Design of a Mixed Reality Environment for the extrapolation of Reference Trajectories in Upper-Limb Rehabilitation

Anna Bucchieri, Stefano Buccelli, Giacinto Barresi
Istituto Italiano di Tecnologia
anna.bucchieri@iit.it
stefano.buccelli@iit.it
giacinto.barresi@iit.it

Federico Tessari
Massachusetts Institute of Technology
Cambridge, Massachusetts
ftessari@mit.edu

Elena De Momi
Politecnico di Milano
Milan, Italy
elena.demomi@polimi.it

Matteo Laffranchi, Lorenzo De Michieli
Istituto Italiano di Tecnologia
Genoa, Italy
matteo.laffranchi@iit.it
lorenzo.demichieli@iit.it

***Abstract*—Upper-limb rehabilitation involves the repetition of the same movements in time. Mixed Reality (MR) technologies can be useful to both enhance patients' engagement and provide guidance through visual and acoustic feedback. In this study we present the design of a MR serious game for the shoulder rehabilitation. The application was tested on five healthy subjects while performing a motion capture analysis with the aim to extrapolate normative volumes, associable to tunnels. In the future work, the resulting tunnel shapes will be then imported into the MR environment to be exploited as reference trajectories for pathologic subjects. The volumes can also be used to implement time-independent control strategies on an upper-limb exoskeleton.**

Keywords—Rehabilitation, Upper limb, Mixed Reality, Serious game.

I. Introduction

Upper-limb rehabilitation is crucial for the recovery of motor functions following a traumatic event, such as a musculoskeletal disorder in case of orthopedic patients or a neuro-functional accident in case of neurological ones. Especially for the latest, rehabilitation is characterized by highly repetitive and intensive movements which may result in long-lasting and tedious therapy sessions [1]. To enhance therapy outcomes, upper-limb exoskeletons have proven to be useful in increasing the intensity and motivation during the rehabilitative sessions [2], particularly thanks to the implementation of assistive control strategies guiding the subjects along defined trajectories. Different kind of technologies can be employed to encourage patient's motivation during the exercises (e.g. serious games presented by means of monitors or headsets for Virtual Reality) which can be integrated to the robotic rehabilitation [3]. However, this application does not encourage the interaction of the patients with the physical environment, leading to Activities of Daily Living (ADLs) deterioration [4].

On the other hand, Mixed Reality (MR) technologies allow to visualize digital objects overlaid to the real world and interact with them as physical objects [5], thus creating serious games characterized by a better hand-eye coordination experience with respect to most common applications on bidimensional displays [4]. This is particularly important in the occupational therapy, where the target is the recovery of movements in ADLs: a Mixed Reality approach allows the design of multiple scenarios for the exercises, making them more engaging and stimulating [5, 6]. Moreover, the employment of MR technologies might be exploited not only to motivate the subject, but also as a source of guidance through feedback to indicate whether the task is being performed correctly or not [7]. Thanks to the visual and auditory cues, the patients are able to self-evaluate and self-correct their performance thus leading to therapy effectiveness [8]. In this study, we selected a series of movements usually performed during shoulder rehabilitation and consequently developed a serious game for MR applications on HoloLens2 focused on a realistic activity such as the Do-It-Yourself (DIY) one. The application was tested on 5 healthy subjects while performing a motion capture analysis of the positions of their right hands. The aim of the work was to analyze the acquired trajectories and extrapolate reference volumes to be then imported on the MR application and exploited as references both for MR and robotic control.

II. Materials and Methods

A. Hardware and Software

The proposed rehabilitation environment was created in Unity and then visualized on Microsoft HoloLens2, a head-mounted display designed for Mixed Reality applications. The Vicon optical capture system was used to acquire kinematic data from subjects. Data were analyzed in MATLAB.

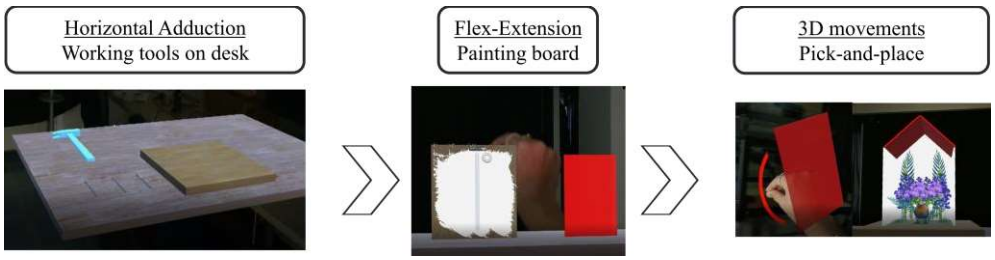

Fig. 1 Schematic of the MR environment created in Unity. The application is composed by three main tasks which lead to the creation of a bird house.

B. Mixed Reality App

The very first step for the design and development of the proposed app was the choice of the set of movements. Particularly, horizontal adduction, shoulder flexion/extension and pick-and-place ones were chosen. Consequently, a DIY experience was designed on Unity for MR applications. The goal of the game is to build a bird house and it is composed by three main steps (Fig. 1). The first one consists in placing tools from one desk to another, both located at 40 cm below the eyes to facilitate the horizontal adduction movement. The target region is indicated by specific feedback. In the second task the subject is required to paint wooden boards that represent the house walls and roofs, all placed on a shelf at the height of eyes. This application was implemented by exploiting vertical slider tools. Once painted, the boards need to be picked from the shelf and placed down on the working desk where the tools were previously dragged. The completion of the three tasks leads to a final reward consisting in the appearance of an already-built bird house.

C. Motion capture Analysis

The application was tested on 5 healthy subjects, male and females between 25 and 27 years-old, while performing a motion capture analysis. For this study, people from 23rd female to 99th male percentiles were selected in order to investigate the performance of movements in a highly variable population of subjects. The subjects wore two markers, one on the back, acting as a reference, and another one on the right hand, which coordinates in space were registered with respect to the reference one. The x, y, z coordinates of the hands were then analyzed.

III. Preliminary Results and Discussion

The extracted curves were processed in order to eliminate the offset given by the different subjects' heights. The analysis showed how each person performs movements following a subjective trajectory. However, it was possible to notice how the set of curves could all be included into a volume of different shapes, associable to tunnels. Particularly, for the first task, the movements associated to the dragging of different objects from one table to another could be included into portions of a torus and a cylinder of mean radius of 15.42 cm (Fig. 2). About the third task, the pick-and-place movements could not be included into a predefined shape: a dedicated algorithm was implemented to define a custom volumetric shape of circular section with variable radius with respect to the standard deviation changes between curves and their mean.

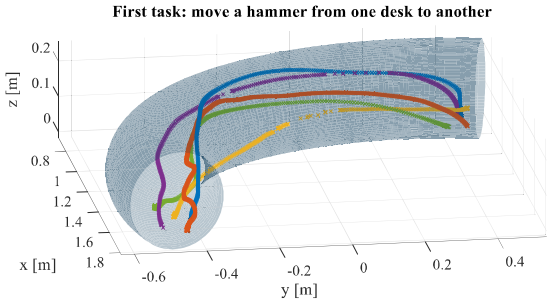

Fig. 2 Set of curves representing the cartesian coordinates of the five subjects' hands while performing the first task (pick a hammer from one table and place it on another table). The curves can all be fitted inside a portion of torus. The light blue curve is related to the subject 1, violet to the second subject, red to the third, green to the fourth, and yellow to the fifth subject.

The obtained surfaces were then exported as stereolithography files to be imported as reference trajectories into the Mixed Reality environment. The 3D curves will be then exploited to implement time-independent control strategies for an upper-limb exoskeleton while performing the interactive rehabilitation in synergy with HoloLens2. In particular, this research activity will lead to create a vector field for providing both an assistance along the longitudinal direction of the exercise (inside the tunnel) and a correction along the orthogonal one (perpendicular to the surface of the tunnels). The combination of the two technologies will be tested on patients to investigate the rehabilitative impact of such approach.

IV. Conclusion

The preliminary study is based on the extrapolation of normative reference curves and related 3D volumes, enabling the upcoming development of a robotic platform for upper-limb rehabilitation empowered by game-based Mixed Reality solutions.

Acknowledgement

This research received funding by the Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro (INAIL), under grant: agreements "PR19-RR-P2 – RoboGYM".

References

[1] E. Martinez-Martin and M. Cazorla, "Rehabilitation technology: assistance from hospital to home," *Computational intelligence and neuroscience*, vol. 2019, 2019.

[2] T. Proietti, V. Crocher, A. Roby-Brami, and N. Jarrasse, "Upper-limb robotic exoskeletons for neurorehabilitation: a review on control strategies," *IEEE reviews in biomedical engineering*, vol. 9, pp. 4-14, 2016.

[3] T. Gueye, M. Dedkova, V. Rogalewicz, M. Grunerova-Lippertova, and Y. Angerova, "Early post-stroke rehabilitation for upper limb motor function using virtual reality and exoskeleton: equally efficient in older patients," *Neurologia i neurochirurgia polska*, vol. 55, no. 1, pp. 91-96, 2021.

[4] M. Khademi, H. M. Hondori, L. Dodakian, S. Cramer, and C. V. Lopes, "Comparing "pick and place" task in spatial augmented reality versus non-immersive virtual reality for rehabilitation setting," in *2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2013: IEEE, pp. 4613-4616.

[5] A. Alamri, J. Cha, M. Eid, and A. El Saddik, "Evaluating the post-stroke patients progress using an augmented reality rehabilitation system," in *2009 IEEE International Workshop on Medical Measurements and Applications*, 2009: IEEE, pp. 89-94.

[6] A. G. D. Corrêa, I. K. Ficheman, R. de Deus Lopes, A. N. Klein, and S. J. Nakazune, "Augmented reality in occupacional therapy," in *2013 8th Iberian Conference on Information Systems and Technologies (CISTI)*, 2013: IEEE, pp. 1-6.

[7] M. Sousa, J. Vieira, D. Medeiros, A. Arsenio, and J. Jorge, "SleeveAR: Augmented reality for rehabilitation using realtime feedback," in *Proceedings of the 21st international conference on intelligent user interfaces*, 2016, pp. 175-185.

[8] V. C. Cavalcanti, M. I. de Santana Ferreira, V. Teichrieb, R. R. Barioni, W. F. M. Correia, and A. E. F. Da Gama, "Usability and effects of text, image and audio feedback on exercise correction during augmented reality based motor rehabilitation," *Computers & Graphics*, vol. 85, pp. 100-110, 2019.