Rehabilitation of Hand Motor Impairment Through Combined Virtual Reality and Wearable Robotics

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Abstract— **Manual operations, such as object manipulation or communication gestures, are at the base of many functional and social everyday-life tasks. For people who lost hand functionalities due to a trauma or an accident, rehabilitation is thus crucial for the improvement or restoration of their quality of life. Mirror therapy is a promising approach to recover from monitor impairments, leveraging on the brain illusion of the recreated motion of the impaired hand. We propose a feasibility study to understand whether the combination of virtual reality and wearable robotics can improve the performance of such therapy. We speculate that by recreating the impaired hand motion in virtual reality and inducing it through the action of a hand exoskeleton, the therapy efficacy increases. Furthermore, we believe that the proposed therapy setup could improve the comfort of both patients and therapists and open interesting application scenarios in the field of telemedicine.**

I. Introduction

Most patients experience limitation of hand functions right after a stroke [1], [2]; many others suffer from long-lasting hand-motor impairments [3]. As hand impairments heavily impact daily activities [4], [5], hand rehabilitation is crucial for the patient's quality of life. Among the others, Mirror Therapy (MT) has a positive effect on motor function recovery [6]–[8]. In a traditional setup, the patient sits in a front of a mirror and performs simple motions with the healthy hand, while the impaired one is hidden behind the mirror. The reflection of the healthy hand is visually perceived as the impaired one, tricking the brain and stimulating neuroplasticity [6]. Virtual Reality (VR) can be used to provide patients with immersive training environments to stimulate motor learning, motor recovery, and neuroplasticity [9]. Indeed, when combined with VR, MT is well-tolerated by patients [10], and can improve the functional abilities of impaired hands [11], [12]. Similarly, several meta-analyses show that robotics-supported therapy is a viable complement to traditional methods, with comparable results to the dose-matched standard of care rehabilitation [13]–[17].

It is noteworthy that the extensive use of these systems in activities of daily living increases acceptance, and potentially enhances efficacy [18], [19]. However, the use of these devices in domestic settings and the consequent widespread implementation of these technologies remains limited [20].

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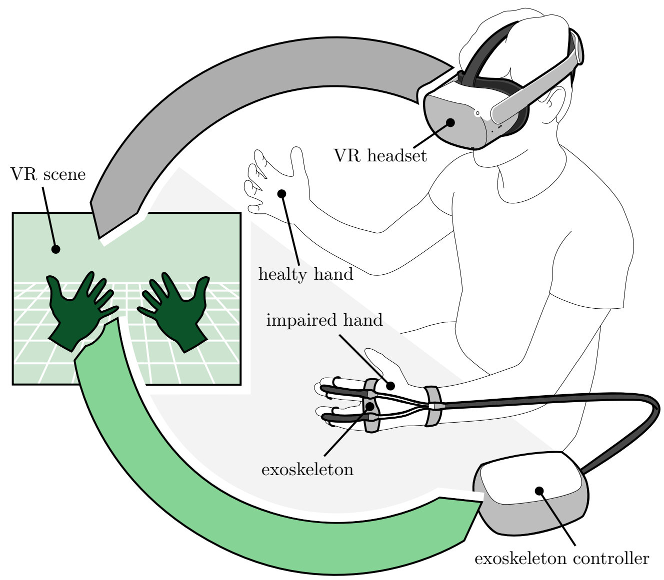

Fig. 1. The concept of our project: in VR, the motion of the healthy hand is tracked and mirrored onto the impaired hand; the configuration of the virtual mirrored hand is then reproduced onto the real impaired hand through the exoskeleton. The illusion of motion of the impaired hand is thus stimulated both visually in VR and physically in the real-world hand.

To the best of our knowledge, robotics combined with VR has not been deployed in MT. However, in general, the combination of VR and robotics is promising for clinical research in neuro-rehabilitation [21]. In fact, incorporating them into rehabilitation programs could increase the frequency and duration of the therapy, resulting in better outcomes [22].

In a recent project funded by Innosuisse—the Swiss Innovation Agency, we have proposed a feasibility study to verify the benefit of combining VR and wearable robotics in MT. We posit that the perception of the impaired hand motion, visually reconstructed in VR and physically transmitted to the patient through an exoskeleton, increases the MT efficacy (Fig. 1). The rationale of our project and its early implementation is presented in Sec. II, whereas Sec. III discusses open challenges and possibilities offered by our framework.

II. The VRHEM Project

Our project "Virtual Reality and Hand Exoskeleton for Mirror Therapy: a Feasibility Study (VRHEM)" aims at improving MT by augmenting the brain illusion of impaired hand motion using visual and physical perception. The first is created by reconstructing the impaired hand motion in VR; the latter is induced to the real hand by the action of the

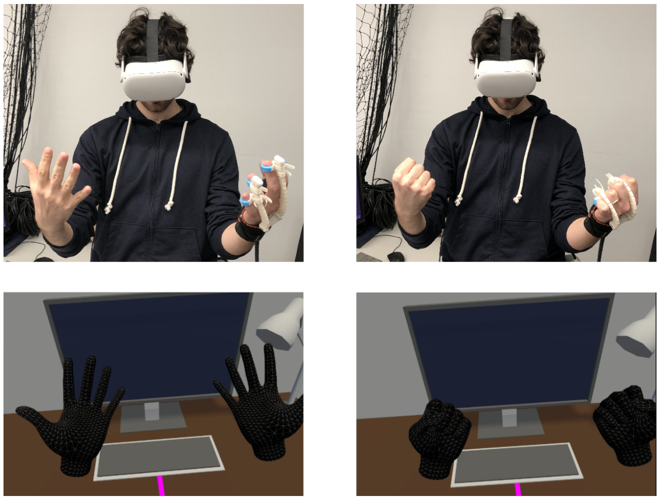

Fig. 2. Implementation of the proposed therapy setup. The user wears a hand exoskeleton and a VR headset while closing and opening their hand.

exoskeleton. The main objective is the integration of the two technologies to verify the soundness of our speculations.

To this end, we have developed a VR application in Unity[1], a video game engine providing realistic virtual environments, using the Meta Quest 2 headset[2]. This headset has onboard external cameras enabling hand-tracking capabilities, used to accurately render in real-time the user's right hand (pretended to be the healthy hand) in VR. The right hand motion is also mirrored along the user's median plane and shown in place of the left hand, pretending to be the impaired one, as in Fig. 1. The exoskeleton is thus used to induce the motion reconstructed in VR to the real left hand of the user. We use the device provided by Emovo Care[3], a portable and lightweight hand orthosis composed of two exoskeletal fingers that are worn coupling the index with the middle finger, and the ring finger with the pinkie, respectively. Both tendons are actuated by the same motor assisting simple opening and closing motions. The exoskeleton, as worn by a healthy user, is shown in Fig. 2

The command sent to the exoskeleton aims at zeroing the difference between the virtual left hand reconstructed in VR (and mirrored from the right hand) and the real left hand (tracked by the VR headset). The intent is to replicate the motion of the virtual left hand with the real one. To this end, we first measure the posture of the virtual and real left hand using the headset tracking tools. For both hands, we consider the relevant angles from a subset of their joint configuration. In particular, we consider the pitch angle for each finger joint, excluding the thumb (as it is not actuated by the exoskeleton). Since we consider only simple opening and closing movements, the average of those values is enough to understand how much the hand is extended. Thus, the signed difference between the average values of both hands is computed and considered to measure how much we need to open or close the impaired one to match the one in VR. This quantity is finally considered as the feedback to compute the opening/closing commands sent to the exoskeleton motor.

Fig. 2 shows the setup of our framework, implementing the mechanism described above: the user's right hand is tracked and rendered in VR, mirrored onto the virtaul left hand, and reproduced to the real left hand through the exoskeleton.

III. Discussion

We argue that our setup could add benefits to traditional MT, increasing the sense of embodiment with the mirrored limb, thus realizing higher efficacy of the therapy. To validate our assumptions, we plan to execute extensive experimentation with a large pool of users. Furthermore, we aim to set up a clinical trial involving motion-impaired patients to assess the impact of our tool on the delivered therapy. In order to do so, we will compile an evaluation procedure to assess the acceptance and easiness of use of our tool, and the benefit introduced in the MT setup.

We claim that the potential of our therapy tool goes behind the efficacy of the MT. The portable nature of our platform allows motor-impaired patients to take the therapy independently at home, facilitating the delivery of higher dosages and repetitions, which would directly influence the outcome of the therapy itself. We believe that this aspect would positively affect the quality of life of both patients and therapists. The same line of developments opens up new perspectives in the field of telemedicine, where a therapist could wear their own VR headset to remotely assist patients.

References

[1] G. Kwakkel, B. J. Kollen, and R. C. Wagenaar, "Long term effects of intensity of upper and lower limb training after stroke: a randomised trial," *Journal of Neurology, Neurosurgery & Psychiatry*, vol. 72, no. 4, pp. 473–479, 2002.

[2] H. Nakayama, H. Stig Jørgensen, H. Otto Raaschou, and T. Skyhøj Olsen, "Recovery of upper extremity function in stroke patients: The copenhagen stroke study," *Archives of Physical Medicine and Rehabilitation*, vol. 75, no. 4, pp. 394–398, 1994.

[3] G. Kwakkel, B. Kollen, J. van der Grond, and A. Prevo, "Probability of regaining dexterity in the flaccid upper limb impact of severity of paresis and time since onset in acute stroke," *Stroke; a journal of cerebral circulation*, vol. 34, pp. 2181–6, 10 2003.

[4] P. Raghavan, "The nature of hand motor impairment after stroke and its treatment," *Current treatment options in cardiovascular medicine*, vol. 9, pp. 221–8, 07 2007.

[5] S. Hunter and P. Crome, "Hand function and stroke," *Reviews in Clinical Gerontology*, vol. 12, no. 1, p. 68–81, 2002.

[6] H. Thieme, J. Mehrholz, M. Pohl, J. Behrens, and C. Dohle, "Mirror therapy for improving motor function after stroke," *Cochrane database of systematic reviews (Online)*, vol. 3, p. CD008449, 12 2012.

[7] D. Gandhi, A. Sterba, H. Khatter, and J. Pandian, "Mirror therapy in stroke rehabilitation: Current perspectives," *Therapeutics and Clinical Risk Management*, vol. Volume 16, pp. 75–85, 02 2020.

[8] M. Yavuzer, R. Selles, N. Sezer, S. Tomruk Sütbeyaz, J. Bussmann, F. Köseoğlu, M. Atay, and H. Stam, "Mirror therapy improves hand function in subacute stroke: A randomized controlled trial," *Archives of physical medicine and rehabilitation*, vol. 89, pp. 393–8, 03 2008.

[9] M. F. Levin, P. L. Weiss, and E. A. Keshner, "Emergence of Virtual Reality as a Tool for Upper Limb Rehabilitation: Incorporation of Motor Control and Motor Learning Principles," *Physical Therapy*, vol. 95, no. 3, pp. 415–425, 03 2015.

[1] https://unity.com/

[2] https://www.meta.com/ch/en/quest/products/quest-2/

[3] https://emovocare.com

[10] L. M. Weber, D. M. Nilsen, G. Gillen, J. Yoon, and J. Stein, "Immersive virtual reality mirror therapy for upper limb recovery after stroke: A pilot study," *Am J Phys Med Rehabil*, vol. 98, no. 9, pp. 783–788, Sep. 2019.

[11] C.-W. Lin, L.-C. Kuo, Y.-C. Lin, F.-C. Su, Y.-A. Lin, and H.-Y. Hsu, "Development and testing of a virtual reality mirror therapy system for the sensorimotor performance of upper extremity: A pilot randomized controlled trial," *IEEE Access*, vol. 9, pp. 14 725–14 734, 2021.

[12] C. Heinrich, N. Morkisch, T. Langlotz, H. Regenbrecht, and C. Dohle, "Feasibility and psychophysical effects of immersive virtual reality-based mirror therapy," *J Neuroeng Rehabil*, vol. 19, no. 1, p. 107, 2022.

[13] J. Mehrholz, M. Pohl, T. Platz, J. Kugler, and B. Elsner, "Electromechanical and robot-assisted arm training for improving activities of daily living, arm function, and arm muscle strength after stroke," *Cochrane database of systematic reviews (Online)*, vol. 11, 11 2015.

[14] J. M. Veerbeek, A. C. Langbroek-Amersfoort, E. E. H. van Wegen, C. G. M. Meskers, and G. Kwakkel, "Effects of robot-assisted therapy for the upper limb after stroke: A systematic review and meta-analysis," *Neurorehabilitation and Neural Repair*, vol. 31, no. 2, pp. 107–121, 2017.

[15] A. Pollock, S. E. Farmer, M. C. Brady, P. Langhorne, G. E. Mead, J. Mehrholz, and F. van Wijck, "Interventions for improving upper limb function after stroke," *The Cochrane database of systematic reviews*, no. 11, p. CD010820, November 2014.

[16] N. Norouzi-Gheidari, P. S. Archambault, and J. Fung, "Effects of robot-assisted therapy on stroke rehabilitation in upper limbs: systematic review and meta-analysis of the literature," *Journal of rehabilitation research and development*, vol. 49, no. 4, p. 479—496, 2012.

[17] G. Prange, M. Jannink, C. Groothuis-Oudshoorn, H. Hermens, and M. IJzerman, "Systematic review of the effect of robot-aided therapy on recovery of the hemiparetic arm after stroke," *Journal of rehabilitation research and development*, vol. 43, pp. 171–84, 03 2006.

[18] J. W. Krakauer, "Motor learning: its relevance to stroke recovery and neurorehabilitation," *Current opinion in neurology*, vol. 19, no. 1, p. 84—90, February 2006.

[19] B. H. Dobkin, "Strategies for stroke rehabilitation," *The Lancet. Neurology*, vol. 9, no. 3, p. 528–536, 2004.

[20] G. Turchetti, N. Vitiello, L. Trieste, S. Romiti, E. Geisler, and S. Micera, "Why effectiveness of robot-mediated neurorehabilitation does not necessarily influence its adoption," *IEEE Reviews in Biomedical Engineering*, vol. 7, pp. 143–153, 2014.

[21] E. Wade and C. J. Winstein, "Virtual reality and robotics for stroke rehabilitation: where do we go from here?" *Top Stroke Rehabil*, vol. 18, no. 6, pp. 685–700, Nov. 2011.

[22] W. E. Clark, M. Sivan, and R. J. O'Connor, "Evaluating the use of robotic and virtual reality rehabilitation technologies to improve function in stroke survivors: A narrative review," *J Rehabil Assist Technol Eng*, vol. 6, Nov. 2019.