POLITECNICO DI TORINO
Dipartimento di Automatica e Informatica

PhD in Computer and Control Engineering

XXIX cycle

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Application of Embedded Model Control to Aerospace Systems

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1. Introduction

The research activity is focused on study, design, development and experimental tests of Guidance, Navigation and Control (GNC) algorithms in the Aerospace field based on Embedded Model Control (EMC) methodology.

The EMC methodology can be very effective in applications involving relevant disturbances, modeling errors and unknown nonlinearities, since it allows a cancellation of all these sources of uncertainty.

As a case study it was chosen the control problem of an Unmanned Aerial Vehicles (UAV), in particular of a quadrotor (four fixed pitch propellers in cross configuration). This category of UAVs presents several analogies with other control systems in the aerospace field as for spacecrafts in the planetary landing phase.

The quadrotor is part of an internal project, called "Borea project", which is developed by the Space and Precision Automatics group (now merged with the Computer and Data Science group).

2. Objectives

Design the GNC algorithms for the quadrotor by means of the Embedded Model Control (EMC) methodology. EMC relies on an input-output model of the plant which contains also a model of the unknown disturbances affecting the plant. This internal model is called embedded model (EM) because it is embedded into the digital control unit and it is real-time executed in parallel with the plant.

The study investigates the use of the feedback linearization approach as a novel way to design the internal model for EMC.

3. Methods

In this work the Embedded Model Control (EMC) methodology is used in order to design the control unit of the quadrotor. Control design requires a so called design model that represents all our plant acknowledgement. In the EMC framework the control unit is designed around a stylized model of the plant, the Embedded Model (EM), which represents the core of the EMC methodology (see Figure 1). The EM includes not only the input-output dynamics (M) controllable by the command but also the dynamics of the unknown disturbances (D). The latter dynamics is driven by noises that are estimated by the so called noise estimator.

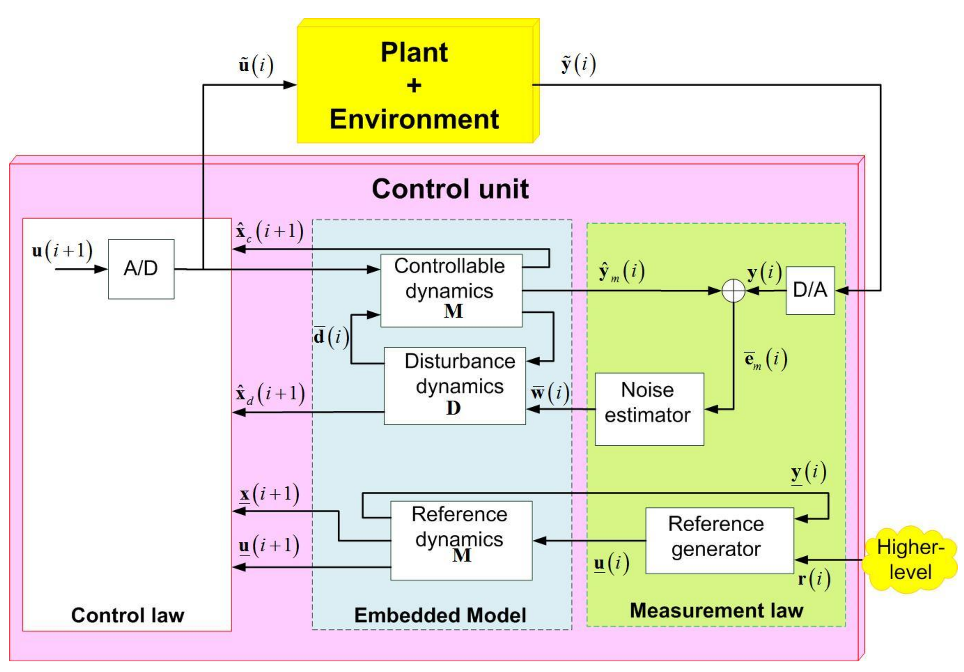

Figure 1: Embedded Model Control scheme

Passing from design model, which is full of uncertainties and nonlinear, to the EM can be achieved by using nonlinear control techniques.

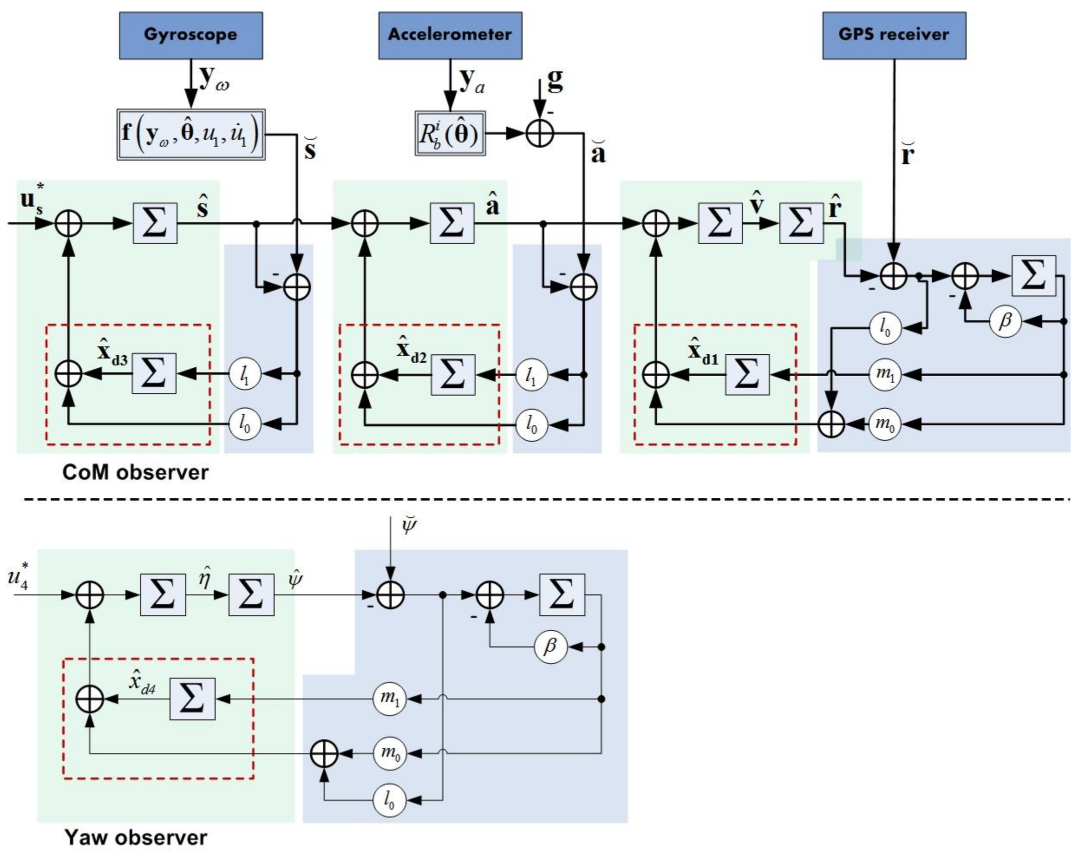

Figure 2: EMC state predictor

The way to obtain EM from design model exploits a nonlinear technique called Feedback Linearization. The method allows to collect all nonlinearities and to move them to the command level.

Nonlinearities contain uncertainties which contribute to the unknown disturbance: the unknown disturbance including parametric and nonlinearity uncertainty will be cancelled because it is estimated by the EM. In particular, the disturbance rejection is performed by the control law which must also be designed. The EMC control unit is completed with the reference generator.

4. Results

As a very first result, the embedded software representing the framework on which the controller has to run in real-time was developed from scratch and tested on the quadrotor microcontroller.

As the first important result the actuator model identification was performed [1]. The identification process involved both static and dynamic tests (see Figure 3).

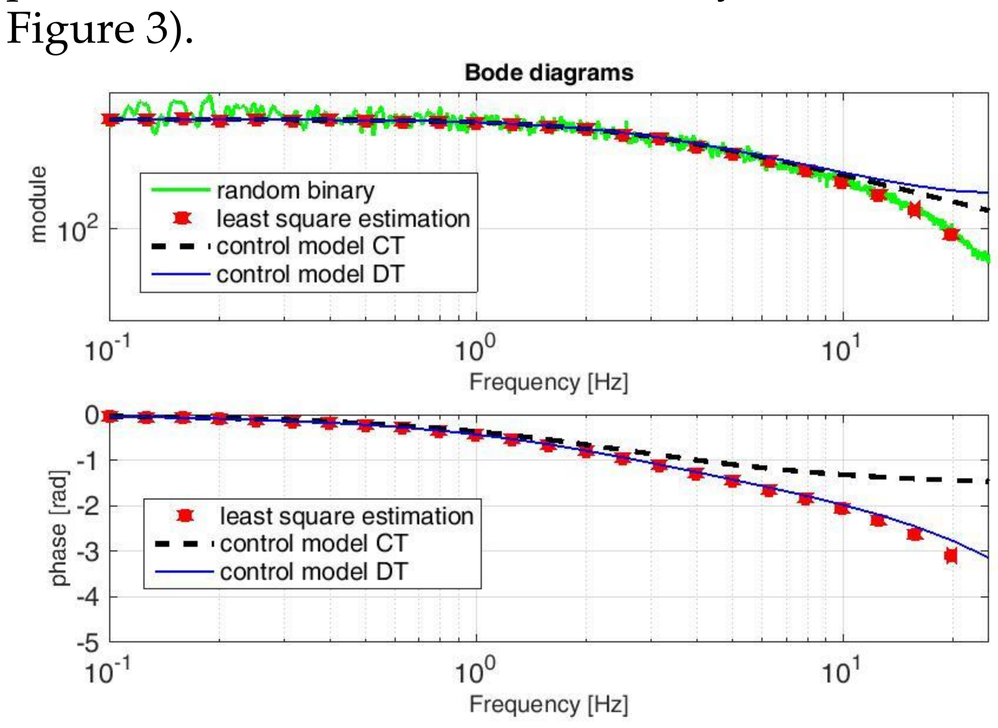

Figure 3: Actuator frequency response

The actuator dynamics allowed to obtain a more accurate model for the control design. Indeed, with this model the EMC controller for attitude stabilization was designed and successfully tested in flight.

The next step has consisted in controlling the position of the quadrotor in three dimensions (horizontal plus vertical motion). The embedded model for the quadrotor center of mass was designed by using a nonlinear control technique, the feedback linearization. The linear model obtained was discretized and completed with the disturbance dynamics and the noise estimator [2] (see Figure 2).

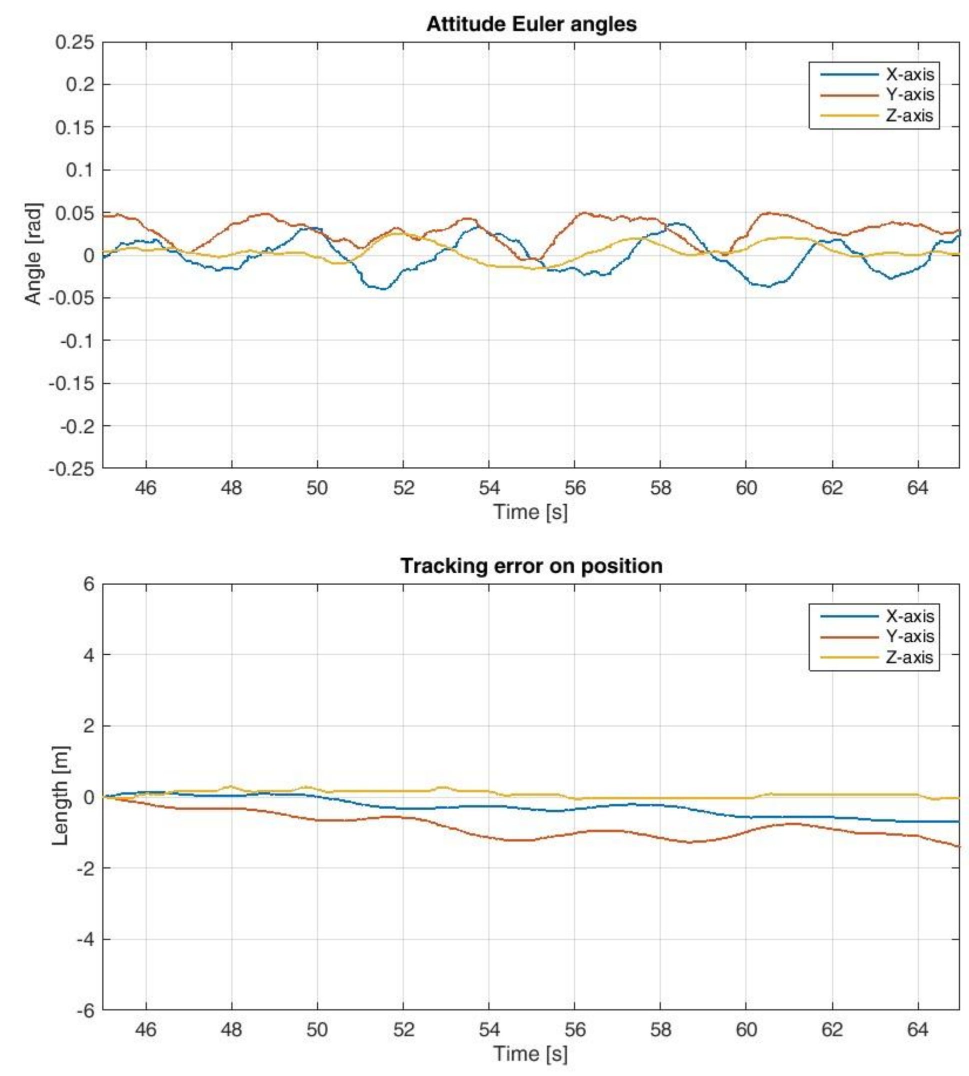

Figure 4: Position controller – flight test data

In order to test the position controller in safety conditions a number of flight modes were considered and the attitude controller developed previously was used as a backup controller.

In Figure 4, data from flight tests of the position controller are reported. In particular, the upper figure shows the Euler attitude angles of the quadrotor. As can be shown, angles are bounded and lower than 50mrad (in module) that means a very stable hovering flight. On the other hand, in the bottom figure, the position tracking error is shown. The tracking error is limited and lower than 1.5m in module which is within the GPS receiver error. These results demonstrate the validity and applicability of the EMC methodology on a nonlinear system in particular on a quadrotor UAV.

5. Conclusions

Attitude and position controllers were developed and tested in real flight for a quadrotor using the EMC methodology. These controllers validates and extend the applicability of the EMC to nonlinear systems. In particular, a nonlinear control technique has been studied (feedback linearization) and formulated in order to develop the Embedded Model in a rather generic conditions.

As possible future works, there is the improvement of the control tuning for optimal performance according to requirements and comparison with other control techniques.

6. References

1. Lotufo, M.A.; Perez-Montegro, C.; Colangelo, L.; Canuto, E.; Novara, C., "Identification and control of a quadrotor from experimental data", 24th Mediterranean Conference on Control and Automation, ISBN 978-1-4673-8345-5, 2016, Pages 895-900
2. Lotufo, M.A.; Colangelo, L.; Perez-Montenegro, C.; Novara, C.; Canuto, E., "Embedded Model Control for UAV quadrotor via Feedback Linearization", 20th IFAC Symposium on Automatic Control in Aerospace, Volume 49, Issue 17, ISSN 2405-8963, 2016, Pages 266–271