PhD thesis: Augmented nonlinear estimation and robust control techniques for a guided projectile with unbounded parameter uncertainties

Entreprise: KMW+Nexter Defense Systems (KNDS)

Laboratory: Signals and Systems Laboratory (L2S)

General information: 3 years, starting from Oct.-Nov. 2023

Key-words: Nonlinear control, estimation, unbounded uncertainties, guidance, navigation

Context and motivation: Traditional ammunition is not piloted during flight. Therefore, it is not possible to improve the accuracy of hitting the target once the shot is made. In order to impact the target, the artillery division ensures a maximum number of hits to cause the damage [1]. One of the consequences is the considerable increase in collateral damage. As the main arms manufacturer in France and in the world, the KNDS group, in response to this problem, focuses on the development of smart munitions with the definition of guidance, navigation and control algorithms necessary to control the trajectory of ammunition during flight to accurately hit the target.

Traditional control based on classic control laws (e.g. PID control) makes it possible to obtain, to a certain extent, interesting performance in simulation [2],[3]. On the other hand, the real conditions can very often be different from the simulation conditions because the bounds on the values of the parameters of the system are not well known [4]. In addition, various effects such as the Magnus effect and the cross-coupling effect caused by the roll speed or the delay induced by the actuators are neglected when determining the aerodynamic coefficients in the laboratory, which again makes the actual flight conditions quite different from the simulation [4].

In order to take into account the evolution of the parameters, contemporary aerospace industries producing missiles and rockets have tested strategies based on a linear model with variable parameters (LPV and Quasi-LPV) for the control and for the analysis [2]. These strategies satisfy the performance and stability criteria when the uncertainties of the system are well bounded with a good known level of confidence. In the case of ammunition, uncertainty bounds are rarely known and the movement of the canard (system of fins to correct for longitudinal and lateral deviations) is non-linear, making linear control strategies quite difficult to obtain the required performance [5]. In order to solve this problem and to obtain satisfactory performance, an in-depth study must be carried out on an augmented estimator structure to provide maximum information to the control to counter the large indeterminations characterizing the uncertainty [6].

In a second step, a new control structure has to be studied, proposing a nonlinear multivariable control to correctly track the desired flight trajectory in case of unbounded uncertainties. For example, several studies in the literature show good performance obtained with sliding mode control, as well as the drawbacks of such methods related to the "chattering" phenomenon and the management of canard angle saturation, in order to be implementable on board [4],[7]. This type of approach could be part of the areas of study to be investigated in the work.

Objectives: The proposed thesis should make it possible to develop advanced control strategies for in-flight control of a projectile. In particular, it will be a question, on the one hand, of considering the strong non-linearities at the level of the actuators and of the movement of the machine, and, on the other hand, of guaranteeing the robustness of the piloting with respect to potentially unbounded uncertainty. Taking these uncertainties into account will require the development of augmented estimators.

Among the approaches considered, one of the objectives of the thesis will be to be able to drive the complete nonlinear ballistic model with 6 degrees of freedom from a simplified guidance model assumed to be perfect with 3 degrees of freedom. In particular, one of the main control problems of the canard-operated ammunition, is surely the coupling between the yaw and pitch axis via the roll rate. Therefore, a two-axis multivariable control could allow to improve the guidance performance of the head of the ammunition in terms of direction and speed.

The main objective of the thesis will thus be the definition of an extended navigation strategy of the model using extended nonlinear control algorithms (relating more specifically to acceleration, speed and position, i.e. the angle of attack) in the case of unbounded parameter variations. The problems of precision and temporal convergence of the developed algorithms will be particularly investigated within the framework of the problem of stability in flight.

Finally, it is planned to test the control structure via hardware-in-the-loop tests, at least for the canard behaviors, with and without load, in order to validate the proposed strategy.

Main steps of the works

- First year: state of the art of ammunition control methods and development of an extended model ammunition control strategy without navigation

- Second year: development of an extended ammunition model control strategy with navigation (6 months)
- Third year: validation of work via HWIL and writing of the thesis

Candidate profile:

- Control system engineer, interested in aerospace systems (missile, rockets, aviation or satellite)
- First experience in GNC (Guidance Navigation Control) is appreciated
- Advanced linear estimation and control algorithms (LQ, LQG, Hinfinity, LPV etc.)
- Knowledge on nonlinear control algorithms is appreciated
- Good notions on stochastics and applied mathematics are expected
- Highly motivated for research and development

References:

1. S. Theodoulis, Y. Morel, P. Wernert, "Trajectory-based accurate linearization of the 155mm spin-stabilized projectile dynamics", AIAA Modeling and Simulation Technologies Conference, Chicago, 2009
2. J. Spagni, S. Theodoulis, P. Wernert, "Flight control for a class of 155 mm spin-stabilized projectile with reciprocating canards", AIAA Guidance, Navigation, and Control Conference, Minneapolis, 2012
3. S. Theodoulis, P. Wernert, V. Gassmann, "Guidance and control design for a class of spin-stabilized fin-controlled Projectiles", Journal of Guidance, Control and Dynamics, vol. 36, no.2, 2013
4. X. Zhao, K. Yi, Z.-M. Tan, G.-Q. Wu, Y. Li, S.-M. Song, "Finite-time sliding mode tracking control for guided projectile", Chinese Control conferences, Guangzhou, 2019
5. G. Mattei, S. Monaco, "Nonlinear autopilot design for an asymmetric missile using robust backstepping control", Journal of Guidance, Control and Dynamics, vol. 27, no. 5, 2014
6. Q. Chen, X. Wang, J. Yang, Z. Wang, "Acceleration tracking control for a spinning glide guided projectile with multiple disturbances", Chinese Journal of Aeronautics, vol. 33, no. 20, pp. 3405-3422, 2020.
7. Y. Shen, J. Yu, G. Luo, , X. Ai, Z. Jia, F. Chen, "Observer-based adaptive sliding mode backstepping output-feedback DSC for spin-stabilized canard-controlled projectiles", Chinese Journal of Aeronautics, vol. 30, no. 3, pp. 1115-1126, 2017.

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Application files: CV, cover letter, recommandation letter, official transcripts

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