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Development and application of an integrated framework for small UAV flight control development

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ABSTRACT

This paper presents an integrated framework for small Unmanned Aerial Vehicle (UAV) flight control development. The approach provides a systematic procedure for flight control design process with a set of design tools that enables control engineers to rapidly synthesize, analyze and validate a candidate controller design. A model-based environment integrated with control synthesis, off-line and real-time simulation is developed for flight control synthesis, analysis and testings. The effectiveness of the proposed integrated framework is demonstrated by applying the framework approach to a small UAV testbed. Software-in-the-loop, processor-in-the-loop and flight testings are conducted with the synthesized controller implemented. Closed-loop performance and robustness results obtained are presented.

1. Introduction

Unmanned Aerial Vehicles (UAVs) are used worldwide today for a broad range of civil and military applications. There continues to be a growing demand for reliable and low cost UAV systems. This is especially true for small to mini-size UAV systems (less than 2 m wing span) where majority of systems are still deployed as prototypes due to their lack of reliability. Improvement in the modeling, testing and flight control for these vehicles would help to increase their reliability and performance during autonomous flight.

The traditional approach used for synthesizing, implementing and validating a flight control system in [1,2] for manned aircrafts is time consuming and resource intensive. Applying the same techniques to the small UAVs is not realistic. To reduce the cost and time to market, small UAV systems make use of low cost commercial-off-the-shelf autopilots [3]. These autopilots are often classical Proportional–integral–derivative (PID) controllers and ad-hoc methods are used to tune the controller gains in flight. This methodology is time consuming, high risk and has limitations associated with performance optimality and robustness. To shorten the development cycle and improve system reliability and robustness of the flight control system, it is important to develop an integrated framework for the flight control design process. This process would consist of a set of design tools that enables control engineers to rapidly synthesize, implement, analyze and validate a candidate controller design using iterative development cycles.

Numerous researchers have made the case for an integrated framework approach in recent years [4–9]. The central paradigm is a model-based development environment where different design tools and techniques can be formulated, deployed and applied. The different processes in model-based flight control development (shown in Fig. 1) are tightly-coupled and the development process may be severely hindered if each process is tackled as a separate problem. Hence flight control development must be looked at simultaneously in the context of dynamic modeling, control and model analysis, simulation, control design, real-time implementation, software and hardware-in-the-loop simulation and flight testing.

One of the main challenges of model-based flight control design approach is in deriving flight dynamics models with adequate fidelity to be used in different stages of controller development. If a precise validated flight dynamic model is available for the controller development, it simplifies the synthesis of a controller to achieve required performance specifications. However, mathematical models used are just an approximation of the vehicle dynamics. They are used to describe complex real flight dynamics. The result is uncertainty in predicting the actual flight dynamic responses. This problem is even more crucial in the development of small UAVs since their aerodynamic data are less well understood than full-size aircraft and limited literatures on detailed dynamics modeling are available [10]. Similarly the sensors used for measurement and control are less accurate than high end aerospace vehicle. With low cost and rapid development cycle constraints, extensive wind tunnel testings to extract aerodynamic data are usually not possible. Similarly flight test system identification approach for estimating the aerodynamic data is challenging with the low quality flight data obtained from the simple and

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