Augmented Human-Machine Interface: Providing a Novel Haptic Cueing to the Tele-Operator

Samantha M. C. Alaimo, Lorenzo Pollini, Jean Pierre Bresciani and Heinrich H. Bülthoff

***Abstract* - The sense of telepresence is very important in teleoperation environments in which the operator is physically separated from the vehicle. Extending the visual interface to a multi-sensory interface could allow the teleoperator to better perceive information of the environment and its constraints. The use of force feedback would complement the visual information through the sense of touch. This paper focuses on a novel concept of haptic cueing developed in order to optimize the performance of a teleoperator and to improve the human-machine interfaces. A first experiment showed the effectiveness of the newly developed haptic cueing, the Indirect Haptic Aiding, with respect to visual cueing only. In a second experiment, we compared the IHA to an existing haptic concept, the Direct Haptic Aiding. The problem of wind gust rejection in Remotely Piloted Vehicles is used as test bench. The results show the effectiveness of both methods but a better performance of the IHA-based system for pilots without any previous training about the haptic aids. DHA-based system provided instead better results after some pilot training on the experiment. Pilots reported better sensation of the wind gusts with IHA-based feedback. The two haptic aids concepts are going to be compared in an obstacle detection/avoidance task.**

INTRODUCTION

THE aim of this work is the investigation of possible haptic aids for teleoperated systems.

In the context of teleoperated systems where visual cues only have always been used, the adoption of an artificial feel system for the stick appears to increase the situational awareness, especially in terms of external disturbances and faults which degrade the vehicle maneuvering capability; this is extremely relevant for Unmanned Aerial Vehicles (UAVs). Tactile cues have shown to complement the visual information (through the visual displays of a remote Control Ground Station) and improve the efficiency of the teleoperation [1].

Haptic cues in supporting collision avoidance has always been represented by repulsive forces created by objects in the environment in order to help the operator to avoid the obstacles. Research on autonomous ground mobile robots usually involves virtual repulsive forces to avoid collisions with obstacles [1, 4]. The class of all Haptic aids which produce forces and/or sensations (due to stick stiffness changes for instance) aimed at "forcing" or "facilitating" the pilot to take some actions instead of others was named Direct Haptic Aiding (DHA) [1]. In general in this case the operator has to be compliant with the force felt on the stick.

The sense of touch could be used instead, as originally intended in Haptic research, to provide the pilot with an additional source of information that would help him, indirectly, by letting him know what is happening in the remote environment and leaving him the full authority to take control decisions. In general, in this case the operator has to oppose to the force felt on the haptic device. This class of Haptic aids, which is clearly complementary to the previously described one, was named Indirect Haptic Aiding (IHA) [2, 5]. As a matter of fact, when a haptic input requires a reaction to a stimuli rather than compliance might be more 'natural' for the human being because it exploits the highly automatic and fast stretch response [3].

Two experiments have been run both with the same simulation environment: the first one proved the effectiveness of the newly developed IHA with respect to the absence of the force feedback (only visual feedback); the second one has been run in order to compare the two just described approaches (Direct and Indirect Haptic Aiding) within the specific field of Remotely Piloted Vehicles control. To run the experiments a simulation environment has been prepared.

I. THE SIMULATION ENVIRONMENT OF THE EXPERIMENTS

A simulated flight experiment was set-up by using a fully non linear aircraft simulator to provide a realistic aircraft response. An aircraft simulator was implemented using a Matlab/Simulink simulation. The selected aircraft model was a De Havilland Canada DHC-2 Beaver implemented using the Simulink Flight Dynamics and Control Toolbox.

We prepared a simple control task: the aircraft is initially flying levelled in trimmed condition at constant altitude (*300 ft*). Three severe vertical wind gusts are simulated by artificially injecting three control disturbances (elevator impulses) of randomized duration (2, 3 or 3.5 seconds), starting time and sign (upward or downward). The task was to fly at constant altitude (300 ft) although the presence of the wind gusts. The IAE (Integral Absolute Error) of the altitude has been chosen as a measure of the performances.

A simulated Integrated Flight Display (Figure 1) was used during the experiments to produce the visual cues; this was designed to be as similar as possible to conventional aircraft head-down display.

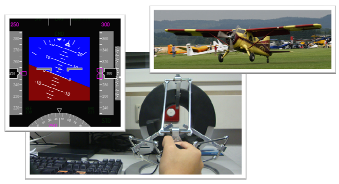

Fig. 1 – The experimental setup.

The control stick was simulated using a high precision force feedback device (omega.3, Force Dimension, Switzerland) which provided control stick simulated force up to 12 *N*.

The force felt on the stick (1) is a combination of an elastic term with constant stiffness, F_{el}, a damping term, F_d and an external force is the external force term, F_E. δ_S and $\dot{\delta}_S$ are respectively the deflection and deflection rate of the stick.

$$F_S = K_{el} \cdot \delta_S + K_d \cdot \dot{\delta}_S + F_E = F_{el} + F_d + F_E \qquad (1)$$

In the first experiment three conditions were compared: the only visual feedback condition (No Force Case in which $F_S = 0$), the haptic feedback condition (IHA or Simple Force Case) and the condition in which the haptic feedback has been doubled to test whether the amount of the force is relevant (Doubled IHA or Double Force Case).

The second experiment consisted of three different cases: NoEF, IHA and DHA.

The first two terms of the (1) are present in all the conditions of the experiment. The external force term is indicative of the condition of the force. In the first condition (NoEF) the external force component is set to zero (the baseline condition). In the IHA condition (Figure 2), the external force term (2) is proportional to the dynamic pressure, q (in turn proportional to the squared velocity of the vehicle), and to the angle of attack, α (α_{trim} is the angle of attack in trim condition) [2, 5].

$$F_E = K \cdot q \cdot (\alpha - \alpha_{trim}) \qquad (2)$$

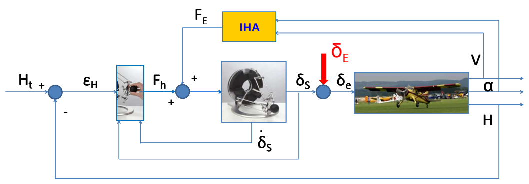

Fig. 2 – The IHA Simulator. δ_E is the wind gust. *H* is the altitude. F_h is the force that the pilot is applying on the stick.

In the DHA condition (Figure 3) the external force term (3) is generated by a compensator based on the structural model of the human pilot developed by Hess (in turn based on the crossover model by McRuer):

$$\frac{F_E(s)}{\varepsilon_H(s)} = \frac{3687\,s^2 + 1477\,s}{s^4 + 14.75\,s^3 + 209.5\,s^2 + 1089\,s + 13.04} \qquad (3)$$

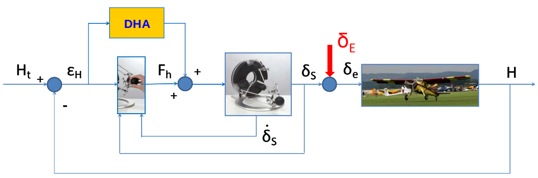

Fig. 3 – The DHA Simulator. δ_E is the wind gust. *H* is the altitude. F_h is the force that the pilot is applying on the stick.

II. General Results and Conclusions

The newly developed IHA concept seems to be a valid help in teleoperation schemes as concerning the telepresence and natural reaction of the teleoperators.

The first experiment showed that providing IHA could constitute a valuable help for the operators. Participant performed significantly better when the haptic cueing was available (with both Simple and Double Cases) than when only visual cueing was available (No Force Case). As none of the participants had any experience with piloting, our results suggest that this type of aiding is rather 'natural' as beneficial effects can be observed without any previous learning.

The second experiment showed that when considering all the trials (12 trials for each condition) no significant difference amongst the three types of aiding can be found. When analyzing only the first two trials for each condition, one can observe that the performance is significantly worse when using the DHA than with the other two types of force feedback. On the other hand, after some training, this tendency is reversed, the performances observed with the DHA aiding scheme being significantly better than in the other two conditions. Taken together, these results suggest that the DHA is less natural than the IHA (even impairing the performance when compared to a condition in which no force aiding is provided), but that only very few trials are necessary to 'master' it so that it allows significantly better performances than both the IHA and a system without external force feedback.

III. Acknowledgments

We gratefully acknowledge the support of the WCU (World Class University) program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (R31-2008-000-10008-0).

References

[1] Lam, T.M., Boschloo, H.W., Mulder, M., van Paassen, M.M.: "Artificial Force Field for Haptic Feedback in UAV Teleoperation". In: IEEE Transactions on Systems, Man and Cybernetics, Part A: Systems and Humans. Vol. 39, Issue 6, pp. 1316 – 1330, Nov. 2009.

[2] Alaimo, S.M.C., Pollini, L.,Magazzù, A.,Bresciani, J.P., Robuffo Giordano, P., Innocenti, M., Bülthoff, H.H., "Preliminary Evaluation of a Haptic Aiding Concept for Remotely Piloted Vehicles". In EuroHaptics 2010 Conference, Amsterdam, July 2010.

[3] Kveraga, K., Boucher, L., Hughes, H.C., "Saccades operate in violation of Hick's law", Exp Brain Res. 2002 October; 146(3): 307–314. Published online 2002 August 10. doi: 10.1007/s00221-002-1168-8.

[4] Diolaiti, N., Melchiorri, C., "Tele-Operation of a Mobile Robot through Haptic Feedback". IEEE Int. Workshop on Haptic Virtual Environments and Their Applications (HAVE 2002). Ottawa, Ontario, Canada, 17-18 November 2002.

[5] Alaimo, S. M. C., Pollini, L., Bresciani, J. P., Bülthoff, H. H., "A Comparison of Direct and Indirect Haptic Aiding for Remotely Piloted Vehicles". Proceedings of the 19th IEEE International Symposium in Robot and Human Interactive Communication (IEEE Ro-Man 2010), 541-547.