Embodied motor learning wearing ALEx exoskeleton

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***Abstract*— This paper presents a task learning technique with haptic and visual feedback, along with experimental results. Haptic feedback is achieved by means of a embodiment in the Arm Light Exoskeleton ALEx, and visual feedback is given through immersion in a Virtual Reality environment. The proposed approach is assessed by means of a between-group evaluation on ten subjects, comparing different kinds of feedback for learning a series of motor tasks. At present, experiments are ongoing.**

I. INTRODUCTION

Motor learning of new tasks is an important aspect of research in sport and robotic rehabilitation. A key advancement in this domain has been provided by real-time motion tracking and feedback that allow to provide instantly the user with cues for improving performance. The policies and the technology for generating such a feedback have important effect on the learning rate, and on the ability to transfer the learned motion to the real world. Physical feedback applied on the user limbs can be provided by means of wearable haptics technology with interesting results. One type of haptic feedback is based on vibrotactile stimulation obtained by vibrating motors applied on different body locations [18], [22], [4]. The alternative approach is provided by kinesthetic feedback in which force is directly exterted on the body of the subject, typically in one single point or through an object tool. Wearable haptics interfaces such as exoskeletons allow to overcome the typical limitation of workspace and transparency found in desktop haptic interfaces. An exoskeleton is an external structural mechanism with joints and links theoretically corresponding to those of the human body. The diffusion of exoskeletons, also called wearable robots, is significantly increasing in recent years. Some relevant examples of upper limb exoskeletons in the literature are ABLE [9], Armeo [10], MGA [14], L-Exos [8], Armin [16], Carex [15], ARMON [11], HE [7] and [1], [19], [21], [17].

The combination of haptic and visual feedback in immersive environments, is promising in supporting the learning of new tasks thanks to the multimodal feedback generation [20]. In particular immersive environments allow to provide feedbacks that maximize the learning process [6] overcoming real-world limitations.

Immersive visual feedback and sophisticated wearable haptics can be combined creating an embodied environment for motor learning. The contribution of this paper is the proposition and experimental test of a task learning technique with haptic and visual feedback, featuring embodiment in an arm exoskeleton and a virtual reality scenario.

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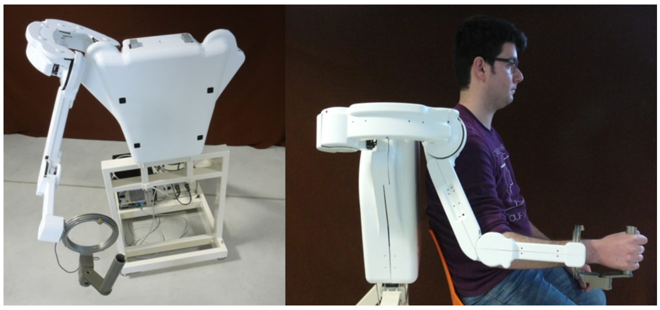

Fig. 1. ALEx exoskeleton and a user wearing it.

II. MATERIALS AND METHODS

Experiments have been carried out using the Arm Light Exoskeleton ALEx [2], [3], depicted in Figure 1. ALEx is an arm exoskeleton with remotely actuated joints. Motors are inside a backpack, and they are connected to the joints by means of tendon transmissions. ALEx features six degrees of freedom (dofs):

- shoulder abduction/adduction;
- shoulder rotation;
- shoulder flexion;
- elbow flexion;
- wrist prono-supination;
- wrist flexion.

The rotation of the shoulder is achieved through a remote center of rotation mechanism. The first three rotational axes are incident and mutually orthogonal in order to emulate the kinematics of a spherical joint with the same center of rotation of the human shoulder. The first four dofs are sensorized and actuated, while the last two dofs are sensorized only. Optical incremental encoders are integrated into the motor groups, and absolute angular sensors are directly integrated in the joints. There are no force sensors.

To physically interact with the exoskeleton, the user puts his/her wrist in a reference ring and grabs a handle (see Figure 1). ALEx features 95% coverage of the natural workspace of the human arm, and the mass of its moving parts is less than 4 kg. ALEx exerts up to a maximum of 50 N continuous force, with 100 N peak force. A novel version of ALEx featuring a new actuation paradigm proposed by our group [12], [13] is also being developed: being the actuation system of ALEx located remotely, only the backpack is replaced.

Fig. 2. User moving its own virtual arm using the ALEx exoskeleton and the Oculus Rift.

The virtual environment is based on the XVR [5] framework enhanced with the support of real-time virtual human and interface with the ALEx control system. The visual feedback is provided through the Oculus Rift HMD providing a first person perspective of the user that is capable of seeing its own body as in Figure 2.

The learning task features a feedback based on physical presentation of the motion that has to be performed by means of the haptic feedback of the exoskeleton from a recorded trajectory, and then visual feedback with "ghost effect" overimposed on the virtual arm for guiding the motion of the subject. The assessment of the proposed approach is based on a between-group evaluation on ten subjects, comparing haptic-only feedback with visuo-haptic feedback for learning a series of motor tasks, such as moving objects from different locations along a trajectory.

Experimental results will be included in the final version of the paper.

III. Conclusion

We proposed a task learning technique involving embodiment in the ALEx exoskeleton and immersion in a virtual reality environment, providing haptic and visual feedback. Experiments are still ongoing.

References

[1] Sunil Kumar Agrawal and Abbas Fattah. Design of an orthotic device for full or partial gravity-balancing of a human upper arm during motion. In *Intelligent Robots and Systems, 2003.(IROS 2003). Proceedings. 2003 IEEE/RSJ International Conference on*, volume 3, pages 2841–2846. IEEE, 2003.

[2] Massimo Bergamasco, Fabio Salsedo, and Basilio Lenzo. Actuating method and device for human interaction multi-joint mechanisms (Application WO 2013186701), 2013.

[3] Massimo Bergamasco, Fabio Salsedo, and Basilio Lenzo. An exoskeleton structure for physical interaction with a human being (Application WO 2013186705), 2013.

[4] Aaron Bloomfield and Norman I Badler. Virtual training via vibrotactile arrays. *Presence: Teleoperators and Virtual Environments*, 17(2):103–120, 2008.

[5] Marcello Carrozzino, Franco Tecchia, Sandro Bacinelli, Carlo Cappelletti, and Massimo Bergamasco. Lowering the development time of multimodal interactive application: the real-life experience of the xvr project. In *Proc. of ACM ACE*, pages 270–273. ACM, 2005.

[6] Philo Tan Chua, Rebecca Crivella, Bo Daly, Ning Hu, Russ Schaaf, David Ventura, Todd Camill, Jessica Hodgins, and Randy Pausch. Training for physical tasks in virtual environments: Tai chi. In *Virtual Reality, 2003. Proceedings. IEEE*, pages 87–94. IEEE, 2003.

[7] Marco Fontana, Fabio Salsedo, Simone Marcheschi, and Massimo Bergamasco. Haptic hand exoskeleton for precision grasp simulation. *Journal of Mechanisms and Robotics*, 5(4):041014, 2013.

[8] Antonio Frisoli, Massimo Bergamasco, Maria C Carboncini, and Bruno Rossi. Robotic assisted rehabilitation in virtual reality with the l-exos. *Stud Health Technol Inform*, 145:40–54, 2009.

[9] P Garrec, JP Friconneau, Yvan Measson, and Yann Perrot. Able, an innovative transparent exoskeleton for the upper-limb. In *Intelligent Robots and Systems, 2008. IROS 2008. IEEE/RSJ International Conference on*, pages 1483–1488. IEEE, 2008.

[10] Domien Gijbels, Ilse Lamers, Lore Kerkhofs, Geert Alders, Els Knippenberg, and Peter Feys. The armeo spring as training tool to improve upper limb functionality in multiple sclerosis: a pilot study. *Journal of neuroengineering and rehabilitation*, 8(5):5, 2011.

[11] J.L. Herder, N. Vrijlandt, T. Antonides, M. Cloosterman, and P.L. Mastenbroek. Principle and design of a mobile arm support for people with muscular weakness. *Journal of rehabilitation research and development*, 43(5):591, 2006.

[12] Basilio Lenzo, Antonio Frisoli, Fabio Salsedo, and Massimo Bergamasco. An innovative actuation concept for a new hybrid robotic system. *Romansy 19-Robot Design, Dynamics and Control*, page 135, 2013.

[13] Basilio Lenzo, Antonio Frisoli, Fabio Salsedo, and Massimo Bergamasco. New gravity balancing technique and actuation concept for spatial serial manipulators. In *Advances in Robot Kinematics, 2014 International Conference ARK, in press*, 2014.

[14] Michael Liszka. *Mechanical design of a robotic arm exoskeleton for shoulder rehabilitation*. PhD thesis, 2006.

[15] Ying Mao and Sunil Kumar Agrawal. Design of a cable-driven arm exoskeleton (carex) for neural rehabilitation. *Robotics, IEEE Transactions on*, 28(4):922–931, 2012.

[16] Tobias Nef, Matjaz Mihelj, Gabriela Kiefer, Christina Perndl, Roland Muller, and Robert Riener. Armin-exoskeleton for arm therapy in stroke patients. In *Rehabilitation Robotics, 2007. ICORR 2007. IEEE 10th International Conference on*, pages 68–74. IEEE, 2007.

[17] Joel C Perry, Jacob Rosen, and Stephen Burns. Upper-limb powered exoskeleton design. *Mechatronics, IEEE/ASME Transactions on*, 12(4):408–417, 2007.

[18] Emanuele Ruffaldi, Alessandro Filippeschi, Antonio Frisoli, Oscar Sandoval, Carlo Alberto Avizzano, and Massimo Bergamasco. Vibrotactile perception assessment for a rowing training system. In *EuroHaptics Conference, 2009 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. World Haptics 2009. Third Joint*, pages 350–355. IEEE, 2009.

[19] Ioannis Sarakoglou, Sophia Kousidou, Nikolaos G Tsagarakis, and Darwin G Caldwell. Exoskeleton-based exercisers for the disabilities of the upper arm and hand. *Sashi S Kommu, Chapter27*, pages 499–522, 2007.

[20] Roland Sigrist, Georg Rauter, Robert Riener, and Peter Wolf. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic bulletin & review*, 20(1):21–53, 2013.

[21] Gabriëlle JM Tuijthof and Just L Herder. Design, actuation and control of an anthropomorphic robot arm. *Mechanism and machine theory*, 35(7):945–962, 2000.

[22] Janet van der Linden, Erwin Schoonderwaldt, Jon Bird, and Rose Johnson. Musicjacket?combining motion capture and vibrotactile feedback to teach violin bowing. *Instrumentation and Measurement, IEEE Transactions on*, 60(1):104–113, 2011.