Multibody analysis of helicopter pilot biomechanics for real-time end point impedance estimation

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EXTENDED ABSTRACT

1 Introduction and motivation

The design of aircraft human-machine interface has received increasing attention in the last several years, both regarding the development of innovative control systems [1] and the extended analysis of established layouts [2]. The latter is focused on assessing the control system performance and its robustness in allowing the pilots to safely accomplish operative targets. An important aspect, to this end, is the robustness of the control system design with respect to rotorcraft-pilot couplings (RPC), i.e. to potentially adverse dynamic couplings between the pilot and the vehicle [3]. When the pilots biomechanics interacts with the helicopter dynamics in a frequency range outside of the bandwidth of voluntary control action - typically identified in the $[0-1]$ Hz range - the interaction takes the name of Pilot-Assisted Oscillation (PAO).
The principal indicator of the potential interaction between the pilot and the vehicle is the Bio-Dynamic Feed-Through, or BDFT, which is the frequency domain relationship between the involuntary control inceptor deflection δ and the vehicle acceleration a, typically measured at the seat reference point. The most common shape of the BDFT is that of a second-order filter:

$$H_{\mathrm{BDFT}}(s) = \frac{\delta(s)}{a(s)} = \frac{\mu}{s^2 + 2\xi_p \omega_p s + \omega_p^2} \tag{1}$$

where μ is the static gain, a function of pilot modal mass associated with the normal mode dominating the pilot-control lever interaction, ξ_p and ω_p its damping ratio and natural frequency.
The shape of the BDFT makes it possible, in principle, to reduce its identification to the identification of three parameters contributing to the pilot arms end-point impedance related to the control lever rotations: a mass m_p, a damping coefficient c_p and a stiffness coefficient k_p, such that $\xi_p = c_p/2\sqrt{m_p k_p}$ and $\omega_p = \sqrt{k_p/m_p}$. The total impedance is not only a function of the pilot "static" bio-mechanical characteristics, but also to the instantaneous muscular activation, which in turn depends on numerous factors, among which the most important can be regarded as the pilots workload in the specific task they are required to perform and the operational environment [4, 5]. It is thus important to assess the robustness of the helicopter design to RPC considering the range of variation of the pilot BDFT.
Estimating the pilot end-point impedance on line, possibly in real time, will enable to assess the BDFT immediate variation due to the variation of exogenous parameters, like task demands, operational environment, flight control system mode switches, etc...
This work is dedicated to the development of a virtual testing framework in which the development of algorithms for the real time estimation of the pilot-helicopter BDFT.

2 Methods

The biomechanics of the pilot upper body, coupled with the dynamics of the control inceptors, is simulated using a multibody model of the human upper body [6], (Cf. Figure 1) developed in the open source multibody solver MBDyn. Simple tracking tasks, in which the virtual pilot is asked to maintain a constant inceptor reference position, are employed initially. Only the collective control channel is analyzed, in this preliminary work.

The basic test to calculate the BDFT consists in an open loop excitation of the pilot in the vertical axis, the most relevant for the collective channel. A sufficient number of tests is performed changing the parameters governing the muscular activation, whereas the pilot biometric parameters are kept constant . Parameters controlling the muscular activation are changed in order to represent either more relaxed tasks or more challenging tasks, requiring a higher precision and effort.
As per real pilots, stricter demands results in an increase of the aggressiveness towards the control inceptors as well as more frequent inputs injected by the pilot. These two effects reflect in an increased muscular activation and consequently in a variation of pilot mechanical impedance and pilot exerted force on the inceptor. Thus, a quantity related to force spectrum and derivative norm together with the impedance are used to estimate the total workload of the pilot. Given the impossibility to get a subjective workload evaluation from the pilot, the total workload is estimated only from objective physical quantities.
The task assigned to the virtual pilot is a pure Point Tracking, representative of an attitude tracking task while subjected to external disturbances. In these type of tasks, the difficulty is strongly related to the precision demands and to the total amount of underwent vibration in the $[1.5-7]$Hz range [7]. To validate the results, the new indices are compared to the Gray's 2D Pilot Inceptor Workload [8], an quantitative index estimating the pilot workload from the inceptor time history.

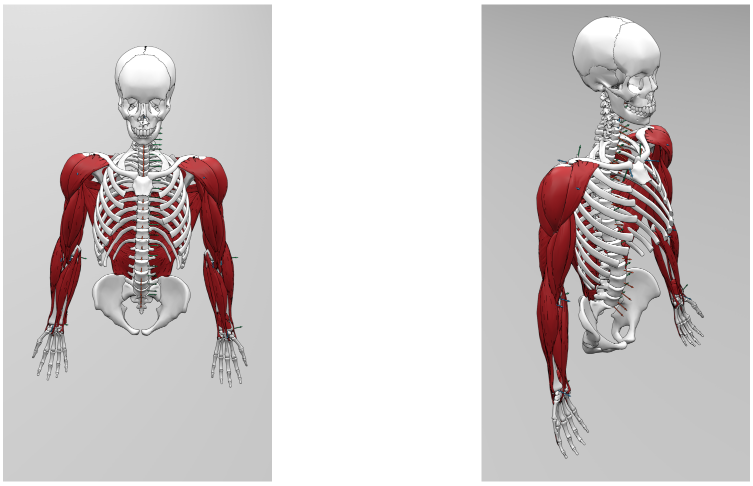

Figure 1: The multibody model of the human upper body.

3 Expected results

A identification algorithm able to produce robust estimates of the end-point stiffness as a function of the objective workload measures is sought, with its structure currently under development.
The identification algorithm will then be tested for its real-time performance by feeding it with time histories coming from simulations in which both the pilot biometric parameters and muscular activation are varied, simulating a context-switching from more relaxed tasks to more challenging ones, and vice versa. Comparison between the results obtained by the identification algorithm and the reference BDFT data will provide for a initial validation of the methods.
At future stages, the comparison between the numerical simulations and experimental tests, performed on a dedicated test facility[9] is envisioned.

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