation.

The first step in the process of image capturing, is the implementation of (ROS) Robot Operating System which captures the image and saves it as a message format sensor_msgs/image. The use of the CvBridge library allows to change the format and convert it from ROS to OpenCv (cv:: Mat) [12]. The process is illustrated in Fig. 1.

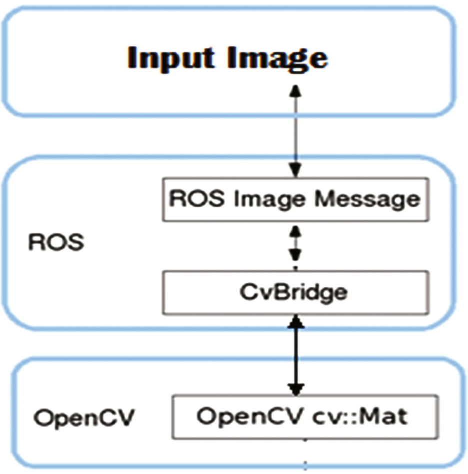

Fig. 1. Conversion process from ROS image to OpenCv image.

Once converted to OpenCv, this file allows the use of pre-trained classifiers and other resources such as specialized libraries in computer vision, the algorithm Histogram of Oriented gradients (HOG) among the most well-known [13]. It is based on the orientation of gradients within localized portions of an image. This image is divided into several cells which contain addresses of the gradient histogram or edge orientation pixel cells, as illustrated in Fig. 2.

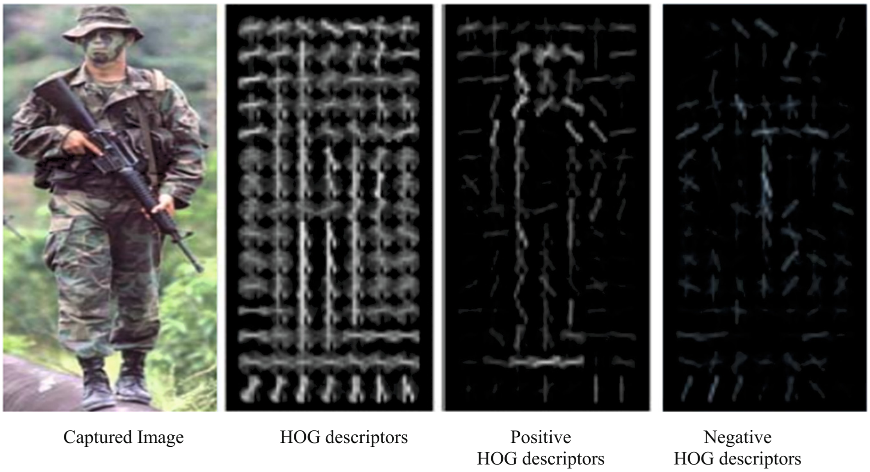

Fig. 2. Captured image and HOG feature descriptor.

HOG descriptors measure the intensity changes based on the borders of an image which are computed by calculating image gradients that capture contour and silhouette information of grayscale images.

It is convenient to standardize histogram values, to minimize the difference on image captions with the purpose of achieving similar gradient magnitudes in both images. Standardization is performed in zones called blocks (group cells). These blocks of standard descriptors are what the authors called HOG descriptors.

As a result of standardization, global values (gradients) of histograms are equal, therefore, the differences of values have been reduced to a final representation among similar images, obtaining a final descriptor [14].

Finally, standardized gradients on each portion of the image are used as input data for a classification system, Support Vector Machine (SVM), these sets of organized vectors in a n-dimensional space will build a separation hyperplane on that space, which is known as Support Vector Machine (SVM). Figure 3 shows the whole process from image capture to vector data storage.

It is considered that the best data classification tool is the hyperplane that maximizes the distance regarding the closest points. Being the support vectors the points which are close to the edge.

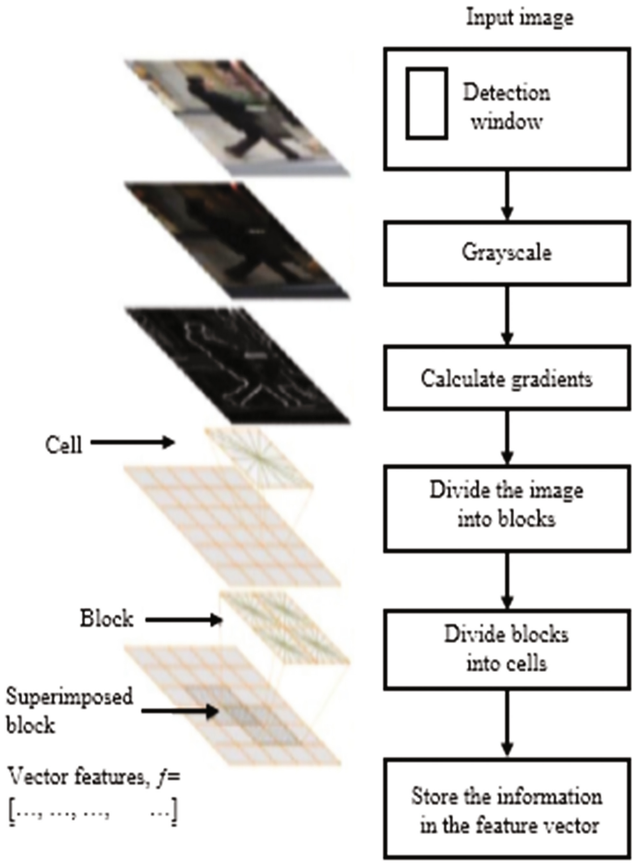

Fig. 3. Process of extraction, gradients calculation and characteristics storage.

The use of support vector machines, for detection, enables the separation of positive and negative class, this means that the data that corresponds to the *person* class are positive samples and the *non-person* class represents negative samples, as it is illustrated in Fig. 4.

The concept of optimal separation is where the fundamental characteristic of SVM is located; this type of algorithm allows the hyperplane to have the maximum distance (edge) with the points closer to them. In this way, the vector points are separated when they are labeled in a category on each side of the hyperplane.

In order to implement these categories, previous training of the machine is needed by providing it examples of persons or *positives* as well as examples of negatives or *non-persons.* Once the examples have been given during training, the algorithm of SVM classification elaborates a M-dimensional curve that divides both groups, obtaining the kernel (function that allows to convert a nonlinear classification problem in the original dimensional space to a simple linear classification problem in a greater dimensional space) of the machine.

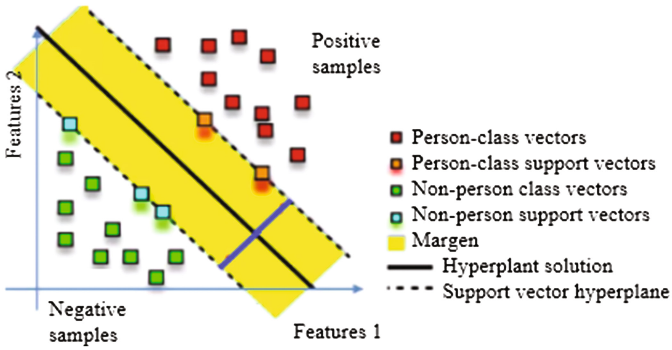

Fig. 4. Classification of samples person and non-person.

3 Tracking Implementation

A. Monitoring of persons or objects in a specific external environment.

For the tracking implementation ROS is employed, it includes packages for the development of applications: its main characteristic is coding reuse and development of robot applications. The package bebop_autonomy has communication controllers among the ROS platform and the Parrot Bebop2, the updated version is called parrot_arsdk [15].

The first step is to set up the package and the libraries, it is essential to create the *workspace* (working area) and the classification of the different packages. Once the package bebop_autonomy has been set up, it will be permitted the access to communicate and get data from various sensors of the Parrot Bebop 2, this includes sending commands to control the quadcopter. Complementarily, the files manisfest.xml and CMakeList.txt must be set up for the compilation that is done by the CMake.

The next step is the *launch* files setting, which are needed to execute effectively the nodes that have been created. In this research two launch files have been executed: (1) the first executes the *bebop_driver node*, opening the image flow from the camera of the quadcopter Parrot Bebop 2; and (2) the second the execution of the node for visualizing the user interface.

Then, the ROS system is executed to implement internal communication among the nodes through subscriptions and publications of topics that are in charge of transmitting and receiving data; in this case there must be communication between the nodes *bebop_driver* and *run_bebop*.

The subscriptions are used to receive information that is sent from the node: the video flow obtained from the camera of the quadcopter by using the topic called/ *bebop/image_raw* along with the position and the speed obtained from the topic/ *bebop/odom*. To these topics and some others is added the node *run_bebop* which receives all the necessary data required to be published in the user interface.

There are also the publishing nodes, these are in charge of sending data from the node *run_bebop* to the node *bebop_driver* which in this case will be commands for the quadcopter: for taking off is the topic/*bebop/takeoff* and for landing the topic/*bebop/land*.

The following step is the execution of the launch files through the terminal for the nodes activation and the communication between the quadcopter and the computer. Table 1 shows the control that can be sent to the quadcopter by using the keyboard of the manual control.

Table 1. Orders of the keyboard to control the debop 2.

Key	Command	Description
T	Take off	Send the order of taking off to the quadcopter
L	Landed	Send the order of landing to the quadcopter
R	Reset	Resets the parameters of the Bebop 2
F	Flattrim	Calibrates the camera in frontal position, in relation to the orientation of the Bebop 2
P	Permit tracking	Allows to start the manual mode
H	Home	Sends the order of going home

Considering that the system that flight tracking is in real time, images processing must be fast; taking this into consideration, it is used the resolution of 640 × 280 pixels to process data. Consequently, the control orders will be executed adequately at the moment of sending them to the drone for tracking, without delay as it may happen when using a higher resolution.

In Fig. 5, it is illustrated the visual field that will cover the frontal camera of the drone. Within this field, reference axis of the drone are established: roll (y axis) and throttle (z axis). Based on this, the body describes a continuous path that will occupy a position (y, z), being an irregular path due to the movement of the target as well as the drone when trying to track.

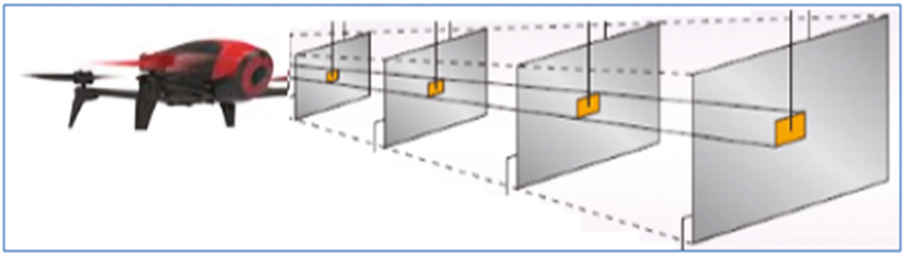

Fig. 5. Communication between nodes, subscription and publication of topics.

The most relevant aspect is the determination of the *position error*. During the tracking, the main objective is to locate and keep the body or object in the center of the received image, for that reason a new point is established in the center of the received image, this is (320; 240) which is illustrated in Fig. 6.

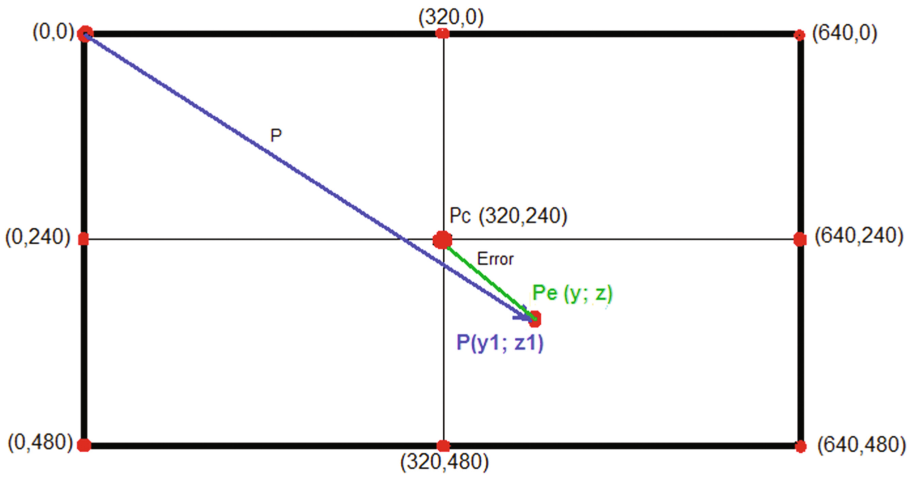

Fig. 6. Center point and position error

The following equation is used to determine the position error of the target in regard to the center of the camera.

$$Pe(y, z) = P(y1, z1) - Pc\,(320, 240) \tag{1}$$

Where, Pe = Calculation error point; *P* = Subject center point; *PC* = Image center point.

The position error calculated may show values within a range of ±320 pixels for the y axis (roll) and as for the z axis (throttle) it will be of ±240 pixels; as a result, a new point of origin in the center of the image will be created automatically.

Next, the *conversion of the position error at speed* takes place, and in order to fulfill this task, flight commands are published through topics (themes), in this case, it is used *cmd_vel*. The conversion of values related to position errors to speed values is done by scaling, in which 320 px is equal to −1 and −320 px and takes the value of 1. The mathematical expression is represented on the Eq. (2).

$$Vy = -\frac{Epy}{320} \tag{2}$$

When the target is located on the left border, the control command sends the maximum value of 1, so the drone moves left until the position of the body reaches the center of the visual field or set point. On the other hand, if the subject is located on the right border (320), it sends the maximum value of −1.

As for the pitch axis (x axis, depth), is a different kind of analysis, which is done by the compilation of the areas obtained from the target when it is positioned within the visual field at certain distance. Once the distance of the target is verified and safe for tracking, it is selected and the area is saved. The area is highlighted in the shape of a rectangle pointing the target, obtaining the maximum value of the area when the target is closer to the quadcopter, whereas, when the target moves off, the size of the area will decrease until reaching the maximum and minimum values of depth position.

To determine the maximum and minimum values of depth position, the reference area or set point can be established by using the Eq. (3).

$$Arefx = \frac{A_{max} - A_{min}}{2} + A_{min} \tag{3}$$

Where Arefx: reference area for the distance of the target; A_{max} = maximum detection area 60000px^2; A_{min} = maximum detection area 10000px^2.

When the target is close to the frontal camera and gets the maximum value of the area, the command value will be sent as −1, so the drone moves backwards. When the target moves off from the drone and gets the minimum value of the area, the command value will be sent as 1, so the drone moves forward directly to its target.

The values that make the drone moves forward or backwards can be obtained by using the following Eq. (4).

$$Vx = \left[\left(1 - \frac{Area}{Arefx}\right) * K\right] \tag{4}$$

K is a compensation constant which is obtained by tracking tests, it is applied in order to make the drone receive the adequate commands for throttle.

Once the previous activities have been achieved, the modelling of the quadcopter *Bebop 2* must be completed to establish the location of the quadcopter at any point in the space; its position must be established regarding a fixed reference point and its orientation about an inertial frame [16]. When the quadcopter moves on any of its axis, the turning speed of its rotors changes applying more or less force on these to reach the desired movement in throttle, yaw, pitch and roll.

To know the orientation of the quadcopter, the Euler angles must be obtained regarding C, being C the frame that indicates the rotation of the quadcopter on the tridimensional space [16]. Where Φ is the roll angle (rotation regarding Xb); θ is the pitch angle (rotation regarding Yb); Ψ is the yaw angle (rotation regarding Zb) [17]. See Fig. 7.

To get the C complete rotational matrix regarding I, the product of the three rotational matrices is calculated [18], getting as a result the rotation matrix of the C reference frame concerning the fixed reference frame I.

$$\boldsymbol{R_I^C} = \begin{bmatrix} \boldsymbol{cos\Psi cos\theta} & \boldsymbol{cos\ \Psi sen\ \theta sen\varnothing - sen\ \Psi cos\varnothing} & \boldsymbol{cos\Psi sen\theta cos\varnothing + sen\ \Psi sen\varnothing} \\ \boldsymbol{sen\Psi cos\theta} & \boldsymbol{sen\ \Psi sen\ \theta sen\varnothing - cos\ \Psi cos\ \varnothing} & \boldsymbol{sen\ \Psi sen\theta cos\ \varnothing + cos\ \Psi sen\varnothing} \\ \boldsymbol{-sen\theta} & \boldsymbol{cos\ \theta sen\ \varnothing} & \boldsymbol{cos\ \theta cos\ \varnothing} \end{bmatrix} \tag{5}$$

The mathematical modelling of a quadcopter expressed in the Eq. (5) shows that it can be decomposed into each of its axis to carry out the control and analysis respectively; in order to achieve this modeling has to be based on its state variables.

This system is similar to a variable-mass system without damping, which can be controlled by the input, having as a result the transfer function [19]. See Table 2.

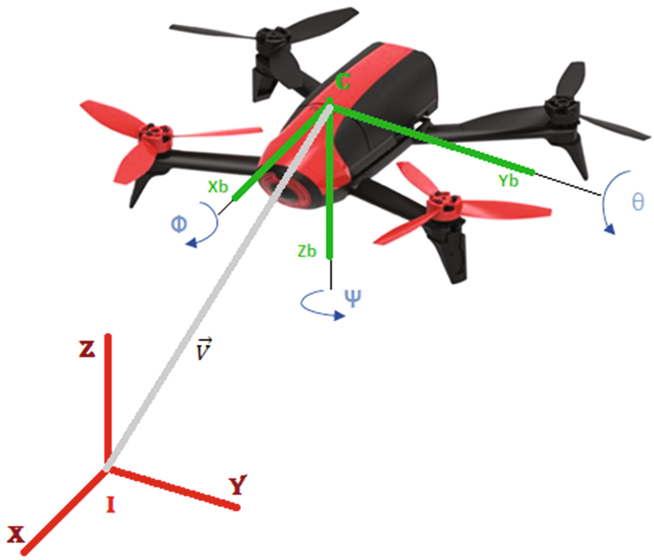

Fig. 7. Reference frames for modelling

Table 2. Keyboard commands to control debop 2

Axis	Transfer function
Throttle	$G(s) = \frac{1}{m.s^2}$
Pitch	$G(s) = \frac{l1}{I_x.s^2}$
Roll	$G(s) = \frac{l2}{I_y.s^2}$
Yaw	$G(s) = \frac{1}{I_z.s^2}$

Next, it is needed to calculate the quadcopter inertial matrix, which is done considering that it is symmetrical [20] according to Eq. (6).

$$\mathrm{I} = \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \tag{6}$$

The inertial calculation for each axis is the following:
X-axis

$$I_{x1} = I_{x3} = \frac{1}{12} m_m \left(I_y^2 + I_z^2\right) \qquad I_{x2} = I_{x4} = \frac{1}{12} m_m \left(I_y^2 + I_z^2\right) + m_m d_{cg}^2 \tag{6.1}$$
$$I_{xx} = 2I_{x1} + 2I_{x2}$$

Y-axis

$$I_{y2} = I_{y4} = \tfrac{1}{12} m_m \left(I_x^2 + I_z^2\right) \qquad I_{y1} = I_{y3} = \tfrac{1}{12} m_m \left(I_x^2 + I_z^2\right) + m_m d_{cg}^2$$
$$I_{yy} = 2I_{y1} + 2I_{y2} \tag{6.2}$$

Z-axis

$$I_{z1} = I_{z2} = I_{z3} = I_{z4} = \tfrac{1}{12} m_m (I_x^2 + I_y^2) + m_m d_{cg}^2$$
$$I_{zz} = 4I_{z1} \tag{6.3}$$

On Table 3 are presented the necessary inertial values to calculate the gain of the Proportional-integral-derivative (PID), when replaced in transfer functions of each axis from Table 2.

Table 3. Values to calculate inertia on different axis.

Variables	Values
Drone mass	0.536 kg
Motor mass (m_m)	0.04275 kg
Rotor length on X (I_x)	0.023 m
Rotor length on Y (I_y)	0.023 m
Rotor length on Z (I_z)	0.0113 m
Distance from the motor to the quadcopter's gravity center (d_{cg})	0.143 m

Once the quadcopter Bebop 2 modeling has been completed, and for having a more suitable result on flight, is recommendable to control each axis separately, in the case of roll and pitch the mathematical expression is the following.

Pitch Axis

$$G(s) = \frac{l1}{I_x.s^2} = \frac{0.114}{0.00175.s^2} \qquad fx(s) = \frac{0.3s^2 + 0.603s + 0.006}{s} \tag{7.1}$$

Roll Axis

$$G(s) = \frac{l2}{I_y.s^2} = \frac{0.088}{0.00175.s^2} \qquad fy(s) = \frac{0.12s^2 + 0.1206s + 0.0024}{s} \tag{7.2}$$

The easiest way to generate the controller is through a transfer function and then apply the Laplace transform [10]. Getting to the Eq. (8).

$$G(s) = K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s} \tag{8}$$

It is important to remember that the maximum values accepted by the quadcopter and that are managed by the bebop driver, fluctuate between −1 and 1, therefore, PID control cannot send higher values than the established.

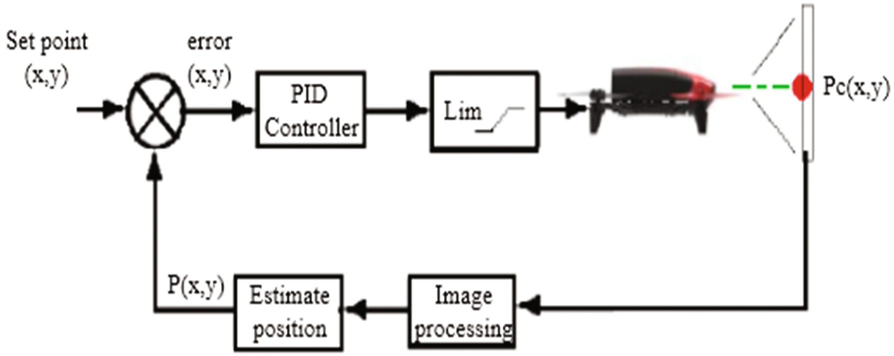

Fig. 8. PID Function Blocks of control diagram.

On Fig. 8, it is illustrated the quadcopter's control blocks diagram; the feedback is done with the obtained image processing since this one brings a point with coordinates and an area that are mandatory for the roll and throttle movement of the drone.

B. Use of drones for reconnaisance and surveillance of Military areas.

The important modernization process that is taking place among humanity, particularly in the Ecuadorian Army, has caused that its members show interest for technological innovation, advances that have forced the modification of the characteristics and management of military operations.

The use of drones to improve public safety is having more relevance, especially in border's control, illegal businesses, facilities surveillance and control of marine spaces.

The Armed Forces possess facilities in all the Ecuadorian territory and most of them are large areas that must be watched by military personnel, for this reason, several guard shifts must be conformed to satisfy this necessity. For example, the Jaramijo Naval Base is a warehouse where weapons and ammunitions of the Armed Forces are stored. The logistic support is ruled by manuals that specifies: the entry, exit, transport, storage, distribution, safety rules as well as removal processes in case of expired ammunitions to prevent accidents. There are also rules for the transportation of this material, these stipulates the vehicle characteristics for each kind of weapon and procedures for safety. There are precise policies for the storage and protection of weapons and ammunitions; in addition, these manuals described how war material must be stowed, labeled by color codes depending on the type of material, and its level of danger. [21].

The advantages of applying this study for surveillance missions of The Jaramijo Naval Base, which has about 11 thousand hectares, are the following:

- Planning Rounds in specific timetables.
- Ease access to dangerous or inaccessible places for human beings.
- Cover wide extensions of territory in a short period of time to achieve better search results.
- Risk reduction for human beings avoiding exposition to tasks considered as dangerous.

- Precision in detection, classification and tracking of people or objects in a limited environment in real time.
- Reduction of time in decision making processes.
- Considerable cost reduction on implementation of UAVs by using open software such as: Linux, ROS, OpenCv.

Optimal computer vision system for light and movement changes which enables the target tracking in low light environment.

4 Conclusions

Image processing for location and tracking of a person or object needs a great amount of technological resources, as much as memory and speed processing. The use of Robot Operating System (ROS) and the Parrot Bebop 2 Quadcopter on this research has represented considerable benefits; the most important, was the access to flight data which made easier the development of applications, and by having its own Wi-Fi signal, the programs were executed directly from the computer by sending commands and receiving different flight states.

When transforming the video image to OpenCv format, some characteristics were lost because of the way these were stored by ROS; due to the camera's resolution of the quadcopter Parrot Bebop 2, this loss was relative, therefore, it did not modify image processing and final results.

The use of HOG algorithm provided solid characteristics to support different light changes in non-controlled environment, and through the use of SVM classifier, to categorize person from non-person, was possible to detect targets effectively when it was applied in the control algorithms of the static camera and drone.

Once detected the person or object, commands in charge of flight control are sent, these are: taking off and landing as well as throttle and pitch movements. It is necessary to point that different tests (not included in this article) have been successfully applied. This fact guarantees the appropriate functioning of the mathematical model selected for this research.

The implementation of this technology would allow more control and coverage of the Armed Forces strategic assets. It would also optimize the resources and minimize the risk in Internal Defense operations including the monitoring of the state dependencies like the Presidential Palace or the National Assembly offices. The Air Force as responsible of the Ecuadorian airspace could implement this device to combat illegal acts on border controls such as: drug-trafficking, arms and explosives trafficking; illegal mining; clandestine drug laboratories.

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