A PRACTICAL UAV CAMERA BASED PILOTING SYSTEM

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Abstract. *The task of remotely piloting an unmanned aerial vehicle can be very hard, mainly if there is a particularly demanding mission to be accomplished by the remote operator. This paper presents a method to decrease the remote operator workload when piloting the UAV, thereby enabling the efforts to be focused on performing the mission. This method uses an onboard PTZ camera as a way to guide the UAV. The remote operator does not manipulate the piloting joystick as usual. Instead, he manipulates the camera joystick. The camera gimbal position is used to calculate references for an autopilot system. Two different strategies of guidance are addressed: in the first, the remote operator moves the gimbal pointing to the desired heading; in the second, the remote operator points the gimbal to an image point, which will then be circulated by the UAV. The system was evaluated through software-in-the-loop simulation, by using Matlab/Simulink for calculations and Flight Gear for visualization, exhibiting good performance and robustness to noise in the sensors. Experiments with hardware-in-the-loop were also carried out, indicating that the proposed method can be used in practical situations.*

Keywords: *UAV, camera guided, gimbal, autopilot, heading control*

1. INTRODUCTION

The demand for use of unmanned air vehicles (UAV's) has increased in the last decade. Related to this demand, there is the growing need for implementing systems which are easy to operate. The task of remotely piloting the UAV can be very hard, since the human remote operator is separated from the vehicle and this can lead to considerable control related difficulties. Furthermore, as the usage and complexity of UAV´s increase, no specific operator piloting skills are required anymore, due to the autonomy level reached by the UAV's systems. In this context, the piloting issues should de deemphasized, thereby releasing the remote operator efforts to be focused on the demanding mission objectives.

In this vein, the use of visual information provided by an onboard camera to aid the piloting and guidance task has been proposed in the literature. In [9] and [3], the visual information is used to perform lateral guidance control to track a ground target. Another target following strategy with circular trajectory is presented in [7]. In [3] an automatic gimbal control is performed in order to pursuit a target. Turret gimbal control to keep the target in the line of sight is performed in [7], [5] and [3].

This paper follows a procedure similar to [9], [7], [5] and [3]. The outcome is a camera based semi-automatic UAV piloting strategy for a remote operator. By using visual information, the payload operator acts in the camera gimbal in order to change the trajectory. The pan and tilt angles are used to calculate references to the actual lateral control law in terms of new heading references. The novelty here lies in the fact that the operator pilots the UAV by manipulating the camera joystick instead of the piloting joystick, which is the usual approach. The proposed approach is shown in (Fig.1).

Figure 1. Practical UAV Camera Piloting System

Two different guidance strategies using the proposed architecture are explained, each one with specific use. An important objective of this work is to provide a realistic implementation for a practical application. For performance evaluation purposes, both wind disturbance and noise in the sensors are taken into account. A human remote operator is also included in the loop. Software-in-the-loop and hardware-in-the-loop simulations in real time are carried out to ensure a feasible solution.

In the strategies conception, Global Positioning System (GPS) data and attitude information from an Inertial Navigation System (INS) of the aircraft are considered available during the entire flight.

2. GUIDANCE STRATEGIES

As mentioned previously, the camera is used by the human remote operator to pilot the UAV. It is very important to ensure a very large visibility. This is obtained by using a PTZ camera [9]. The PTZ camera is mounted usually in the nose or backwards, but always in the roll axis, and pointing to the front of the UAV (Fig. 2).

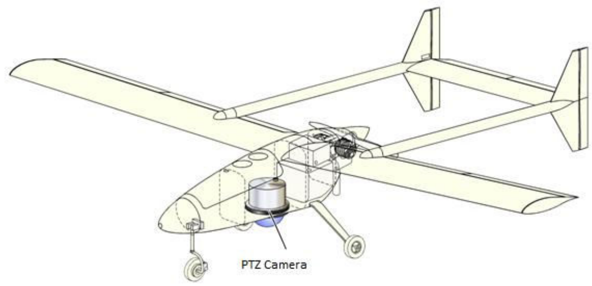


Figure 2. Installation of the PTZ Camera

The Practical UAV Camera Piloting System is a method to be added in an already existing flight control system (Fig. 3). The two strategies to generate heading references to the autopilot are: Guidance by Camera and Locked by Camera.

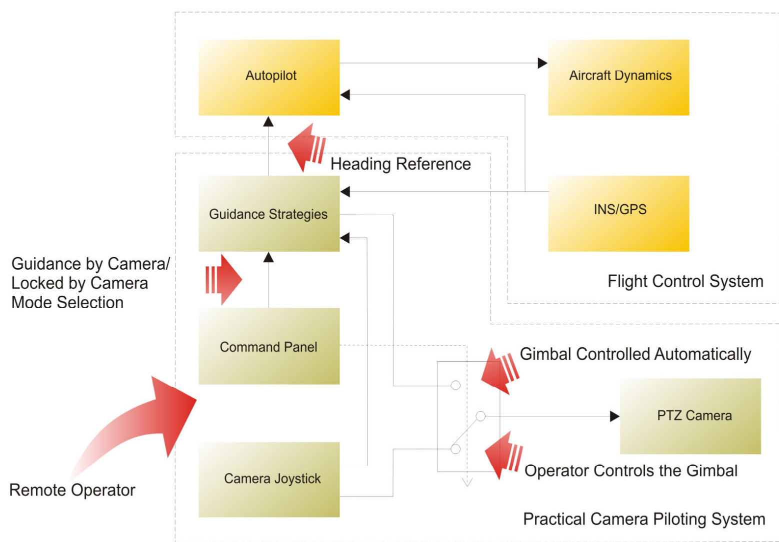


Figure 3. Structure of Practical UAV Camera Piloting System

A. GUIDANCE BY CAMERA

This is a very straightforward method. By using the visual information, the human remote operator points the PTZ optical axis to the desired course and gives a command, e.g., pushes a button in the command panel (Fig. 3), and one event is started: a new heading reference is calculated and send to the autopilot;

At this point, the UAV is heading to reach the new course and the gimbal is free to the remote operator to get new references or to visualize the terrain.

B. LOCKED BY CAMERA

The remote operator, whenever wanting to circulate a point (or an object) in a flat surface, switches the camera piloting mode to Locked by Camera. This causes the camera to be used as an aiming device. The remote operator points the PTZ camera optical axis to this point and gives a command, e.g., pushes a button in the command panel (Fig. 3). Two events are simultaneously started:

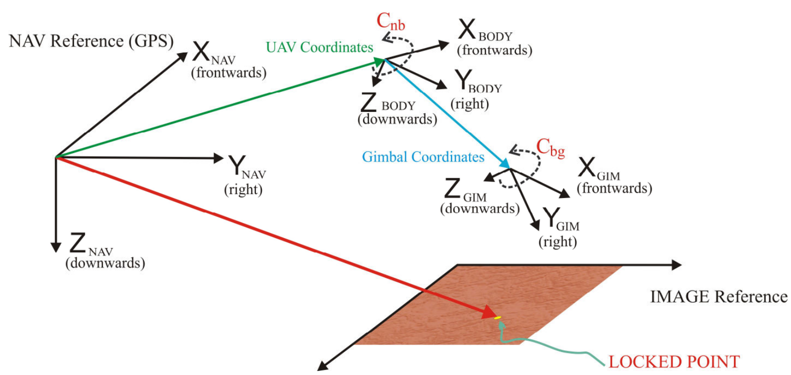
- the heading reference is calculated and send to the autopilot, and

- pan and tilt references are calculated and sent to the turret gimbal controller.

By these two events the following will happen: due to the fist event, the UAV will circulate the point, and due to the second one the target point will be centered in the image automatically. The remote operator also has the possibility of switching to the automatic gimbal control by interacting with the command panel.

COORDINATE MODEL

In order to perform the heading reference calculation, a coordinate model was assumed (Fig. 4). The camera orientation are obtained considering the two coordinate transformations: $C_{bg} = C_{bg}$(pan, tilt), from gimbal axis to body axis, and $C_{nb} = C_{nb}(\psi, \theta, \varphi)$, from body axis to navigation axis (NAV). The camera yaw angle (ψ_{cam}) gives the desired heading in the Guidance by Camera strategy. This paper considers the side slip angle, β, approximately zero, due to the auto-rudder autopilot feature.



(single space line, size 10)
Figure 4. Coordinate model

The point of interest in the ground, which may, for instance, represent the position of a vehicle, is called LOCKED POINT and must be transformed to the navigation coordinates. This is done by starting from the image reference coordinate and by using a pinhole camera model. The outcome is the point transformed to the CCD axis. By applying coordinates transformation C_{cg}, C_{bg} and C_{nb}, the point is brought to the navigation reference frame [2].

3. SOFTWARE-IN-THE-LOOP SIMULATION

Software-in-the-loop Simulation (SILS) is an inexpensive approach in which the simulated process and the simulated controller can be connected to each other and run in real time [4]. This method was applied during the development cycle and to verify the effectiveness of the camera piloting strategy. Because only software is in the loop, all components were developed in Matlab/Simulink platform, providing an easy way to integrate all of them. In this work a nonlinear aircraft model was used in the simulation. Matlab/Simulink built-in blocks and AeroSim blocks [10] were applied to modeling sensors, actuators, noise and wind behavior. The autopilot is also implemented in Matlab/Simulink. As the strategy requires visual information, the Flight Gear turned out to be an ideal tool to simulate the PTZ camera. The current view of Flight Gear was positioned in the camera place. Flight data are sent to Flight Gear during the Matlab/Simulink simulation and this causes a sensation of a real flight. The software loop is presented (Fig 5).

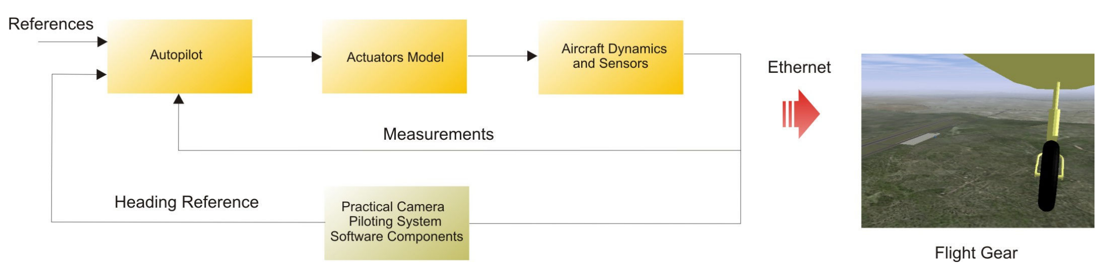


Figure 5. Software In the Loop Simulation

In the simulations, the camera field-of-view was assumed to be 90° vertically (caused by a tilt angle range from 0º to 90º) and 180º horizontally (caused by a pan angle range from -90º to 90º). The first group of simulations performed the

Guidance by Camera method. It is supposed a point of start far away from the airport runaway. The payload operator must find the runaway visually and then use the strategy to bring the UAV aligned with it. Results are shown (Figs 6-10). The same path was also simulated by inserting noise in the sensors. The UAV measured position by the Global Positioning System was affected by random walk noise [6] and the Inertial Navigation Unit measurements, Euler angles and body accelerations, were affected by white noise (Fig. 10). Wind disturbance results are also showed (Fig. 11). For the simulations, the UAV was in level flight at a speed of 30m/s and at an altitude of 1000m. The camera dynamics were not considered due the assumption that in real application the camera actuators are much faster than the aircraft dynamics.

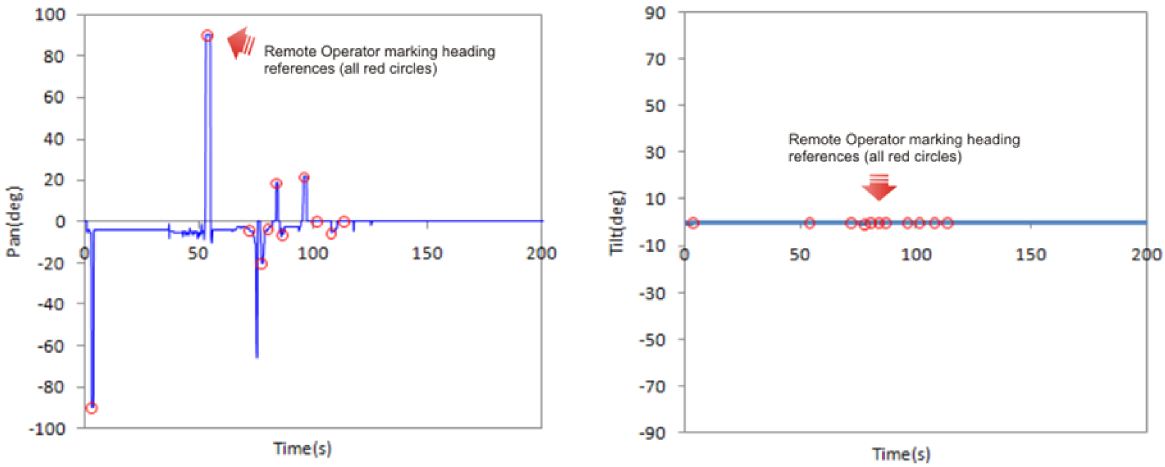


Figure 6. Gimbal pan and tilt angles corresponding to the human remote operator actuation

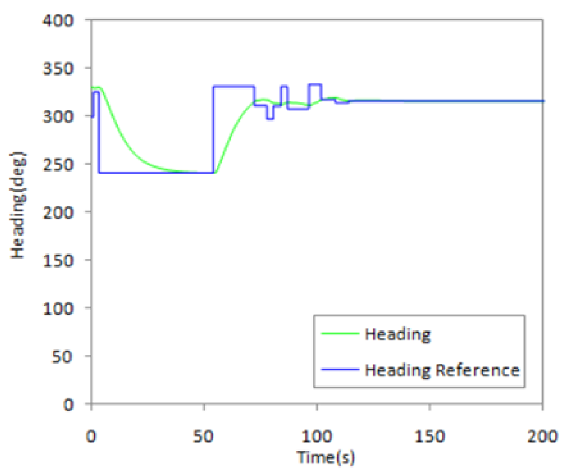


Figure 7. Heading time histories of UAV compared with reference generated by the Guide by Camera corresponding to Figure 6

Figure 8. Flight trajectory of UAV guided by camera corresponding to Figure 6

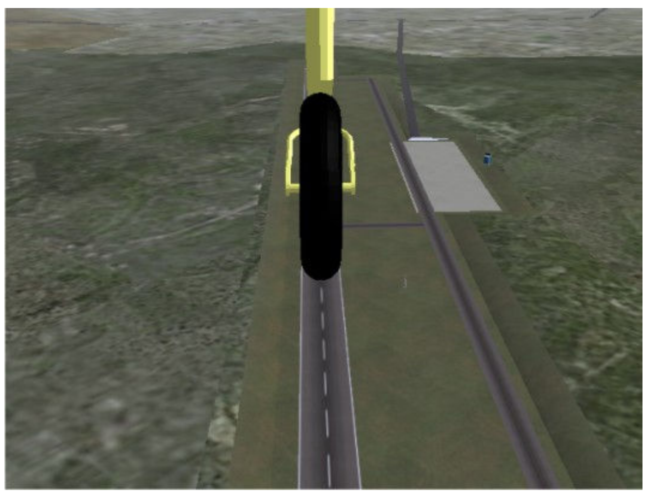


Figure 9. Image of camera simulated by Flight Gear corresponding to Figure 6

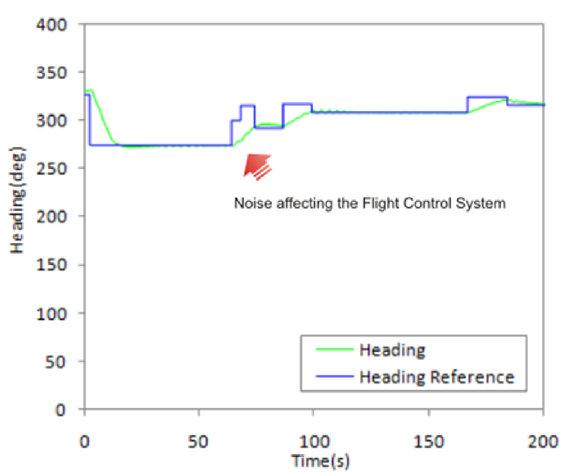


Figure 10. Reference and actual headings in the presence of sensor noise

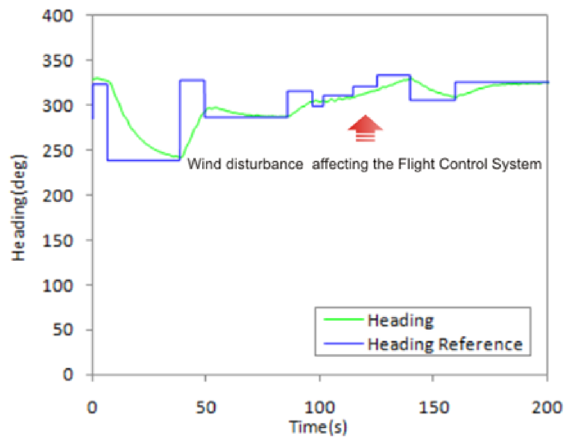


Figure 11. Reference and actual headings in the presence of wind

In the second group of simulations, the Locked by Camera method was employed. The payload operator uses the Guidance by Gimbal mode to find visually the desired point to be circulated. The Locked by Camera is engaged, once the point is in the sight of view. In this simulation, the point of interest in the ground is close to the airport runaway (Fig. 11). This causes the UAV to start a circular path around this point (Fig 12). Pan and tilt angle references are generated to keep the point centered in the video image (Figs. 13 and 14). The locked point is at Cartesian coordinates in NAV frame, $X_{point} = 2318$ and $Y_{point} = -4119$. The circumference radius was set up to 300m.

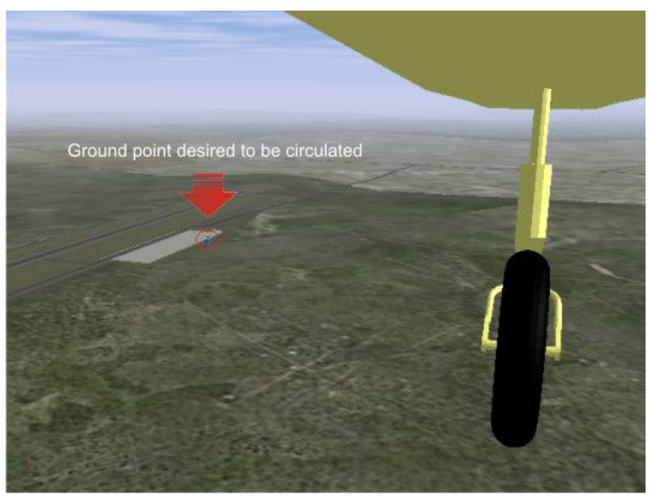


Figure 12. Payload operator points to the desired point in the ground to be circulated

Figure 13. Flight Path to circulate the point corresponding to Figure 12

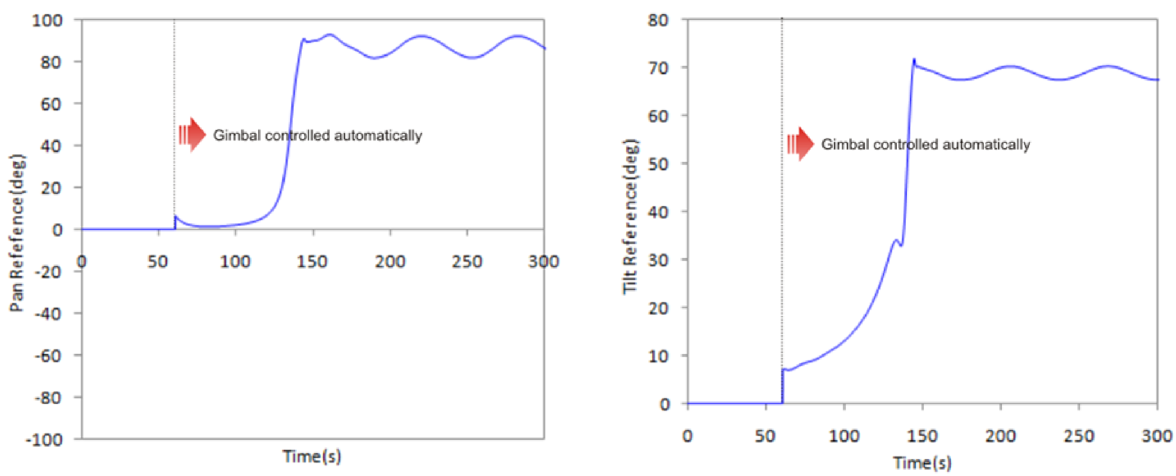


Figure 14. Reference for pan and tilt corresponding to Figure 12

Figure 15. Point being circulated corresponding to Figure 12

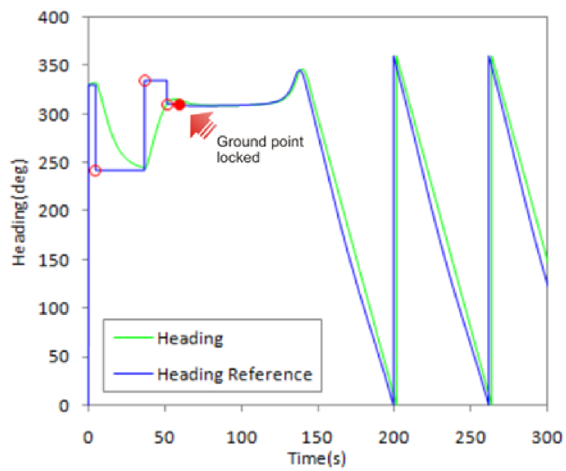


Figure 16. Course time histories corresponding to Figure 12

4. HARDWARE-IN-THE-LOOP SIMULATION

The Practical Camera Piloting System was implemented in an existent flight control system of a commercial UAV. The field trial is one of the most critical steps in UAV development, since usually the system has highly priced components: airframe, inertial navigation unit, payload, engine, and so on. In this context, it is recommended that the entire system be evaluated in the ground, before any flight is attempted. Hardware-in-the-loop Simulation (HILS) is one of most relevant solution for dealing with this issue [1], [6], since it minimizes the possibility of failures in the field. HILS consists in closing the loop with the real hardware components of the system, and simulate all inputs and outputs of the process in real time. By this way, it is possible to test the final embedded system under real conditions. In the case of the Practical Camera Piloting System proposed here, the HILS was implemented via Matlab/Simulink and xPC Target [8]. The involved hardware is shown in Figure 17.

Figure 17. Hardware employed in the HILS

5. DISCUSSION AND CONCLUSIONS

In this paper a practical piloting system for UAV´s was presented. In the life cycle of the development, the guidance strategy was evaluated be means of software-in-the-loop simulation and hardware-in-the-loop simulation. In the software-in-the-loop simulation the feasibility of the solution was considered. The software components were evaluated and modified until the specifications were satisfied. The simulations results indicate that the proposed strategy simplifies the task of piloting the UAV in terms of demanded maneuvers, thereby enabling the pilot to concentrate in planning the flight path. As consequence, the strategy can be very useful in situations where the pilot has no appropriate skill and complex maneuvers are required. As application examples can me mentioned reconnaissance, surveillance, search and rescue missions.

In all the simulations, the human operator included in the loop had no difficulties to pilot the UAV. Only few corrections were necessary in order to reach the desired heading. The two methods applied together shown that few interventions were necessary to keep the ground target properly surrounded (Figs 12-16). Hence, it can be concluded that the effort in piloting the UAV has considerably decreased.

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