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A novel design and control solution for an aircraft sidestick actuator based on Halbach permanent magnet machine

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Abstract:
This paper is concerned with the design and control of a new sidestick actuators used to handle a civilian aircraft behaviour. Indeed, a discrete robust adaptive sliding mode control for a new designed aircraft sidestick based on synchronous Halbach permanent magnet machine.
The main objective is to provide a new design structure and a control solution that ensures maintaining high performance specifications for the actuator and respects the set of constraints required by the considered aeronautical application. Indeed, this study achieved in a partnership with an industrial center of excellence for Fly by Wire Cockpit Controls (side sticks, rudder controls, thrust controls), proposes a novel design that enhances the characteristics of the actuator's structure and the human machine interface between the pilot and the aircraft. Then, a new control strategy is proposed to optimize the efficiency of this actuator for the considered application. It is based on a discrete optimal adaptive sliding mode control considering time delays and uncertainties in the model by using a delay ahead predictor. The proposed strategy combines an optimal sliding mode surface with the delay ahead predictor in an adaptive control structure. Indeed, a varying parameter is used to achieve an "on-line" adaption to the varying level of disturbances that affects the system. Then, since the sidestick actuator is designed to handle an aircraft displacement, the proposed control strategy is designed for position tracking. Simulations performed on the previously designed actuator prove the efficiency of the proposed technological solution for aircraft position control.

Keywords: Actuator design, structure optimisation, discrete system, , linear quadratic control, sliding mode control, adaptive control.

1. INTRODUCTION

During the last decades, the evolution of the aeronautical technologies has provided huge advances in the design and control of the aircraft and aerospace vehicles. Indeed, the continuously increasing interest of the big industrial groups in this field and the increasing number of the air transportation companies has led the academic community to develop several studies that aim to provide novel solutions for the encountered problems. Indeed, a lot of innovations have been provided to optimize and manage the behaviour of these aerodynamical vehicles (especially aircrafts) and to improve their characteristics and performances.
One of the most important issues is to improve the pilot handling of the aircraft using flight control surfaces (see MORGAN (1991)). First, the mechanical passive sidestick system were conventionally used for the fly-by-wire as explained in Wyllie (1988).
Usually, two passive sidesticks are available in the cockpit (see Fig. 1) to create force feedback depending on the displacement angle of the stick compared to the natural resting position: on the left side for the pilot and for the right side for the copilot.
The following two Fly-by-wire systems are the most used in the aeronautical industry: electro-hydraulic ones allow to adapt the aircraft behaviour to flight envelope through a variable stiffness (see Navarro (1997), and Karpenko and Sepehri (2009)) and the electric systems (see Brière and Traverse (1993))that provide excellent characteristics regarding force feed back (with high bandwidth allowing to change the stiffness and adapt the aircraft behaviour) and also new functions that ensure haptic feedback.
Due to the increasing size of the aircrafts, the passive

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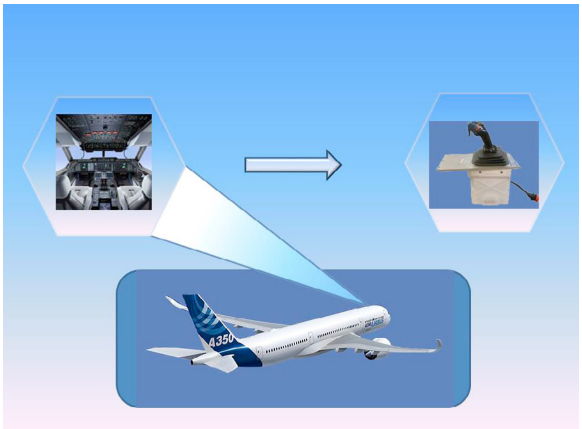

Fig. 1. Aircraft cockpit

sidesticks can not handle properly the flight control surfaces. This has led to the use of the "active sidestick" that uses motors, electronics and high bandwidth closed loop control systems to overcome this issue. It allows to handle the oversized aeronautical vehicle with less pilot effort while providing better haptic sensations (Hanke and Herbst (1999), Hegg et al. (1995)).
Recently, it has been proven that haptic sensation of the pilot can be enhanced thanks to the active sidestick technology. Some of these works have focused on teleomerization and UAV control as in Lam et al. (2008), Gandhi et al. (2014) and Zanlucchi et al. (2014).
The control of this type of sidesticks has been subject to several studies. Many control approaches have provided some solutions to enhance the use of the active sidesticks actuators for aerodynamical vehicles handling.
One interesting control approach is the linear state feedback control since it has the full flexibility of shaping the dynamics of the closed loops system to meet the desired specification (Carriere et al. (2010)). But, the problem is once the external disturbances and/or parameter uncertainties exist, the desired responses may not be obtained (lack of robustness), (see Kumar et al. (2008)). Also, another problem is to handle the time delays that occurs on the considered models.
To overcome this problematic, some robust control strategies have been proposed to handle the disturbances and the parameter uncertainties (Bhattacharyya et al. (1995), Adams et al. (2012). It can be understood that each one of the proposed strategies focuses on only some robustness issues and mostly aren't able to handle the time delays.
In this paper, a new discrete adaptive optimal sliding mode robust control strategy based on LQR gain, sliding surface and adaptation parameter. Indeed, this parameter is achieved as follows: the LQR optimal approach used to shape the actuator dynamics and meet the requirement of the performance index in nominal conditions for the reaching phase, then the result obtain from this approach is used to generate the sliding mode control that ensures the robustness in the sliding phase of the variable structure control regarding disturbances, time delays and uncertainties. Also, a varying parameter is used to adapt "online" the robust control to the level of the disturbances in linear varying parameter strategy. The use of a discrete control approach allows faster, easier and more realistic result for the experimental implementations.

This paper is organised as follows: section 1 is devoted to introduce the aspects of design and control of the new proposed actuator. In section 2, the actuator design procedure is presented with specification requirements and parameter optimization. Section 3 presents the new control strategy proposed for the position control of the newly developed actuators. Section IV presents the simulation results in different scenarios that validates the developed control strategy for the designed actuator. Conclusions and some future works that have been already started are presented in last section.

2. DESIGN OF A NEW GENERATION FORCE FEEDBACK SIDESTICK FOR AIRCRAFT COCKPIT CONTROL

The objective of this work is to provide a new solution to enhance the aircraft's flight performances using a new design and control for sidesticks actuators considering the human factor interaction in loop. Indeed, the pilot behaviour can be influenced by the haptic sensations generated while controlling the flight surfaces (see Allias et al. (2014) and Bailey (1963)).
In this study, a new generation of the active sidestick sytem is developed to improve the haptic sensations and then the flight performance. This actuator is a double airgap synchronous permanent magnets machine with non-entire arc and a Halbach array pattern (see Fig 2) in order to provide more torque.
To cope with the constraints and specifications that this

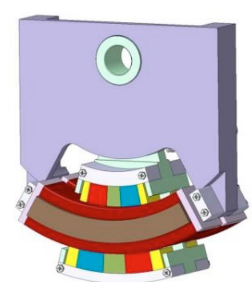

Fig. 2. Double airgap synchronous permanent magnets actuator

embedded aeronautical application requires, an optimization process is used.

2.1 Set of Specification requirements

The aeronautical application requirements must be respected in the design of the new actuator. Indeed, it implies a set of specifications that the design must comply with (dimensions, forces, strokes, speed, temperature and force ripples). Also, to respect the safety requirements, two identical actuators have to be implemented in parallel (security conditions impose redundancy over each one of the pitch and roll axes).
Usually, the effort of commonly used passive stick in the cockpit is linearly dependent to the input displacement angle while in this active case, the effort of the sidestick can be considered as a piecewise continuous function of the displacement angle as in Fig. 3.
One of the main characteristic of this system is the