Human-Centered Design of Haptic Aids for Aerial Vehicles

PhD in Automation, Robotics and BioEngineering

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1st year

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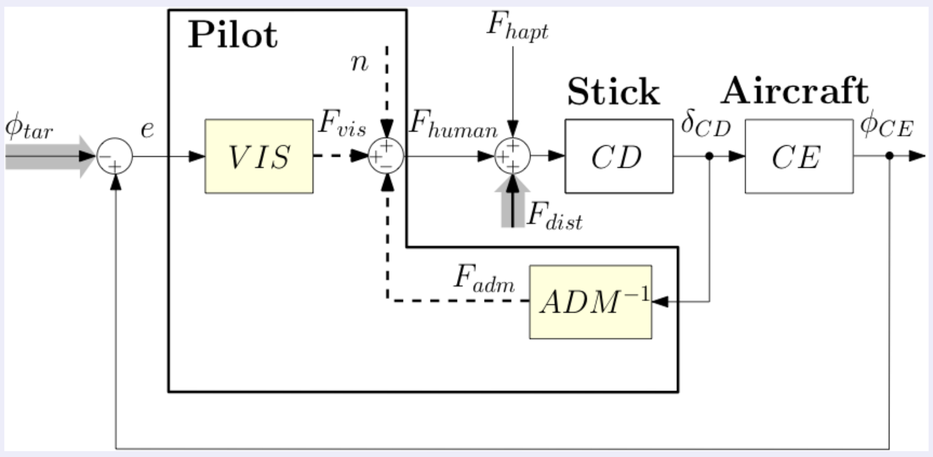
Introduction

The control of an aerial vehicle is a complex task that requires a pilot's continuous attention. Haptic aids can be used to help pilots during the manual control task. Haptic aids provide tactile sensations through a continuous external force applied to the control device. The design of the haptic force becomes a crucial issue, since it has to represent information that pilots can easily exploit. The aim of the PhD project is to design the haptic force based on the effect it has on the human dynamic responses (***human-centered design***).

Control Task

The first part of the PhD project focused on the design of haptic aids for a compensatory tracking task.



Multi-loop Pilot Identification [1, 2]

To identify pilot visual (VIS) and neuromuscular (ADM) responses, multi-loop identification techniques are needed. The conventional identification technique was proved to provide biased estimates. Two novel methods were proposed that do not show the same limitation of the conventional method.

- **CSD-ML METHOD**

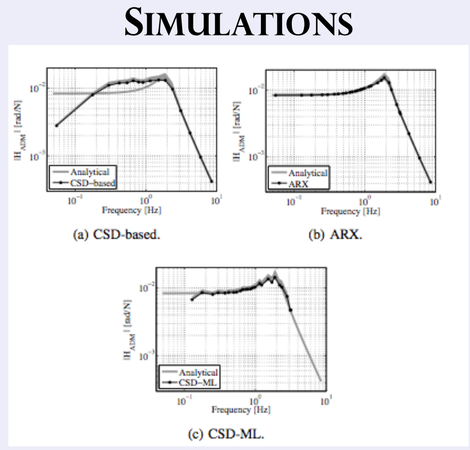
$$H_{tar} = \frac{S_{\varphi_{tar}\delta_{CD}}}{S_{\varphi_{tar}\varphi_{tar}}}, \quad H_{dist} = \frac{S_{F_{dist}\delta_{CD}}}{S_{F_{dist}F_{dist}}}$$

- **ARX METHOD**

$$\delta_{CD} = H_e e + H_{dist} F_{dist} + H_n n$$

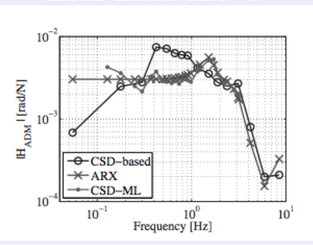
Block diagram algebra to find H_{adm} and H_{vis}

Simulations



(a) CSD-based. (b) ARX. (c) CSD-ML.

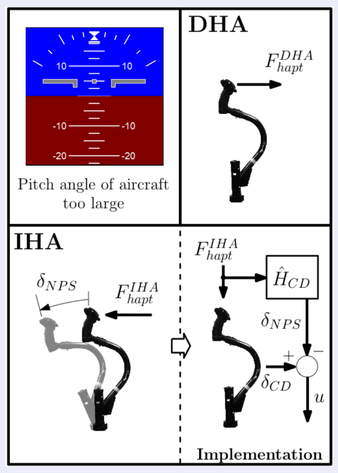
Experiment



DHA vs IHA [1, 3]

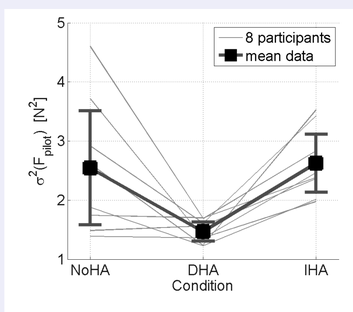
Two different approach were investigated to design the haptic aid:

- the Direct Haptic Aid (**DHA**), which produces tactile sensations that suggest the right control action to pilots. This was achieved by designing the DHA as a standard compensator that regulates *e* to zero.
- the Indirect Haptic Aid (**IHA**), which informs pilots and increases situational awareness indirectly. The IHA was designed to provide a force opposite in sign with respect to the DHA. Furthermore, the neutral point of the control device was shifted so that the actual command to the aircraft was zero with pilot out-of-the-loop.

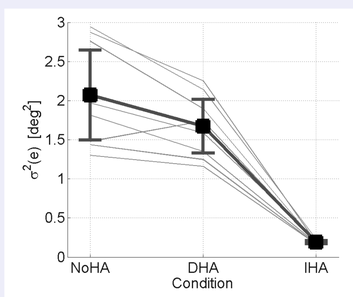


Experimental Results

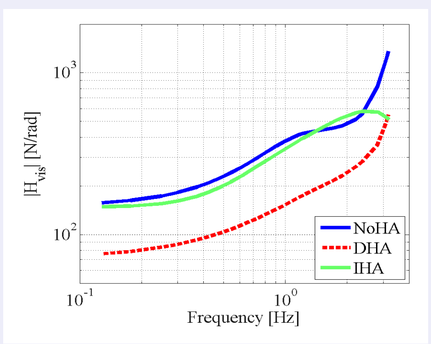
Control Effort: Lower with DHA.

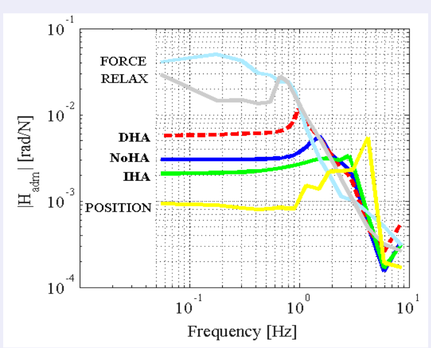


Performance: Better with IHA.



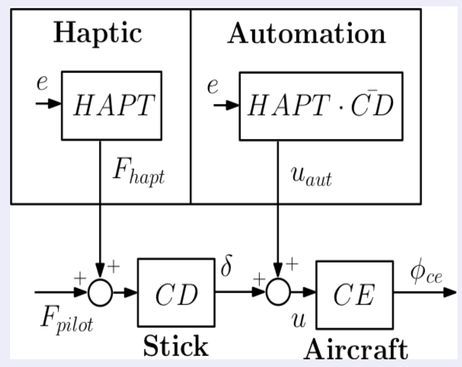
Pilot Responses





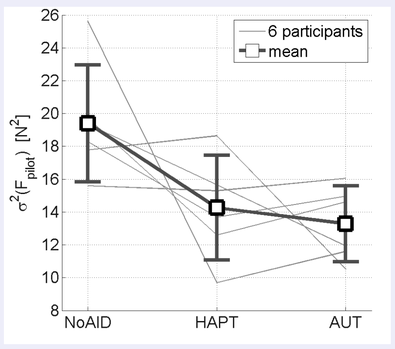
DHA vs Automation [4]

Automated systems surpass the performance usually achieved by pilots. However, they suffer from several issues caused by pilot unawareness of the control command from the automation. Haptic aids allow to overcome these issues by showing their control command through the haptic forces. To investigate how the transparency of the haptic control command influences performance and pilot behaviour, two ***equivalent haptic and automated systems*** were compared.

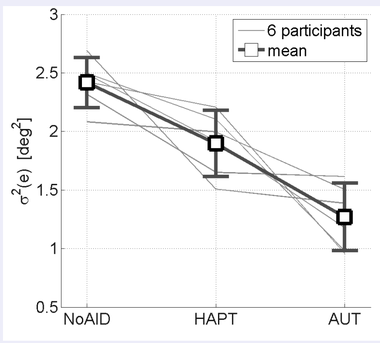


Experimental Results

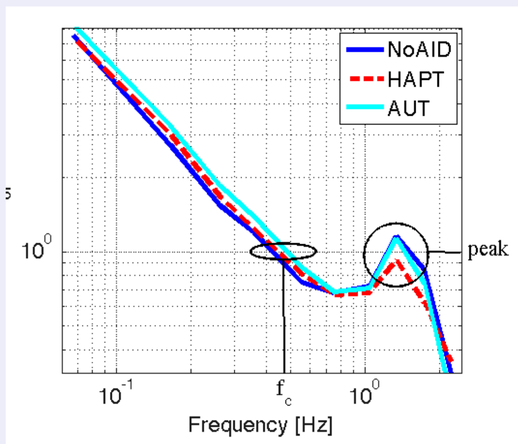
Control Effort: Lower with HAPT and AUT in a similar way.



Performance: Better with HAPT and AUT. AUT outperforms NoAID and HAPT.



Open-Loop Pilot Response



Higher crossover frequency f_c with AUT.
Lower neuromuscular peak with HAPT.

Publications

- [1] M. Olivari, F.M. Nieuwenhuizen, J. Venroij, H. H. Bülthoff, L. Pollini, ''Multi-loop Pilot Behaviour Identification in Response to Simultaneous Visual and Haptic Stimuli'', in *Proc. AIAA Model. and Simul. Technol. Conf.*, no. AIAA 2012-4795, Minneapolis, Minnesota, Aug. 2012
- [2] M. Olivari, F.M. Nieuwenhuizen, J. Venroij, H. H. Bülthoff, L. Pollini, ''Methods for Multi-Loop Identification of Visual and Neuromuscular Pilot Responses'', *IEEE Transactions on Cybernetics*, April 2013, submitted for publication
- [3] M. Olivari, F.M. Nieuwenhuizen, H. H. Bülthoff, L. Pollini, ''Pilot Adaptation to Different Classes of Haptic Aids in Tracking Tasks'', *AIAA Journal of Guidance, Control and Dynamics*, January 2014, submitted for publication
- [4] M. Olivari, F.M. Nieuwenhuizen, J. Venroij, H. H. Bülthoff, L. Pollini, 'An Experimental Comparison of Haptic and Automated Pilot Support Systems'', in *Proc. AIAA Model. and Simul. Technol. Conf.*, no. AIAA 2014-1739322, National Harbor, Maryland, Jan. 2014