Visual Control of an Autonomous Aerial Vehicle for Crop Inspection

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Resumen: *El presente trabajo muestra el control visual en un vehículo aéreo no tripulado para navegar a lo largo de las líneas en un campo de cultivo. El sistema integra un método de visión por computador basado en el concepto de texturas orientadas para determinar la orientación de las líneas de cultivo. El ángulo obtenido por el sistema de visión es la referencia para el control visual de modo que conduce a un conjunto de acciones sobre los motores del vehículo, así éste es orientado de forma paralela a las líneas. Finalmente el trabajo es complementado con el diseño y desarrollo de un planificador de trayectorias el cual determina la ruta de vuelo que asegure la cobertura total del campo a ser inspeccionado. Las pruebas realizadas por simulación han llevado a excelentes resultados en la navegación, lo que permite la realización de una retroalimentación en tiempo real desde el sistema de visión mediante el uso de un bucle de control y de esta manera tomar imágenes aéreas de buena calidad.*

Palabras clave: *Control Visual, Visión por computador, Procesamiento de Imágenes en Tiempo Real, Agricultura de Precisión.*

Abstract: *This paper presents a visual control applied on an unmanned aerial vehicle to navigate along the crop rows. The system integrates a computer vision method based on the oriented textures concept to determine the orientation of the crop rows. The angle obtained by the vision system is the reference for visual control, so that leads to a set of actions on the vehicle´s motors, so it is oriented in parallel to the rows. Finally the work is complemented with the design and development of a path planner which determines the flight plan that assures a whole cover of the field to be inspected. Results have been obtained by simulation, obtaining excellent responses in navigation, which allows realizing a real-time feedback from the vision system by using a control loop and in this good quality aerial images are attained.*

Keywords: *Visual Control, UAV, Computer Vision, Image Processing Real-Time, Precision Agriculture.*

1. INTRODUCTION

The concept of Precision Agriculture in the 80 listed in the U.S. as agricultural management adapted to the spatial and temporal variability of the crop. The implementation of a management accurate scheme requires the use of technologies to acquire information using Global Positioning Systems (GPS), sensors, satellite and aerial images together with Geographic Information Systems (GIS) to estimate, evaluate and understand the variations that occur along a crop. The information, which is collected from the crops, was used to evaluate aspects such as density, estimate fertilizers to crops, generation of risk maps and even to predict the level of production of the land.

The collection of technical information requires that experts go to the field and move trying to produce the least possible impact on the crop. Now, commercial crops have several acres (>4ha); therefore, sampling becomes costly and impractical in many cases. For this reason, the usage of an aircraft to perform the inspection or field data collections is highly valuable.

A camera mounted on an autonomous vehicle provides visual information (crops' images) very important for the management of a plot. The information collected in the field is focused on generating different types of maps. Thus, several crop aerial images are captured and integrated with mosaic process [1]; the success of this process depends directly on the quality of input images, i.e. minimum angular rotations and distortions geometric, that in small crops can be corrected with ground reference. However, for large areas of

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crop (> 4 ha) often is considered neither the rotation nor the distortion of the image, due to these techniques cause high percentage of error in the mosaic avoiding taking pictures with a high degree of overlap. It is enough to get images with a 60% overlap in advance (also called longitudinal or horizontal) and 30% lateral overlap (also called vertical). Ultimately, the map generation process becomes a tedious process and therefore costly.

Applications developed in agriculture based on image processing have a common operation whose goal is to separate the vegetal layer from other elements that appear on the image (bare soil, shades, straw, etc.). When it is needed to know the distribution of infestations, the pixels of the vegetation that belong to the weed must be distinguished, so we can find different approaches based on RGB color space [2],[3] and [4] and others working in the HSI color space [5],[6]. By combining various techniques [7] may be performed three textures segmentation (vegetal layer, ground and sky) by a fuzzy classifier unsupervised; in all cases shown, good results approaches for different types of crops and infestations.

By discriminating the vegetation layer in crop images, The information that distinguishes the crop line can be extracted, [8] taking advantage of the vertical orientation lines present in the images obtained in a plane parallel to the ground (overhead) with a tripod, achieving satisfactory results. In an alternative way, images are processed by a perspective acquired using a camera mounted on a tractor. In this case the image is affected by vibration and pitching of the vehicle due to uneven ground. To discriminate the crop line using the Hough transform with good results. In this paper, processed aerial images acquired from a camera mounted on an unmanned aerial vehicle (UAV), specifically a quadrotor Fig. 1. In this case the direction of the crop is obtained with an approach based on oriented texture analysis.

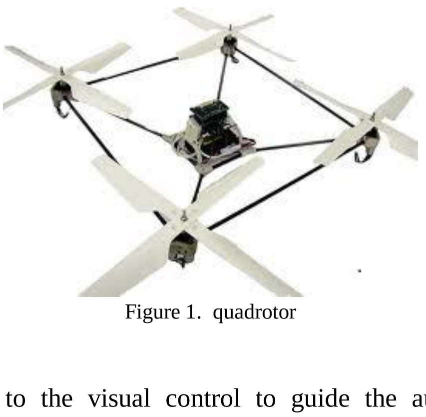

Figure 1. quadrotor

Regarding to the visual control to guide the autonomous vehicles, visual control techniques based on PID controllers can be used [5], [10] these techniques are applied on land vehicles of small size. In order to position and guide the vehicle autonomously so that it moves within the grooves established for transit. It is also possible to use other information from the vision system which [11] describes the self guided, based on a fuzzy visual inspection for commercial vehicles (Citroën C3). The vehicle follows a line painted on the ground with 49 fuzzy rules reaching speeds of 50 km / h. In the case of UAVs, control is very complex, because it is a multivariable nonlinear system naturally very unstable. It is therefore of great importance to have a reliable and robust controller [12]. Working with visual information for controlling speed, obtaining the absolute or relative position serves to control the orientation of the aerial robot. In [13], [14] visual control strategies are applied on a quadrotor to follow a 3-D object that has certain characteristics of color and form. In other work [15], [16] visual information is used to maintain altitude, takeoff and landing. In [17] performed a comprehensive review on the use of data from a computer vision system for controlling the movement of a robot providing taxonomy.

This paper presents the **design and development of visual control of a UAV based on visual discrimination** crop line structure as a guide for navigation. The camera is mounted on the vehicle. It discusses two general tasks: 1) obtaining the orientation angle of line structure in the crop aerial image taken with the camera on board (vision system) and 2) from the angle obtained by the vision system with information UAV sensors, generating the control actions on the UAV to navigate along the crop lines and according to the flight plan generated by a path planner. The ultimate goal is that the UAV cover the entire area to be inspected with a crop line-guided navigation.

The next section describes the problem and the proposed method for guided navigation crop line. Section 3 presents the design and development of visual control. Section 4 shows the experiments and results obtained. To conclude with Section 5 displays the most relevant conclusions of this work.

2. PROBLEM DESCRIPTION AND PROPOSED METHOD

The collection of images from a UAV of extensive cultivation areas to generate risk maps motivates the realization of a system able to obtain images that provide further analysis and integration on a map. Keep in mind that to generate risk maps are needed two types of operation on the pictures: 1) combining all the individual images collected form a single image (mosaic generation) and 2) the discrimination of vegetal layer, then distinguishing between weeds and crop.

2.1 Acquisition of images

When working with large areas crops, the collected images often imply a complicated integration task mosaic process, which is tedious and costly. The images acquired in an ordered manner facilitate the process of mosaic and even allow its full automation. In brief, the hypothesis is that navigation along the lines of crop will take all images with roughly the same orientation crop lines (approximately vertical to the base image or x axis). Thus the crop line can be used as ground reference to compose the total image and increase the overall accuracy of the generated maps.

2.2 Proposed method

As it was already mentioned the objective of this work is to develop visual control of a UAV to navigate along the crop lines. Fig. 2 displays a global scheme of the developed system. The system consists of two main tasks: 1) obtaining the signal input through perception, treatment and processing of the acquired image and 2) visual control or piloting the UAV taking into account the information provided by perception.

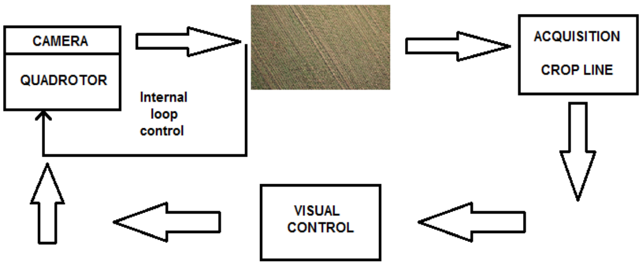

Figure 2. Overall system diagram

Crop lines can provide the necessary information to control the UAV and that it is placed in a flight path parallel to the crop. The idea is to achieve an organized sequence of snapshots and use the element in the crop line for mosaic generation process in order to automate the full procedure and improve the accuracy of the resulting map.

3. VISUAL CONTROL

3.1 Computer vision system

Crop lines orientation are obtained from an approach based on texture analysis where the input is the crop image grayscale. The grayscale image is obtained from the linear combination of the RGB channels, refer to (1). In Fig. 3 shows an example of an crop wheat image and in Fig. 4 one can see the image obtained by applying the linear combination with the values for the constants, r = -0884, g = 1.262 and b = -0311, given by [2] and obtained with an optimization method based on genetic algorithms.

Figure 3. Picture of a wheat crop

$$\mathrm{Im}G = r \times CanalR + g \times CanalG + b \times CanalB \qquad (1)$$

Figure 4. Grayscale image, refer to (1)

Then, the grayscale image is rescaled to a size of 320 x 320 pixels, in order to reduce the amount of information to be processed achieving greater connectivity between the crop rows. After, the image is applied to the gradient of the Gaussian (GOG). Specifically, the image is filtered with a Gaussian convolution kernel with a size 3 sigma (σ) is equal to 0.5 in order to obtain an image with smooth transitions between the edge of the lines and the ground, refer to (2) .

$$\nabla f(x,y) = \begin{bmatrix} \partial f(x,y)/\partial x \\ \partial f(x,y)/\partial y \end{bmatrix} = \begin{bmatrix} Gx \\ Gy \end{bmatrix} \qquad (1)$$

Thus, for each pixel (i,j) of the image the components "x" and "y" can be calculated. These components belong to the gradient vector, i.e. $G_x(i,j)$ and $G_y(i,j)$. In each pixel (i,j) gradient vector pointing in the direction of increasing the maximum possible intensity and gradient vector module corresponds to the amount of change of intensity in this direction. Then calculate the dominant angle from a texture polar gradient representation, refer to (3).

$$\theta_{nn} = \tan^{-1}\left(\frac{\sum_{i=1}^{i=N} \sum_{j=1}^{j=N} G(i,j)^2 \sin 2\theta_{(i,j)}}{\sum_{i=1}^{i=N} \sum_{j=1}^{j=N} G(i,j)^2 \cos 2\theta_{(i,j)}} \right) \Big/ 2 \qquad (2)$$

Where θ is the angle of orientation for a region (W) of NxN pixels in the image, such as $\theta_{nn} + (\pi/2)$, due to the calculated gradient is perpendicular to the direction of the lines.

Thus, taking the angle of orientation θ_{nn} in the region of analysis (W), data obtained by (3), and considering for each pixel (i,j) value gradient in magnitude $G(i,j)$ and orientation $\theta(i,j)$ can calculate the coherence index by flow orientation, refer to (4), i.e. projecting the gradient magnitude with its guidance on the unit vector in the direction of θ_{nn} and adding all the projections of each pixel.

$$\rho = \frac{\sum_{(i,j)\in W} \left\| G(i,j)\cos\left(\theta_{nn} - \theta_{(i,j)}\right) \right\|}{\sum_{(i,j)\in W} G(i,j)} \quad (3)$$

With the coherence measure flow guidance is possible to minimize the effects of disordered crop lines, giving more weight to the angles which regions have a high value.

Finally, we have considered three different strategies to calculate the overall angle of orientation in the image: 1) the angle of the region with the highest consistency index (E1 method) 2) the angle that is the weighted average of the local orientations maximum consistency index and all values not lower than 70% of the maximum (E2 method) and 3) finally the angle that is the weighted average of the central local orientations of the image (E3 method).

3.2 Flight control with visual feedback

Regarding to control, the aim is to design and develop a control strategy that allows the UAV navigate parallel to the lines of the crop. In this paper the UAV is a quadrotor. Fig. 5 shows the flight control architecture used in this work and based on the dynamic model defined for a quadrotor in [15], [16].

With information from onboard sensors and through interaction cascaded controllers maintaining the stability of the UAV in flight. The parameters of the PID controllers used are summarized in Table 1.

In this paper, both the quadrotor dynamic model as the flight control system has been implemented with Matlab Simulink tool. It was considered the computer control-quadrotor as a single block whose entries are the references to the quadrotor flight path and outputs the position and posture of the same. Consider the set has, among others, the advantage of being more flexible and easily allow the exchange platform flight.

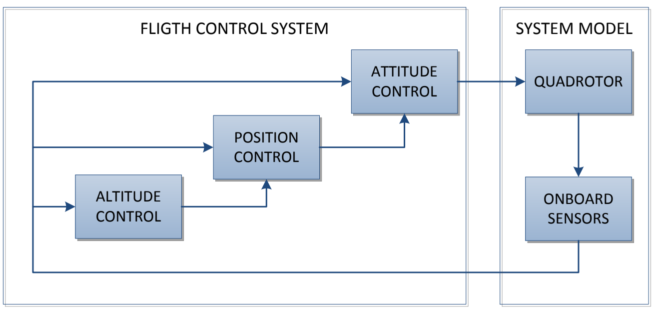

Figure 5. Flight control architecture implemented for the quadrotor

Table 1. Parameters of PID controllers for flight system

Description	Value
Roll PID Control Gain (proportional; derivative; integral)	(1; 0.2; 0.5)
Pitch PID Control Gain (proportional; derivative; integral)	(1; 0.2; 0.5)
Yaw PID Control Gain (proportional; derivative; integral)	(0.5; 0.5; 0.45)
X-axis PID Control Gain (proportional; derivative; integral)	(0.1; 1; 0)
Y-axis PID Control Gain (proportional; derivative; integral)	(0.1; 1; 0)
Z-axis PID Control Gain (proportional; derivative; integral)	(2.5; 5; 0)

It was also necessary to create a virtual world in order to check the response of the entire system, so we developed a 3-D environment in which integrated the quadrotor model and soil crop is represented on the which make the flight. It also included the ability to define and test lighting and a wide range of scenarios. For the generated virtual world was compatible with the implementation of the quadrotor model in Simulink, the block was used 3-D animation (VR Sink). Fig. 6 shows the quadrotor and configuration parameters, while Fig. 7 shows a developed view of the virtual world.

The virtual world is used to simulate the displacement of the quadrotor while the captured image is generated by the camera connected to the body of the UAV. The latter is the information used by the vision system to generate the signal that closes the control loop, in this case visual control. In short, the visual controller is responsible for guiding the quadrotor make for it to maintain its position parallel to the crop rows.

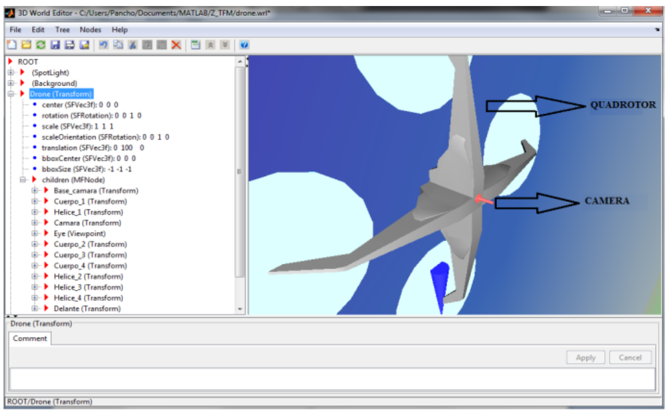

Figure 6. View quadrotor developed in world editor interface 3-D

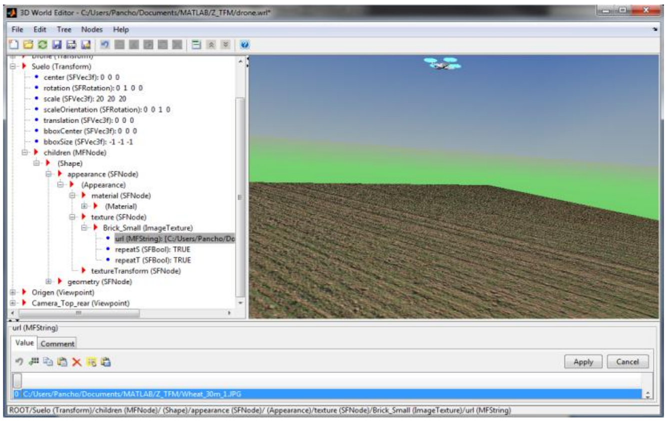
Figure 7. View virtual world developed in the world editor interface 3-D

Summarize the most important characteristics of the proposed control are: eye-in-hand camera configuration, watch and move dynamics and strategy of image-based visual control (IBVS).

Ultimately the strategy used is an indirect visual high level as the corresponding references are generated for the low-level controller (flight control) of quadrotor. Fig. 8 shows the architecture proposed visual control.

For flight control (inner loop) is considered an autonomous flight at low speed (5m/s) with constant height, while visual control (outer loop) the vision system provides the orientation angle of the crop lines over the UAV. Fig. 9 shows how to adjust the relative position of the quadrotor with respect to the lines.

Due to the versatility of the vision algorithm can be used as visual controller a PID classical architecture. Proportional parameters, derivative and integral are: 0.5, 0.5, and 0.45 respectively, these values are adjusted by a trial and error procedure.

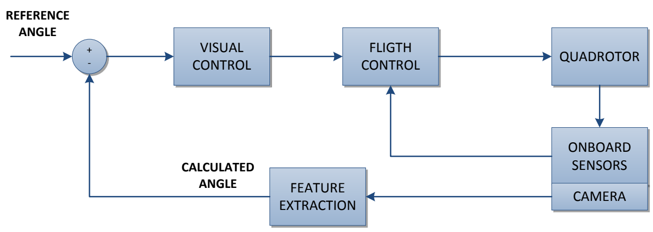

Figure 8. Visual control scheme

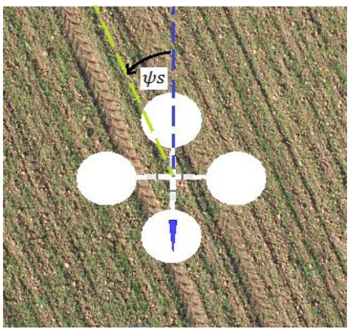

Figure 9. Direction of rotation on the UAV with visual control

It is also included a Kalman Filter to mitigate the effect on sharp turns camera on quadrotor orientation movements because the dynamics of the system. By toolbox of computer vision systems can be implemented in Simulink the Kalman Filter from the value of the variance of the test measurement, which is 0.0051. Thus, the filter can predict future states and minimizing the error optimally. Also sharp variations in the motion of the UAV are minimized.

After guiding the UAV resolved parallel to the lines of culture, a path planning was developed, which ensures that the quadrotor perform a full coverage of the area to explore/inspect.

The developed planner preliminary receives information as input like the shape and dimensions of the field, namely the vertices of a polygon in UTM, and some other features of the camera such as resolution and field of view. With this information the strategy followed by full coverage of the area to be inspected is:

- Location of the quadrotor at constant height, knowing his position (P0).
- Guidance on the initial point P0 of quadrotor placing it parallel to the crop rows.
- Calculation of the path to navigate from the initial position to the final position (Pf), which is the closest border edge of farm field in the direction of the crop rows.
- Rotate and displacement of quadrotor, considering an area of overlap so that the camera does not lose visual information from the crop field in the return path.
- Checking termination condition. If it has reached full coverage of the area to inspect the flight ends and otherwise the process is repeated along the lines of crop to reach the opposite side of the crop edge.

4. EXPERIMENTS AND RESULTS

There have been two types of experiments in order to analyze the system developed from two perspectives: 1) the operation of the vision system and 2) visual control operation with integrated vision system.

In the part of perception, yet tested considering the three proposed strategies based on flow orientation coherence, namely: 1) E1-making the best candidate that represents the overall direction of image cropping, 2) E2-making the best candidate and not lower than 70% of the value of the best candidate, and 3) E3 - considers only the central part of the image. In the study we used a repository of 308 wheat crop images, resolution 1280x960 pixels that collect a variety of possible situations, for example with other land borders, thin vegetation regions, regions with poor stands excess grass or tractor ruts. It should be noted that the crop line spacing is 15 cm. For each of the images from the repository was manually defined ground truth, i.e. actual crop orientation.

Table 2 summarizes the results obtained with the proposed approach showing the mean square error (MSE) with respect to ground truth expressed in degrees and the required processing time in milliseconds.

Table 2. Results for the three strategies

	E1 Method	E2 Method	E3 Method
Mean Square Error (°)	4.38	4.11	4.15
Average processing time (ms)	64.4	65.2	66.8

Examining Table 2, the E2 method is the best results supplied with MSE of 4.11° and a response time that can process approximately 15 frames per second. In Fig. 10 one can find the error obtained for each image and in Fig. 11 the processing time.

In Fig. 10 shows that the maximum absolute error ranges approximately 15 ° which are the cases in which culture lines are not continuous due to errors in the planting and also shows that the minimum absolute errors are close at 0 °, which is generally satisfactory considering the wide range of images used for the tests.

In Fig. 11 shows that the maximum processing time per image is about 90 milliseconds and the minimum is around 55 milliseconds, which means that it can process at least 11 frames per second.

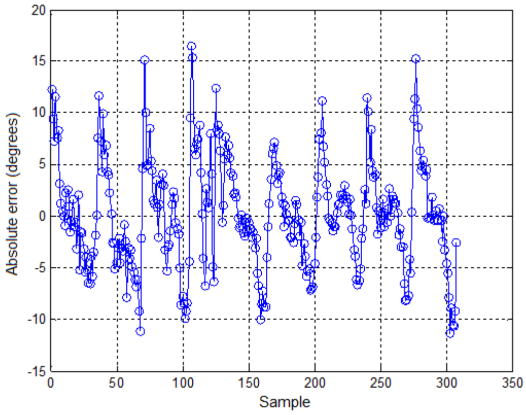

Figure 10. Absolute error using the E2 method

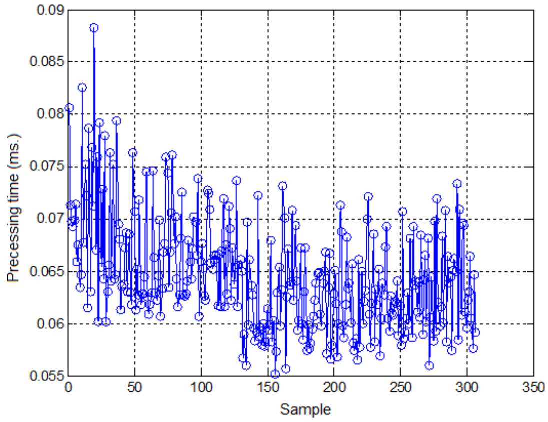

Figure 11. Processing time using the E2 method

As it is stated in E2 method visual control is integrated with the vision system and joined the path planning, two scenarios are analyzed exploring a wheat crop by simulation, one to 30 meters high and over 100 meters in height.

To analyze visual control operation yielded the highest percentages of errors, one on 30 meters has 8.80% and one on 100 meters 9.68%. Even with these errors, due to the actions executed control is achieved by capturing aerial images in a plane parallel to the direction or trend of crop lines. In Fig. 12 are shown on the right side aerial images captured by the camera at two different times and in close proximity.

To reach the end point of the line which coincides with the crop edge rotation phase begins, where it is considered a visual overlap area to prevent the loss of information from the crop field as shown in Fig. 13.

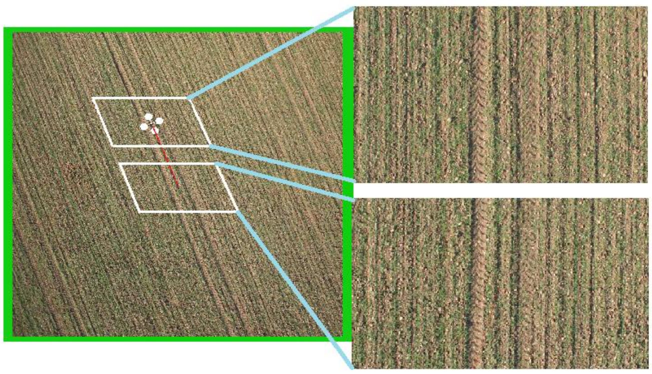

Figure 12. Quadrotor navigation on the farm field. Close view

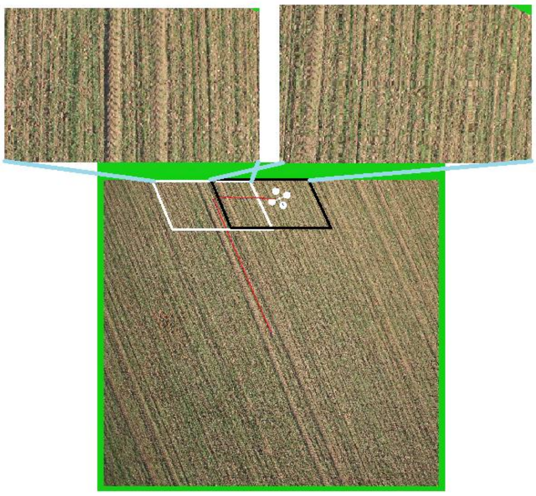

Figure 13. Quadrotor navigation on the farm field. Turning operation overlap

The references generated by the trajectory planner, Fig. 14 shows the path traveled by the quadrotor during scanning of the crop needs successfully completing navigate a constant height parallel to the cultivation lines, plus the properly executed swing action.

Also in Fig. 15, it shows the value of the rotation angles which determine the position of quadrotor during the various stages that execute the scan job. Shows two moments (about 1s, 30s and 43s) coinciding with the beginning of the navigation and the change line rotation in which pitch and roll angles have a high value since this depends on the UAV move in a given direction in the XY plane. In other periods can be seen that these angles take a very low value allowing certain stability in the chamber and therefore the optimal imaging during navigation air parallel to the crop lines.

Figure 14. Quadrotor navigation task on wheat crop field

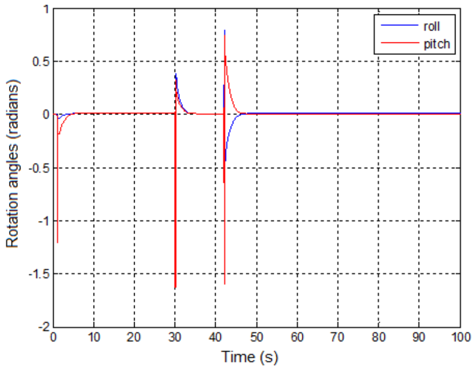

Figure 15. Rotation angles defining the movement in the XY plane

Finally, Fig. 16 shows the visual control response to the reference given in the scan job. In other words, the UAV is maintaining its angle of orientation (yaw) in parallel with the crop lines while it is moving on the plane flight maintaining constant height.

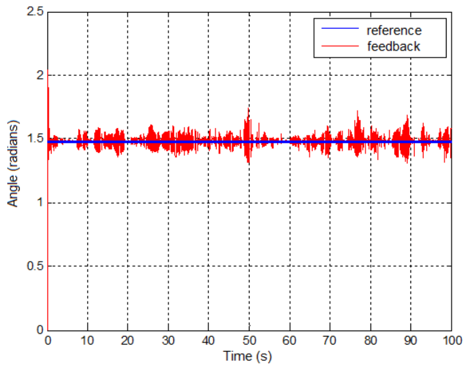

Figure 16. Visual Response Control

5. CONCLUSION

This paper presents the design and development of visual control of a UAV in order to navigate it in the direction of the crop lines through a computer vision system that takes care of finding the angle of orientation of these lines. It has solved the problem of detecting the orientation angle of the wheat breeding lines in an image captured by a camera mounted on a quadrotor. Three methods have been proposed for the vision system (E1, E2, E3) that operate in a similar fashion when there is little vegetal layer regions or areas with weed stands, resulting in a mean square error of approximately 4.21° and a response which can process approximately 15 frames per second. When the quadrotor explores the culture using visual information how navigational guidance has a maximum error of 9.68% on the actual angle presenting crop lines. This result is satisfactory because in the aerial images captured have a perpendicular orientation of the crop rows relative to the base of the image, and this is expected to improve the mosaic process.

Perception problem is more complex in wheat crops because the line spacing seed is small (15cm) which greatly hinders the operations to perform on the image. Also, the fact that the aerial images taken at high elevations (>100m) depend on the resolution of the camera, but this behavior is desirable and necessary, since the quadrotor has little energy independence so the aerial shot at higher heights implies a greater coverage of the crop in less time. Finally it is proposed a scheme for modular simulation in which all parts are easily modified to replace each module allows simple and thus flight test different platforms, control strategies, or other scanning modes.

The results obtained allow proposing as future work the generalization of vision algorithm corn and sunflower, which have a different planting pattern of wheat with greater separation between crop rows.

REFERENCES

[1] D. Gómez-Candón, S. Labbé, M. Jurado-Expósito, J. M. Peña-Barragán, G. Rabatel, F. López-Granados, "How the spatial resolution can affect the quality of mosaics and assessment of optimum number of tie points necessary to obtain good quality images", RHEA-2011 Robotics and Associated High-Technologies and Equipment for Agriculture, pp. 61-72, 2011.

[2] X. P. Burgos-Artizzu, A. Ribeiro, A. Tellaeche, G. Pajares. "Optimisation of natural images processing using different evolutionary algorithms", 2008 IEEE CONGRESS ON EVOLUTIONARY COMPUTATION 1-8, pp. 1268-1275. 2008.

[3] A. Tellaeche, X. P. Burgos-Artizzu, G. Pajares, A. Ribeiro. "A vision-based classifier in precision agriculture combining bayes and support vector machines", Intelligent Signal Processing 2007 (WISP) IEEE International Symposium on, pp. 1-6. 2007.

[4] Li Chen, Jin-Guo Zhang, Hai-Feng Su, Wei Guo. "Weed identification method based on probabilistic neural network in the corn seedlings field", Proceedings of the Ninth International Conference on Machine Learning and Cybernetics 3, pp. 1528-1531. 2010.

[5] R. Gottschalk, X. P. Burgos-Artizzu, A. Ribeiro, G. Pajares, A. Sainchez-Miralles. "Real-time image processing for the guidance of a small agricultural field inspection vehicle", 15th International conference on Mechatronics and Machine Vision in Practice (M2VIP08) 2-4, pp. 493-498. 2008.

[6] W. Lanlan, W. Youxian. "Application of support vector machine for identifying single corn/weed seedling in fields using shape parameters", Information Science and Engineering (ICISE) 2010 2nd International Conference on, pp. 1-4. 2010.

[7] M. Guijarro, G. Pajares, I. Riomoros, P. J. Herrera, X. P. Burgos Artizzu, A. Ribeiro, "Automatic segmentation of relevant textures in agricultural Images", Computers and Electronics in Agriculture 75, pp. 75-83. 2011.

[8] A. Ribeiro, C. Fernández-Quintanilla, J. Barroso, M.C. García-Alegre. "Development of an image analysis system for estimation of weed", Proceedings 5th European Conf. On Precision Agriculture (5ECPA), pp. 169–174. 2005.

[9] J. Barreda. "Seguimiento visual de líneas de cultivo", Universidad de Murcia, Tutores: Ángela Ribeiro y Alberto Ruiz, España. 2009

[10] J. Conesa-Muñoz, R. Gottschalk, X. P. Burgos-Artizzu, A. Ribeiro. "Método de detección visual de líneas de cultivo para el control en dirección de vehículos agrícolas", Conferencia de la Asociación Española para la Inteligencia Artificial (CAEPIA) 2011. Workshop: Computer Vision in Natural Environments: agriculture and forestry (CVNE). Universidad de la Laguna. 2011.

[11] M. A. Olivares-Mendez, I. Mellado, P. Campoy, I. F. Mondragon, C. Martinez, "A visual AGV-Urban car using fuzzy control". Automation, Robotics and Applications (ICARA), 2011 5th International Conference on, pp. 145-150. 2011.

[12] L. Mejías, "Control visual de un vehículo aéreo autónomo usando detección y seguimiento de características en espacios exteriores", Universidad Politécnica de Madrid, España. 2006.

[13] I. F. Mondragón, P. Campoy, J. F. Correa, L. Mejias, "Visual model feature tracking for UAV control". Intelligent Signal Processing. WISP 2007. IEEE International Symposium on, pp. 1-6. 2007.

[14] I. F. Mondragón, P. Campoy, M. A. Olivares-Mendez, C. Martinez, "3D Object following based on visual information for unmanned aerial vehicles". Robotics Symposium, 2011 IEEE IX Latin American and IEEE Colombian Conference on Automatic Control and Industry Applications (LARC), pp. 1-7. 2011.

[15] R. W. Beard, "Quadrotor dynamics and control", Brigham Young University. 2008.

[16] J. D. Colorado, "Towards miniature MAV autonomous flight: a modeling & control approach". Universidad Politécnica de Madrid. España. 2009.

[17] B. Siciliano, O. Khatib (eds). Springer Handbook of Robotics. Springer, Berlin, Heidelberg, Ch. 24, pp. 563–583. 2008.