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Virtually turning robotic manipulators into worn devices: opening new horizons for wearable assistive robotics

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Abstract—Robotic sensorimotor extensions (supernumerary limbs, prosthesis, handheld tools) are worn devices used to interact with the nearby environment, whether to assist the capabilities of impaired users or to enhance the dexterity of industrial operators. Despite numerous mechanical achievements, embedding these robotics devices remains critical due to their weight and discomfort. To emancipate from these mechanical constraints, we propose a new hybrid system using a virtually worn robotic arm in augmented-reality, and a real robotic manipulator servoed on such virtual representation. We aim at bringing an illusion of wearing a robotic system while its weight is fully deported, thinking that this approach could open new horizons for the study of wearable robotics without any intrinsic impairment of the human movement abilities.

A video showing the set-ups and some of their applications can be found on YouTube at: <https://youtu.be/EgwzT784Fws>, and we will be referring to it throughout the paper.

I. INTRODUCTION

Among wearable robotic devices, robotic sensorimotor extensions are serial augmentations of the human body aiming to increase the user’s motor abilities. These devices include but does not limit to prosthesis [1], supernumerary limbs [2] or handheld robotic tools [3]. Despite mechanical advances over the last decades, embedding these robotic devices on the human body remains critical as their weight [4], [5], cumbersomeness and limited functionalities [6] restrain their comfort and acceptance [7], leading many potential users to prefer simple mechanical devices [8] or the use of their natural limbs [9].

In spite of these disadvantages, those wearable devices remain unique: as indicated by their name, they are worn by their user, meaning that, in addition to being transportable, the robot end-effector’s transform relative to the world frame $T_{E_R \rightarrow W}$ can be written as a composition of:

- the robotic control relative to its human attachment base $T_{E_R \rightarrow E_H}$;
- and the movement of the human body relative to the world $T_{E_H \rightarrow W}$.

We can rephrase it as: the robot and the human kinematic chains are serially connected. It writes:

$$T_{E_R \rightarrow W} = T_{E_R \rightarrow E_H} T_{E_H \rightarrow W}, \quad (1)$$

where $T_{A \rightarrow B}$ the transform from frame A to frame B , E_R the robotic end-effector frame, E_H the human effector frame to which the robot base is attached, and W the world frame.

If the human plus the robot system form a kinematically redundant chain (i.e. when the dimension of joint space is greater than the dimension of end-effector space [10]), it also means that the task completion is shared between the human motion $T_{E_H \rightarrow W}$ and the robotic motion $T_{E_R \rightarrow E_H}$ (Fig. 1):

- $T_{E_R \rightarrow E_H}$ is usually governed by an auxiliary signal coming from a joystick-like input [11], a sensor system measuring electrophysiological activities (such as muscles activities through EMG [12] or cerebral activities through EEG [13]), or an automatic task-oriented behaviour [14];
- $T_{E_H \rightarrow W}$ depends on the attachment point of the worn device, whether the arm or forearm for an upper-limb prosthesis, the trunk or hips for a supernumerary limb, or the hand for an handheld tool, and of the movements of the user.

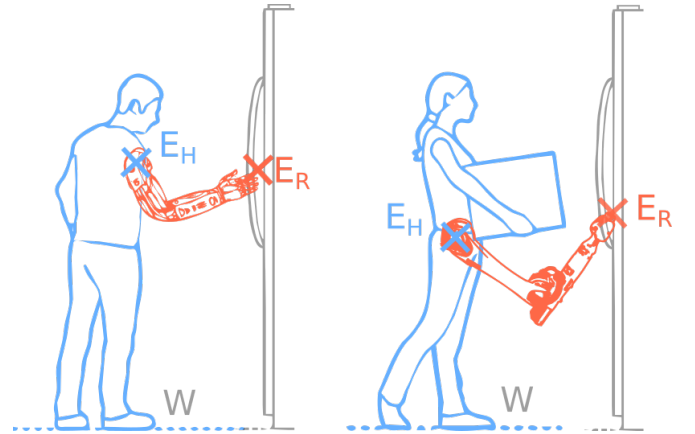


Figure 1: A robotic sensorimotor extension in orange (prosthesis or supernumerary robotic limb) with effector E_R (orange cross) is attached on an user at E_H (blue cross), to perform a reaching task.

Yet, this kinematic redundancy is frequently underused, leading to undesirable postures for the user:

- in prosthesis control, $T_{E_R \rightarrow E_H}$ is piloted by myoelectric activities of the stump and is often slow and non-intuitive leading to important body compensations [15] by $T_{E_H \rightarrow W}$ over $T_{E_R \rightarrow E_H}$;
- oppositely, in supernumerary robotic limbs, the weight of the robotic device limits the dexterity [16] of $T_{E_H \rightarrow W}$ (by creating imbalance and fatigue) and imposes the use of $T_{E_R \rightarrow E_H}$ over $T_{E_H \rightarrow W}$.

Currently, the discomfort and limited performances of these devices and of their control still limit the potential of their usage, as the weight of the device is fully carried by the user.

II. VIRTUALLY TURNING ROBOTIC MANIPULATORS INTO WORN DEVICES

To solve the previous issue, we propose a new set-up which fully deports the weight of the robotic device to a nearby environment, while still keeping a serial connection between the user and the device: we create an augmented-reality representation of an arm, attached to the body frame E_H , ending with a virtual end-effector frame E_{AR} , while a robotic manipulator set nearby with an end-effector frame E_R is servoed to follow E_{AR} (see Fig. 2 and video Sec. 1):

$$\begin{cases} T_{E_{AR} \rightarrow W} = T_{E_{AR} \rightarrow E_H} T_{E_H \rightarrow W} \\ T_{E_R \rightarrow W}(t) = f(T_{E_{AR} \rightarrow W}(t)) \end{cases} \quad (2)$$

with f the robot dynamics and control, causing delay when visually servoing the position of robotic end-effector.

The fundamental serial connection of worn robotic devices is now purely virtual, allowing to deport the weight, whereas the real robotic manipulator, physically detached from the human body, performs the desired task with a certain delay (imposed by its dynamics or control loop limitations). By doing so, we aim at virtually creating a sensation of physical embodiment of the deported manipulator.

As said, the robotic manipulator is often slower than the human motions $T_{E_H \rightarrow W}$, creating a delay between the virtual frame E_{AR} motions and the robotic effector E_R motions. But, by representing the virtual arm in augmented-reality, we partially solve these dynamic issues as we delete the perception delay for the user, tending to more stable motions. This representation is however not necessary for the system to actually work and, with training, can be removed (see video Sec. 4).

Finally, $T_{E_H \rightarrow W}$ can be generated from any body part E_H , such as the head, trunk or arm (see video Sec. 2) depending on the user's preference and the applications, while $T_{E_{AR} \rightarrow E_H}$ can still be controlled by an auxiliary input, like a joystick (see video Sec. 3).

To sum up, the proposed set-up allows to:

- shift the weight and embody any existing robotic system as a virtually worn device, even heavyweight devices, offering the possibility to reach higher robotic performances and higher comfort;
- create mechanically unfeasible limbs, such as an arm attach to the head for disability assistive applications, or a extended third arm with wide workspace for industrial applications;
- instantly attach and detach any robot device to the user's body, switch systems and shift the attach point from one to another for different use-case scenarios, unlike current devices which usually require important preparation times.

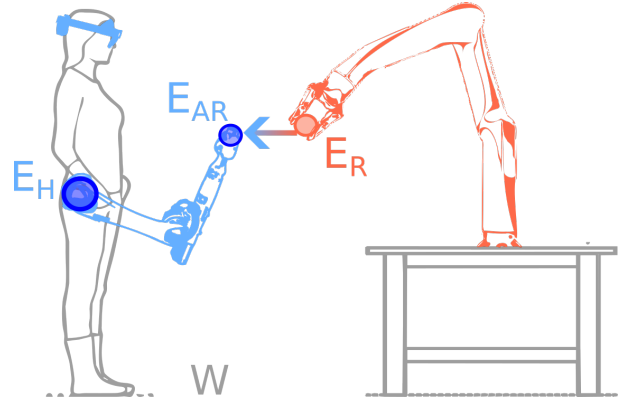


Figure 2: The user (grey) wears a virtual robotic arm in blue at attach point E_H (blue circle on the user), with virtual end-effector E_{AR} (blue circle at the end of the robot). The virtual arm made visible thanks to the AR headset in blue on the users' head. Then, the virtual end-effector servoed the effector of a deported robotic arm's (orange circle) set on a table, with a delay depending on the robot dynamics and control (symbolized by the arrow).

III. PRACTICAL IMPLEMENTATION

A. Controlled Environment

For research purposes, in controlled and room-sized environments, the easiest and most flexible implementation is to use an optical motion capture system such as the Optitrack system, and an augmented-reality headset like the Microsoft HoloLens V2 for display, as seen Fig. 3.

The motion capture system allows to capture the body transform $T_{E_H \rightarrow W}$ while easily switching from one body attach point E_H to another. By putting another marker on the robot end-effector E_R it also allows to perform visual position servoing. The augmented-reality headset is then only used for display and is actually not necessary to control the robot, rather serving as a visual feedback provider which increases the easiness of use. Finally, another auxiliary control input, such as a joystick, button or electrophysiological system can be added, whether to reconfigure and control the virtual linkage $T_{E_{AR} \rightarrow E_H}$ or to control a robotic gripper.

B. Fully wearable set-up for applied scenarios

Optical motion capture systems cannot be worn. However, the Microsoft HoloLens V2 is equipped with a visual 3D slam function which allows to detect at all time the position of the user's head and can be used to calibrate the robot with the headset. By using Inertial Measurement Units on the trunk and the arm, and a simple kinematic model of the user, one can then reconstruct the upper-body joint positions and the transform $T_{E_H \rightarrow W}$ (see video Sec. 5). Auxiliary inputs measurement can also be implemented in the headset, using its gaze tracker to control the gripper for example.

This measurement system is fully wearable and transportable (the headset being autonomous) and cheaper than the optical motion capture system, but it requires more development and time to be fully operational, as well as previous



Figure 3: The user frame E_H (blue cube) and robot end-effector frame E_R are tracked using an Optitrack system. The Microsoft HoloLens V2 headset displays the virtual arm (blue), its virtual effector E_{AR} (blue octagon) and current robot arm effector configuration (orange cube), represented here. The robot effector is servoed to follow the virtual effector.

knowledge regarding the user's body part to which the virtual robotic arm should be attached.

However, as it can be seen on our setup, a critical aspect of worn robotics which was not resolved here is the transportability of the system, as the robotic manipulator is set on a table. To solve the latter, we could consider to embed the manipulator on a mobile base, wheeled or legged, which could follow the user's motions in a larger environment, or on a wheelchair for assistive applications, and use an inverse kinematic model of both the base and the manipulator to servo the system.

IV. CONCLUSION

We proposed a novel approach for robotic extensions, in which the worn device is fully virtual but distantly controls a real robotic manipulator. This allows to virtually embody any high-performance robotic device without weight or embodiment issues, and explore applications that were previously unfeasible — an arm attached to the head or a very long arm fixed to the trunk — without constraining the user's body with heavy and uncomfortable wearable devices. We think that this approach opens new horizons for the study of wearable robotics by fully emancipating from the mechanical constraints of the systems, allowing to explore both fundamental and applied aspects of worn devices without intrinsic impairment of the human motions.

REFERENCES

- [1] J. Ribeiro, F. Mota, T. Cavalcante, I. Nogueira, V. Gondim, V. Albuquerque, and A. Alexandria, "Analysis of man-machine interfaces in upper-limb prosthesis: A review," *Robotics*, vol. 8, no. 1, p. 16, Feb. 21, 2019, ISSN: 2218-6581. DOI: 10.3390/robotics8010016. [Online]. Available: <http://www.mdpi.com/2218-6581/8/1/16> (visited on 02/28/2022).
- [2] B. Yang, J. Huang, X. Chen, C. Xiong, and Y. Hasegawa, "Supernumerary robotic limbs: A review and future outlook," *IEEE Transactions on Medical Robotics and Bionics*, vol. 3, no. 3, pp. 623–639, Aug. 2021, ISSN: 2576-3202. DOI: 10.1109/TMRB.2021.3086016. [Online]. Available: <https://ieeexplore.ieee.org/document/9446590/> (visited on 02/28/2022).
- [3] A. Gregg-Smith and W. W. Mayol-Cuevas, "The design and evaluation of a cooperative handheld robot," in *2015 IEEE International Conference on Robotics and Automation (ICRA)*, Seattle, WA, USA: IEEE, May 2015, pp. 1968–1975, ISBN: 978-1-4799-6923-4. DOI: 10.1109/ICRA.2015.7139456. [Online]. Available: <http://ieeexplore.ieee.org/document/7139456/> (visited on 03/04/2022).
- [4] D. Handy Eone, E. Nseme Etouckey, M. Essi, T. Ngo Nyemb, B. Ngo Nonga, F. Ibrahima, and M. Sosso, "Satisfaction of patients with amputated lower limb wearing external prostheses," *International Journal of Orthopaedics*, vol. 4, no. 1, pp. 368–372, 2018.
- [5] D. Prattichizzo, M. Pozzi, T. Lisini Baldi, M. Malvezzi, I. Hussain, S. Rossi, and G. Salvietti, "Human augmentation by wearable supernumerary robotic limbs: Review and perspectives," *Progress in Biomedical Engineering*, vol. 3, no. 4, p. 042005, Oct. 1, 2021, ISSN: 2516-1091. DOI: 10.1088/2516-1091/ac2294. [Online]. Available: <https://iopscience.iop.org/article/10.1088/2516-1091/ac2294> (visited on 02/28/2022).
- [6] F. Cordella, A. L. Ciancio, R. Sacchetti, A. Davalli, A. G. Cutti, E. Guglielmelli, and L. Zollo, "Literature review on needs of upper limb prosthesis users," *Frontiers in Neuroscience*, vol. 10, May 12, 2016, ISSN: 1662-453X. DOI: 10.3389/fnins.2016.00209. [Online]. Available: <http://journal.frontiersin.org/Article/10.3389/fnins.2016.00209/abstract> (visited on 10/18/2022).
- [7] U. Martinez-Hernandez, B. Metcalfe, T. Assaf, L. Jabban, J. Male, and D. Zhang, "Wearable assistive robotics: A perspective on current challenges and future trends," *Sensors*, vol. 21, no. 20, p. 6751, 2021.
- [8] S. Millstein, H. Heger, and G. Hunter, "Prosthetic use in adult upper limb amputees: A comparison of the body powered and electrically powered prostheses," *Prosthetics and orthotics international*, vol. 10, no. 1, pp. 27–34, 1986.
- [9] J. W. Guggenheim, F. Parietti, T. Flash, and H. H. Asada, "Laying the groundwork for intra-robotic-natural limb coordination: Is fully manual control viable?" *ACM Transactions on Human-Robot Interaction*, vol. 9, no. 3, pp. 1–12, Sep. 30, 2020, ISSN: 2573-9522.

- DOI: 10.1145/3377329. [Online]. Available: <https://dl.acm.org/doi/10.1145/3377329> (visited on 10/21/2022).
- [10] E. S. Conkur and R. Buckingham, “Clarifying the definition of redundancy as used in robotics,” *Robotica*, vol. 15, no. 5, pp. 583–586, Sep. 1997, ISSN: 0263-5747, 1469-8668. DOI: 10.1017/S0263574797000672. [Online]. Available: https://www.cambridge.org/core/product/identifier/S0263574797000672/type/journal_article (visited on 10/28/2022).
- [11] A. H. Zahraee, J. K. Paik, J. Szewczyk, and G. Morel, “Toward the development of a hand-held surgical robot for laparoscopy,” *IEEE/ASME Transactions on Mechatronics*, p. 5523951, Dec. 2010, ISSN: 1083-4435, 1941-014X. DOI: 10.1109/TMECH.2010.2055577. [Online]. Available: <http://ieeexplore.ieee.org/document/5523951/> (visited on 03/04/2022).
- [12] G. Li, A. E. Schultz, and T. A. Kuiken, “Quantifying pattern recognition—based myoelectric control of multifunctional transradial prostheses,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 18, no. 2, pp. 185–192, Apr. 2010, ISSN: 1534-4320, 1558-0210. DOI: 10.1109/TNSRE.2009.2039619. [Online]. Available: <https://ieeexplore.ieee.org/document/5378627/> (visited on 03/04/2022).
- [13] M. Vilela and L. R. Hochberg, “Applications of brain-computer interfaces to the control of robotic and prosthetic arms,” in *Handbook of Clinical Neurology*, vol. 168, Elsevier, 2020, pp. 87–99, ISBN: 978-0-444-63934-9. DOI: 10.1016/B978-0-444-63934-9.00008-1. [Online]. Available: <https://linkinghub.elsevier.com/retrieve/pii/B9780444639349000081> (visited on 03/04/2022).
- [14] J. Luo, Z. Gong, Y. Su, L. Ruan, Y. Zhao, H. H. Asada, and C. Fu, “Modeling and balance control of supernumerary robotic limb for overhead tasks,” *IEEE Robotics and Automation Letters*, vol. 6, no. 2, pp. 4125–4132, Apr. 2021, ISSN: 2377-3766, 2377-3774. DOI: 10.1109/LRA.2021.3067850. [Online]. Available: <https://ieeexplore.ieee.org/document/9384151/> (visited on 10/26/2022).
- [15] A. Hussaini, A. Zinck, and P. Kyberd, “Categorization of compensatory motions in transradial myoelectric prosthesis users,” *Prosthetics & Orthotics International*, vol. 41, no. 3, pp. 286–293, Jun. 2017, ISSN: 0309-3646. DOI: 10.1177/0309364616660248. [Online]. Available: <https://journals.lww.com/00006479-201741030-00009> (visited on 03/04/2022).
- [16] H. Shimobayashi, T. Sasaki, A. Horie, R. Arakawa, Z. Kashino, and M. Inami, “Independent control of supernumerary appendages exploiting upper limb redundancy,” in *Augmented Humans Conference 2021*, Rovaniemi Finland: ACM, Feb. 22, 2021, pp. 19–30, ISBN: 978-1-4503-8428-5. DOI: 10.1145/3458709.3458980. [Online]. Available: <https://dl.acm.org/doi/10.1145/3458709.3458980> (visited on 03/04/2022).