Study of Approach Trajectories by Image Recognition System Based on Artificial Intelligence

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***Abstract*—This paper proposes a pioneering method to calculate the position of an aircraft in order to provide support during the landing process. Mainly, images are obtained thanks to an onboard camera and the position regarding the runway is calculated after analysing said images using artificial intelligent and digital image processing techniques. The experimental results indicate that the proposed method is capable to successfully recognize the aircraft position with sufficient accuracy. Furthermore, a PID control system has been developed to correct the deviation with respect to the glide path using as input the position given by the images. Both position problem and glide-path-correcting problem have been studied in an uncoupled way. For that reason, to test the PID control system has been implemented a virtual-geometrical runway which simulates the motion of the airplane in response of the PID output.**

Keywords—Landing process; Image Recognition; Artificial Intelligence;

I. INTRODUCTION

Although artificial intelligence and image recognition are techniques that are now emerging in aeronautics, these are being widely used in industries such as the automotive industry. Autonomous vehicles have received more attention in recent years due to the promising potential of reducing traffics accidents and transportation fares. Thus, the safe autonomous driving must be guaranteed by achieving high performances of the auto-driver modules. Many researchers have implemented and modified these modules with impressive results such as localization, path planning, motion control and detecting-tracking of surrounding obstacles. The last module is very important to attain safety as it affects the frameworks of the other modules. The drivable path is generated based on the detected objects in the surrounding environment [1][2].

To illustrate the importance of the development of self-driving capabilities Google's self-driving car is going to be used as example. Google's self-driving car project began in 2009 and transitioned to its own business entity -Waymo- in 2016. Waymo drove over 750K kilometres in autonomous mode in 2016. From a hardware perspective, Waymo's self-driving technology is divided into three key areas: sensing, compute, and embedded control. The sensors send their information to a high-performance computer. The computer fuses, processes, and interprets the sensor data, ultimately generating trajectories that the vehicle must follow. Sensor used to recognize the surrounding environment are Radar to calculate speed, LiDAR in order to calculate distances and Cameras for the purpose of recognize obstacles in the path [2].

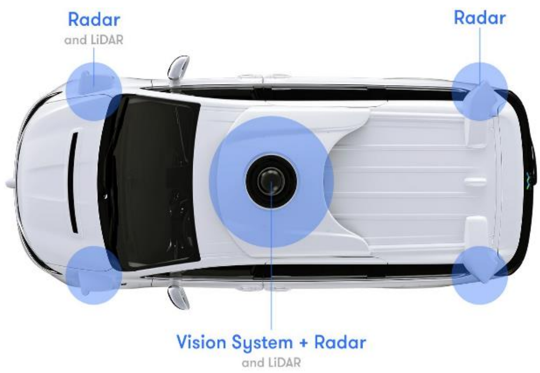

Fig. 1. Sensors on Waymo's self-driving cars

For these reasons, in view of the outstanding development in automotive industry towards a self-driving industry, this paper tries to serve as a first step towards a more autonomous aeronautical industry through the development of a state-of-the-art landing system using new methods such as image recognition and artificial intelligence that are currently being used in automotive industry. The method is proposed follow the work flow shown in Fig. 2.

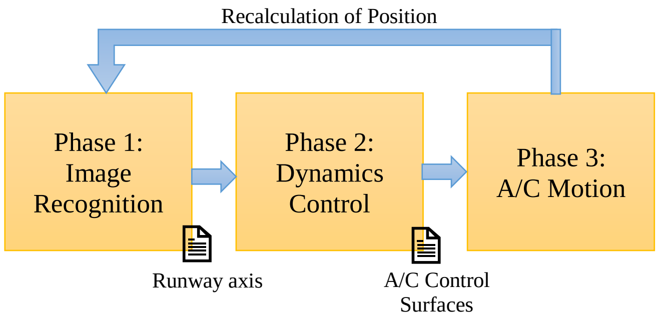

Fig. 2. Work flow from image recognition to A/C motion.

Next sections dive into the image recognition and dynamics control problems.

II. Image Recognition Process

The aim of this stage is to calculate the position of the runway edge with the most accuracy possible for every single frame taken with a camera onboard in real time. This position will be given by the deviation angle respect to the runway edge, α (Fig.3.b). This information will be used for the PID control system to correct the position of the A/C in order to optimize the glide path. As a first step, some assumptions have been done in order to obtain the position.

i. There is no yaw angle ($\Psi = 0°$);

ii. Camera is fixed to the aircraft.

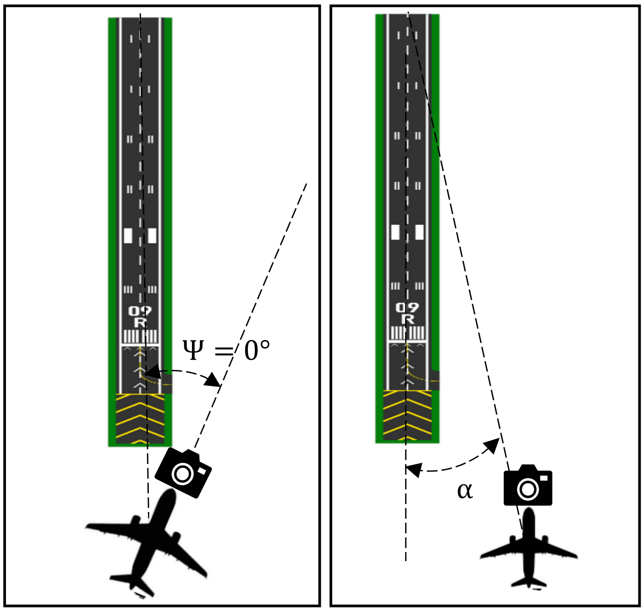

Fig. 4. Outline of the position problem.

The assumptions used to calculate the position and the desired angle (α) are shown in Fig.3. These assumptions have been taken to study a one-degree-of-freedom problem where the position is defined with the α angle.

This angle has been calculated using image processing techniques to the images taken with the camera onboard. The algorithm developed to process such as images is detailed in the lines below according with work flow shown in Fig.4.

A. *Original Image*

Firstly, a camera onboard is taken picture in real time. Each RGB image is stored as an *m*-by-*n*-by-3 data array that defines red, green, and blue colour components for each individual pixel.

B. *Grey Scale Image*

As it is explained in the previous paragraph each frame is an *m*-by-*n*-by-3 data array. Thus, working with this kind of images implicate so much time. For that reason, it is necessary to change the original image to a grey scale format where the picture is defined as *m*-by-*n* matrix that define the intensity of the black and white given a value between 0 (black) and 255 (white). Hence, the processing time was to a third of the initial time.

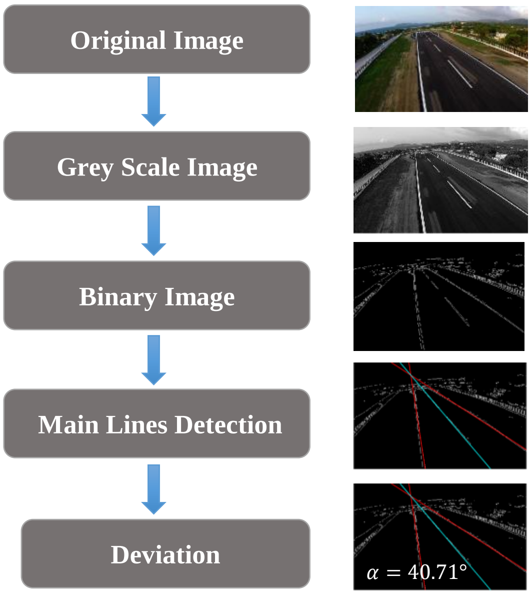

Fig. 3. Work flow to calculate the deviation angle

Before identifying runway boundaries, it is important to analyse runway characteristics. The characteristics of runway images are:

a. Grey value is higher on the runway edges when compared to the scenery around and runway neighbourhood.

b. The runway border lines appear to be two continuous straight lines inclined at a particular angle.

The first characteristic of the runway favours edge detection technique to be used on the runway image [3]. Once the edges of the objects in the image are detected, the second feature favours straight line detection to be used on the edge detected image.

C. *Binary Image*

In order to adapt the picture to the next step (Main Lines Detection) another change of format is required. On this occasion, the format change needed is to Binary format. Binary format, also called bi-level format, stores each pixel as a single bit i.e., a 0 or 1. A threshold to calculate which pixels form the Grey Scale Image will be black and which will be white is used. This threshold is calculated using the MATLAB function *graythresh* which uses Otsu's method. Otsu's method appears more appropriate in its scenario, since the interest region is only the runway edges and not the surroundings. Otsu's method chooses the threshold value in such a way that the intra-class variance of black and white pixels is minimized [4].

D. *Main Line Detection*

Once the image is in binary format, having optimized the threshold, applying a boundary detection filter is required to gain insight into the object that there are around the runway.

After trying many algorithms, Sobel algorithm has been chosen for this task. [5] According to the runway characteristics detailed in *B. Grey Scale Image*, the runway border lines appear to be two continuous straight lines inclined at a particular angle. Thus, enhanced image containing only the runway edge information is subjected to Line Detection Techniques to extract the pair of lines representing the runway boundaries.

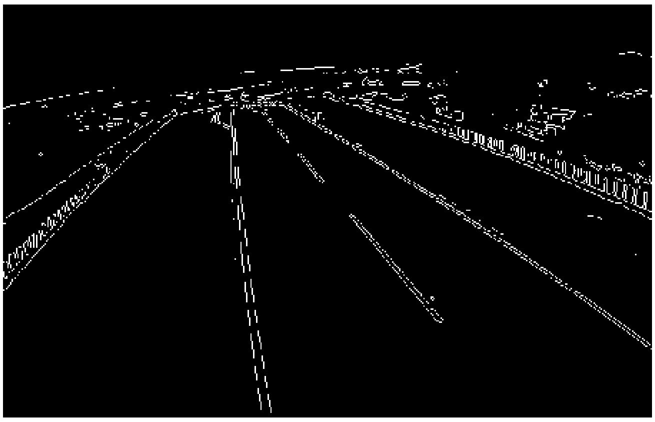

Fig. 5. Image after applying Sobel algorithm

Once the runway boundaries are roughly obtained, like is shown in Fig.5, straight line detection is performed, considering the runway edges to be a pair of straight lines in some orientation. The runway boundaries are considered to be oriented vertically, horizontally or approximately around 45° or -45° during approach.

Hough Transform is a robust method used to extract arbitrary shapes, such as lines, circles, ellipses, out of an image [6][7]. It is extensively used to detect straight lines, with the unique ability of detecting even disjoint line segments [7][8][9][10]. Hough Transform approach is:

1. Straight lines with coordinates (r1, c1) and (r2, c2) are assumed to be parameterized in the form

$$\rho = x cos\theta + y sin\theta, \quad (1)$$

   where ρ is the perpendicular distance from image origin and θ is the angle with a normal to the line from the origin as shown in Fig.6.

2. The Hough transform generates a parameter space matrix whose rows and columns correspond to ρ and θ values respectively. In a Hough space, lines are mapped to a point such that a point represents all possible lines through that point.

3. This way, all contiguous edges are transformed to straight lines that could pass through a particular point in Hough space. Peak values are points in this space which represent the longest lines in the image

4. In order to extract peaks pertaining to runway boundaries, θ values which satisfy the below criteria are only considered for the line extraction [11].

   a. During approach and landing i.e. when the aircraft is approximately aligned to the centre of the runway, the runway boundaries would be well within 45° and -45°. Hence, Hough peaks of lines outside this range are eliminated.

   b. Further, the two runway edges appear parallel in the image. Hough space matrix is searched for theta values with opposite peak pairs representing a runway (e.g. +25° and -25°). In order to consider the fact that the aircraft may not be exactly aligned to the centre of runway during approach, ±10° deviation is allowed in the pair angles (e.g. +25° and -25°±10°). Each opposite peak pair corresponds to a line pair.

5. To proceed with line segment detection, pair angles were considered. Coordinates of the line segments corresponding to the filtered theta values are obtained and drawn as runway boundaries over the original runway image.

The implementation of the Hough Transform in the developed algorithm has been done using the function *hough* of MATLAB.

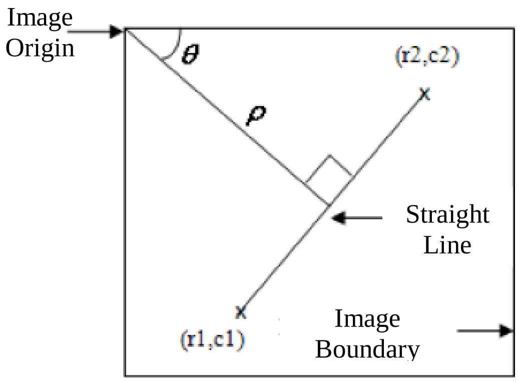

Fig. 6 Hough coordinate system

E. Deviation

After the previous step, the deviation angle can be easily calculated. Once the runway boundaries are known, the runway edge will be the bisector of the two runway boundaries like can be shown in Fig.7.

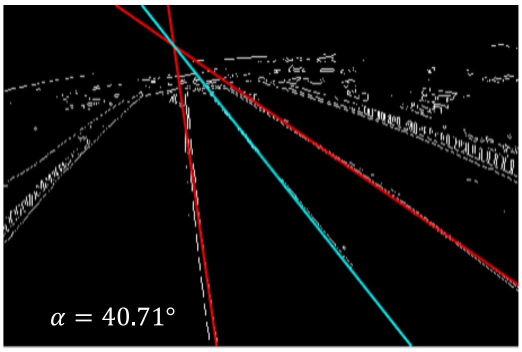

Fig. 7. Deviation angle calculation

F. *Real Time Processing*

Next step was real time processing. After optimizing the algorithm, it is possible to use it to obtain information in real time. In order to check the algorithm is able to process videos in real time, an experimental setup was necessary to obtain a video that could be processed. Some frames of the video have been shown in Fig. 8. as an example of the outstanding performance of this innovative project.

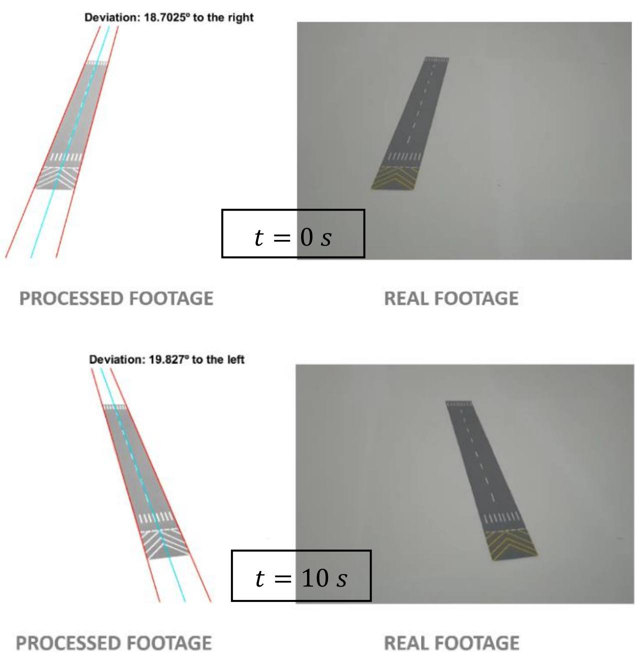

Fig. 8. Algorithm applied to a video

III. Dynamics Control

The aim of this part of the project is to correct the position of the aircraft during the landing process to be always in the glide path. So far, this paper has been focussed on obtaining the position of an aircraft with respect to the glide path. From now on, the idea of this paper will be focus on using such position as an input to correct the deviation from the glide path as appears in the following scheme shown in Fig. 2.

Due to the high processing capacity that requires to recognize a frame given by the camera, apply the controller to that specific situation and give orders to the aircraft control surfaces to correct the position practically on live, an equivalent geometrical law was set as assumption to replace the image recognition and flight dynamics steps. A scheme of the simplified process is shown in Fig. 9.

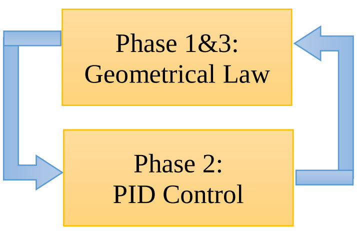

Fig. 9. Work flow of the Dynamics Control

In order to correct the deviation from the glide path, a PID control system has been implemented. The reason why a PID has been used and not another control system resides in the fact that to accomplish the path correction in a more efficient way, an underdamped movement has to be avoided. In that case, with a PID control system it is easily possible to correct the deviation from the glide path with an overdamped movement, avoiding being oscillating on the glide path.

One typical case was simulated as an example to prove the performance of the proposed solution. The initial conditions of this manoeuvre are:

- Transversal distance: 1000 m
- Distance from Runway: 6000 m
- Height: 165 m

How the position of an aircraft changes with this PID until achieves the desired path, taken into account the geometrical law imposed, is shown in Fig. 10.

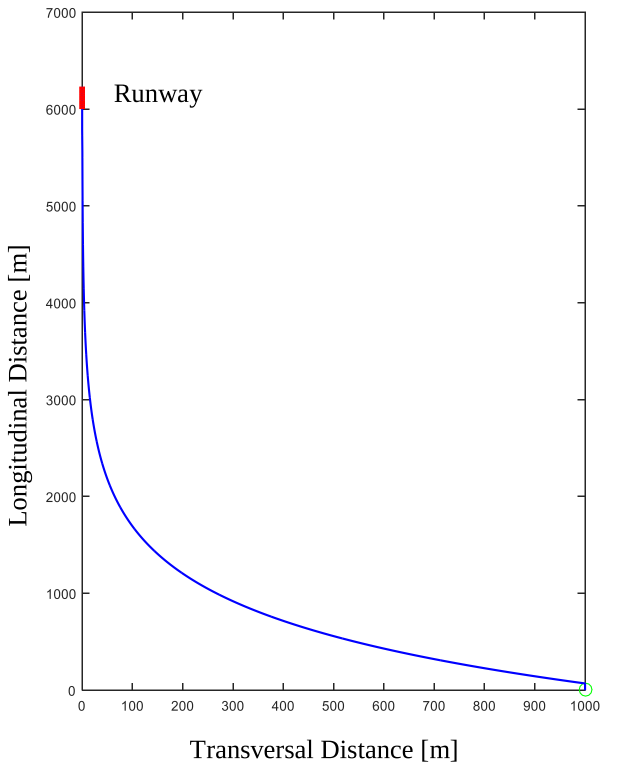

Fig. 10. PID Control System correcting deviation from the glide path

With all that, the position of the aircraft is changed in 85 seconds, accomplishing a successful landing.

IV. Conclusions

In this paper has been shown that a new landing system is possible thanks to the use of new cutting-edge technologies that are currently been used in other industries like automotive obtaining outstanding results. Increasing the use of new ground-breaking technologies, not only is possible to improve the approximation of the aircrafts to the runway but also changes aeronautics like we have known thus far.

This is the first step of a long journey until everyone can see this system implanted in the aircraft. For these reasons, with the aim of accomplish the implementation of this landing system in aeronautics, the following fields of studies are proposed:

- Integration of both stages: On the Phase 1, the runway is recognized but there is no control of the position of the aircraft. On the other hand, in the Phase 2 there is this control, but the runway is given by geometrical laws. Thus, the integration of both phases is proposed as the next step to continue with the development of this pioneering project.

- Improvement in the image process with Artificial Intelligence: Using Artificial Intelligent the accuracy with which the deviation with respect the glide path is calculated would have a remarkable improvement.

- Obstacle/Taxiway identification: This idea could be used not only in the landing process but also in other aeronautics applications like the recognition of obstacles near to the trajectory of the aircraft or supporting aircrafts detecting the main lines during the taxiway.

- Cameras working like autonomous TCAS: Related with the previews point, if detecting a foreign object is possible, for instance, another aircraft, this system could provide an autonomous TCAS which has no relationship with other airplanes.

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