A Mini UAV for security environmental monitoring and surveillance: telemetry data analysis

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Abstract. This paper presents the results of some flight tests on our SR-H3 Mini UAV. After a brief description of the system architecture, the data acquired during a flight are illustrated and analyzed, in order to evaluate the performance of the Automatic Flight Control system.

1 Introduction

The whole control system of any unmanned aerial vehicle comprises three main layers, namely Mission Planning (MP), Flight Guidance (FG) and Automatic Flight Control (AFC). The Mission Planning level is mostly based on the use of suitable Man Machine Interfaces and requires some form of human intervention. Mission Planning is usually carried out in advance; depending on the mission objectives, continuous re-planning may be required on-line, such as in the case of rescue and security applications.

The Flight Guidance layer convert the planned mission into a trajectory that can be actually followed by the vehicle, taking into account the possible constraints that derive from the aircraft dynamics.

Finally, the Automatic Flight Control layer is responsible for improving system stability and performance, i.e. the tracking of the assigned trajectories.

The aerial unmanned system under test is composed of a tail-less aircraft, an autopilot, a launcher (Fig. 1) and a Ground Control Station (GCS). The aircraft is electrically powered with 3 m wing span and weights 4 kg.

Both Mission Planning and Flight Guidance layers run on the GCS. The GCS is implemented on a PC through which it is possible to plan the mission and to monitor the state of the aircraft flight. Mission data are a list of waypoints (WPs) that the aircraft must follow; they are trasmitted to the autopilot that implements the AFC, which is described in the following section [1],[2].

In the subsequent section some data acquired by telemetry during a real flight mission will be presented and analyzed, with the purpose of evaluating the Automatic Flight Control performance.

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(a) The system

(b) SR-H3 in flight

Fig. 1. SR-H3 Unmanned Aircraft System

2 Autopilot Description

The Automatic Flight Control layer improves the system stability, namely increase the damping on the natural modes of the aircraft. It also must ensure the tracking of the assigned trajectories, despite external disturbances. The AFC layer relies on a number of sensors on board: an Inertial Measurement Unit (IMU) for attitude measurements, a Pitot probe for the indicated air speed, a baroaltimeter and a GPS receiver .

The AFC is organized into three partly independent regulators, for speed, altitude and direction control [1],[2]. The scheme is reported in Fig. 2.

Speed control. The speed control subsystem consists of a single linear regulator R_v and employs the indicated air speed measured by the Pitot probe. The raw data are filtered by a 4^{th} order FIR filter. The regulator is a low pass filter, in order to decrease the bandwidth of the command signal, preventing current spikes that are not effective for the speed control and increases the power consumption.

$$R_v(z) = c_{0v}\frac{1 - c_{1v}}{1 - c_{2v}z^{-1}} \tag{1}$$

Altitude control. The altitude control is performed by the elevons, commanded symmetrically. A two-loops scheme is employed. The inner loop is devoted to the pitch control, basing on the measurements provided by the IMU. The pitch reference θ_d is provided by the outer loop by R_h that regulates the altitude. Also the altitude measurements are filtered by a 4^{th} order FIR filter.

The altitude controller is a PI regulator, in order to achieve zero steady state error, despite constant disturbances.

$$R_h(z) = c_{0h}\frac{1 - c_{1h}z^{-1}}{1 - z^{-1}} \tag{2}$$

The pitch controller is a lead-lag network:

$$R_\theta(z) = c_{0\theta}\frac{1 - c_{1\theta}z^{-1}}{1 - c_{2\theta}z^{-1}} \tag{3}$$

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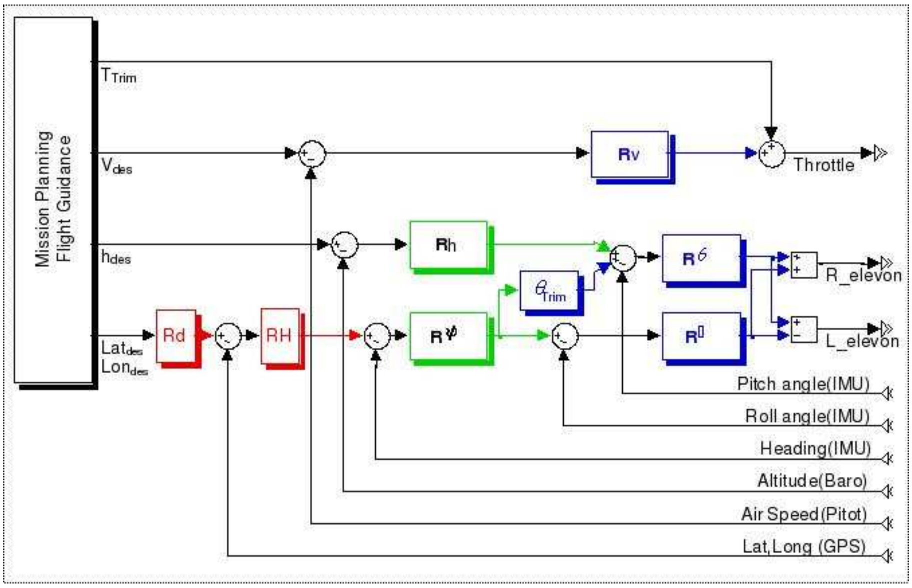

Fig. 2. The Automatic Flight Control System

During the banked turns the lift would tend to decreases; therefore a feedforward pitch reference signal is also provided in function of the desired roll angle ϕ_d. Therefore, the pitch error signal used by the pitch controller R_θ is

$$\begin{gathered} PitchErr = (\theta_d - \theta) + \theta_{trim} \\ \theta_{trim} = k|\phi_d| \end{gathered} \tag{4}$$

Direction control. For the tail-less architecture the direction control can be achieved only by bank-to-turn manoeuvres, namely by the roll angle controlled by the elevons commanded antisymmetrically. For this reason, a three-loops control scheme is employed. The outer loop, basing on the actual position and on the target one, computes the desired heading H_d, which is similar to the desired yaw angle ψ_d for small pitch and roll values. The intermediate loop, basing on the yaw measurements provided by the IMU, generate the roll angle reference ϕ_d, that is controlled by the inner loop; the roll angle is provided by the IMU, too.

The desired heading is computed in function of the position of the future target and the present one, expressed with latitude and longitude. If the distance between the waypoints is sufficiently small, the positions can be specified on a tangent plane to the earth at a certain latitude: therefore, assuming a local earth frame with $(x, y, z) = (North, East, Down)$, the position errors are

$$\begin{gathered} \Delta x = R_E(Lat_{des} - Lat_{meas}) \\ \Delta y = R_E(Lon_{des} - Lon_{meas})\cos(Lat_{meas}) \end{gathered} \tag{5}$$

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where R_E is the local earth radius; the desired heading is

$$H_d(\approx \psi_d) = arctan(\Delta y/\Delta x). \tag{6}$$

The intermediate yaw regulator R_ψ is a simple gain (7). The inner roll controller R_ϕ is a lead- lag network (8). The desired roll angle is also employed to compute the trim command for the pitch control system.

$$R_\psi(z) = c_{0\psi} \tag{7}$$

$$R_\phi(z) = c_{0\phi}\frac{1 - c_{1\phi}z^{-1}}{1 - c_{2\phi}z^{-1}} \tag{8}$$

3 Flight test and data analysis

The flight was a path cycled between two way-points: 43.0035°N, 12.3180°E (WP1) and 43.0055°N, 12.3225°E (WP2). The desired altitude was 120 m above the ground level and the set-point speed was 20 m/s. The performed path is showed in Fig. 3.

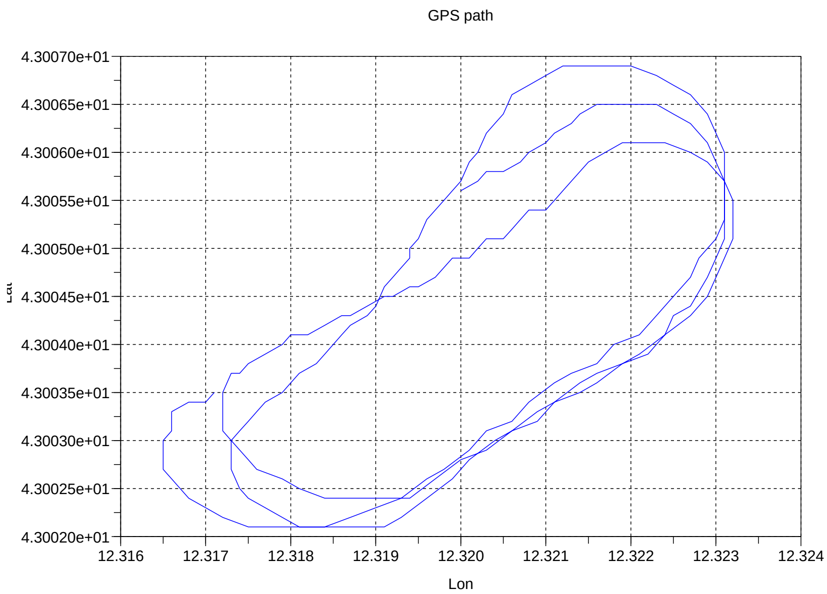

Fig. 3. UAV path

The value reported in the subsequent figures are: speed, altitude, pitch, yaw and roll angle. The values are sampled at 25 Hz.

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Fig. 4 shows how the desired speed is followed by the AFC. The output of the speed controller (1) is a quantity that is subtracted, in percent, to a trim value for the throttle. Is possible to see, at time 4500 s, how the regulator responds to a fall of the velocity.

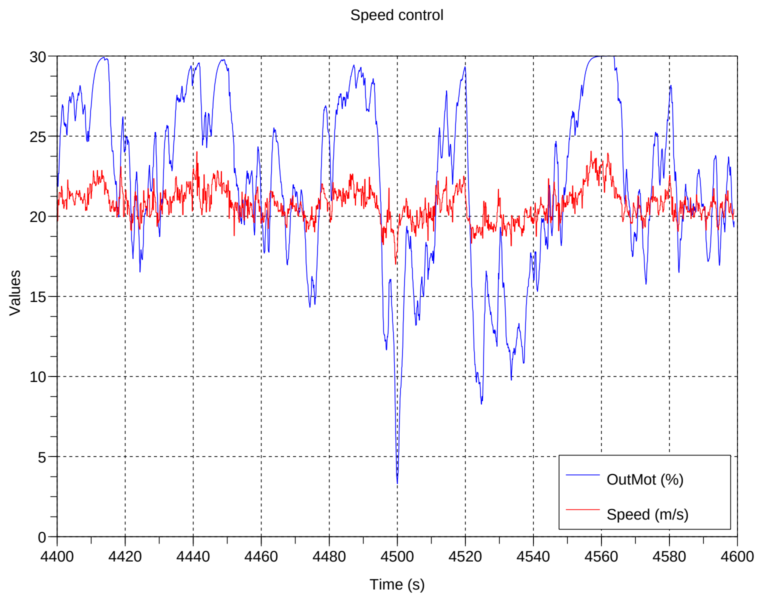

Fig. 4. Performance of the speed control loop: set point 20 m/s. Actual speed and motor command

Fig. 5 shows the altitude of the UAV. The desired value is 120 m. The error is about $\pm 15m$ and depends on: the quantization of the baroaltimeter (about 4 m), the lift decrease during the banked turns and the wind disturbances that influence the aircraft speed and therefore the lift. The sensor quantization is partly compensated by the signal filtering. The lift decrease during the turns is partly compensated by the feedforward term of pitch controller. As for the wind disturbances, an improvement in the speed control could be introduced. In fact, an increase of the rate of climb can be obtained by increasing the aircraft speed: the altitude controller should be coupled with the speed controller, but this would cause an increase in energy consumption (the kinetic energy given by the propeller is converted in potential energy).

Fig. 6 shows how the desired pitch *RefPit*, which is calculated by the altitude controller (2) and controlled by the pitch controller (3) is followed by the aircraft. This signal is composed of two parts: the first one depends on the altitude error and the second one is a function of the actual roll by formula (4). The offset depends on the disturbance caused by the pitching moment that cannot be recovered by

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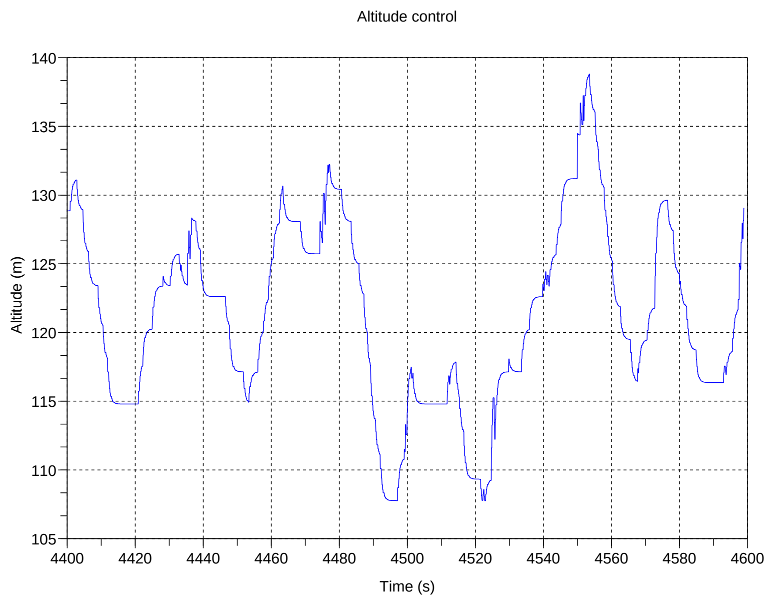

Fig. 5. Altitude control: set point at 120 m

the controller (3), due to the absence of an integral action. In fact, the actual pitch is always smaller than the desired one, ensuring a certain security margin against stall phenomena.

Fig. 7 shows how the desired yaw *RefYaw*, that is calculated by the Direction Controller (6), is followed by the AFC by means of the yaw controller (7).

Fig. 8 shows how the desired roll (*RefRol*), calculated by the yaw controller (7) and controlled by (8), is followed by the AFC . This signal changes according to the manoeuvres (bank-to-turn). During the banked turn the roll reference is bounded at $\pm 15°$. A large roll angle causes a decrease of the lift, which must be compensated by an increase of the pitch angle, leading the wing to possible stall. On the other hand a small roll angle limits the curvature of the trajectory. The real roll angle seems noisy due to the turbulence effect.

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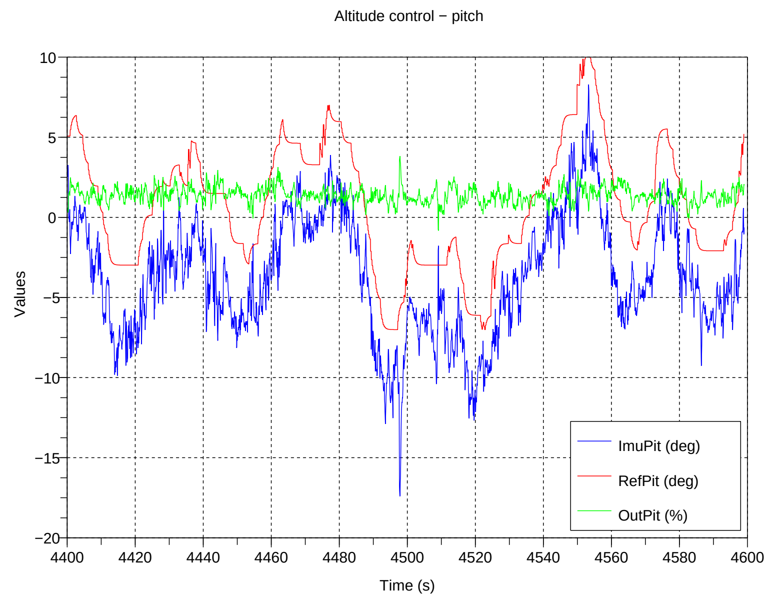

Fig. 6. Altitude control: desired and actual pitch; elevon command

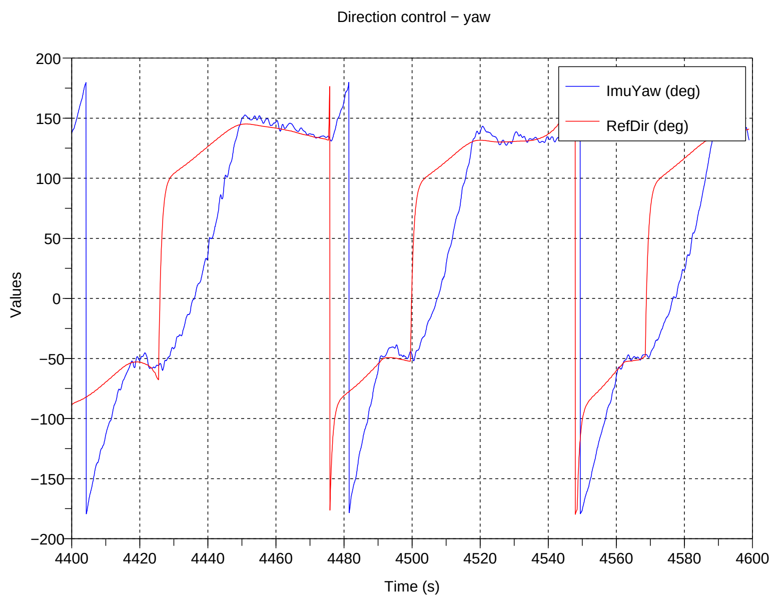

Fig. 7. Direction control: reference from the heading control and actual yaw

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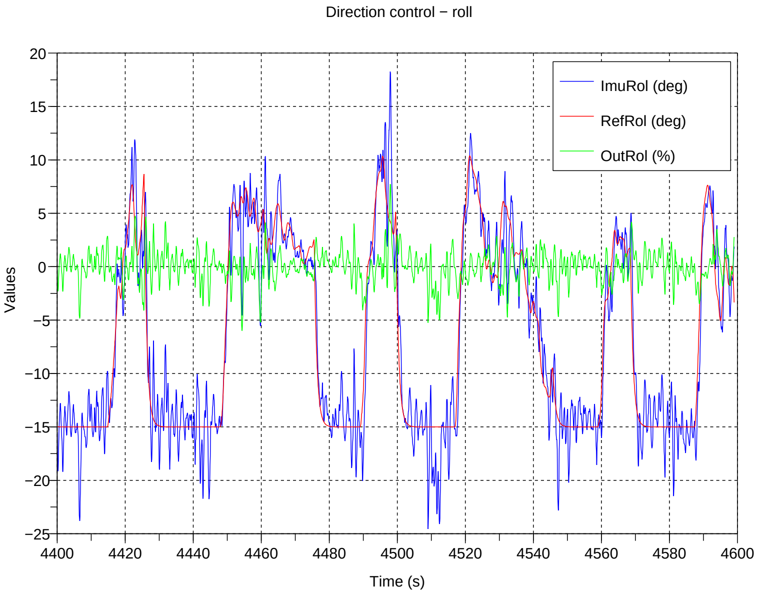

Fig. 8. Direction control: roll reference from the yaw controller, actual roll and elevon command

4 Conclusions

In this paper some experimental results on the control of a mini UAV have been presented. The Automatic Flight Control system is based on small and light-weight components and was designed by the authors. Future activities will concern the increase the performance of the altitude controller and to test different IMU sensor to enhance the autopilot performances.

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