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A Preliminary Study of a Co-embodiment Approach for Welding Training

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***Abstract*—Co-embodiment enables users to share a single virtual avatar with other users, robots, or autonomous agents. Recent studies explored co-embodiment usage in Virtual Reality and proved its potential in training scenarios as motor skill learning and retention can be improved. This paper investigates co-embodiment applied to high-accuracy tasks, which usually require high spatial and temporal accuracy. A virtual reality, multi-user application for welding tasks has been designed and developed. The application supports two different teaching approaches. In the learning-by-imitation approach, the trainer controls his avatar, whereas the trainee can observe the trainer performing the welding procedure and replicate the task by controlling his avatar. In the co-embodiment approach, the trainer and trainee control the same avatar and should work together to complete the task. An experiment has been proposed to compare the usability of the two approaches. Questionnaires and user interviews have been used to obtain subjective measures of the system's usability. Users' evaluation and feedback provided helpful insight into the proposed system and led to the definition of other possible approaches for designing co-embodiment interfaces for teaching high-accuracy tasks. Future research will be aimed at developing and testing these different paradigms.**

***Keywords*—Human-computer interaction; Virtual reality; Collaborative software; Immersive experience; Co-Embodiment**

I. Introduction

Advances in computer graphics, immersive virtual environments, and interaction technologies have fueled the research and development of novel paradigms and approaches for virtual reality (VR). Hi-tech companies envision a Metaverse for the near future where everyone can interact with multiple users in different environments by personalized avatars. The relation between the physical body, the digital one, and the mind is becoming of primary importance for understanding and designing effective virtual environments for the Metaverse. To this end, recent studies explore the self-perception of users in the virtual world: Kilteni et al. [12] investigated the user's own-body perception in the virtual world, whereas Longo et al. [17] proposed a psychometric approach to define the sense of embodiment (SoE), which is the user's perception of an avatar as their representation in the virtual environment. According to Kilteni et al. [11], the SoE consists of three dimensions: the sense of agency (SoA), the sense of self-location (SoSL), and the sense of body ownership (SoBO) [22]. However, these studies do not consider the scenario of virtual co-embodiment, a recent concept in the VR research domain.

The usage of VR for training welding procedures has been widely investigated in recent years [2], [23], [26]. Welding processes are complex, and trainees often require many trials to understand how to perform them properly; thus, they represent a meaningful, high-accuracy task that could benefit from a co-embodiment approach in VR. Moreover, in the real world, safety issues do not allow the trainer to physically interact with the trainees to correct them during the task, and a speech interaction is the only possible approach. Co-embodiment could enable trainers to interact with the physical position of the welding torch used by the trainees, thus allowing a teaching approach not available in the real world. This result could be extended to all the tasks that do not allow physical interaction between the trainer and the trainees in the real world due to safety concerns, spatial constraints, or teleoperation limitations.

This paper aims to answer the following research questions:

- is it possible to develop a co-embodiment approach for training high-accuracy tasks, such as welding, in VR?
- Do high-accuracy tasks require a different approach to

co-embodiment from those envisioned in the state of the art?
- Do trainees appreciate a co-embodiment approach more, less, or equally compared to a learning-by-imitation approach?

In this paper, a virtual co-embodiment approach for welding is proposed. The contributions of this study are as follows:

- a virtual reality, multi-user application for welding tasks has been designed and developed;
- the application supports a learning-by-imitation approach: two users control their avatars and can see each other as they carry out the task in a shared environment;
- the application supports a co-embodiment approach: two users control the same avatar to accomplish the given tasks;
- the application saves the position and rotation of the welding torch, as well as the resulting welding path, and the trainer can monitor these parameters in real-time through a dedicated interface;
- subjective measures of the system usability have been carried out by questionnaires and interviews with the users.

The manuscript is organized as follows: the analysis of the state of the art is proposed in Section II. The system is presented in detail in Section III. The experiment design and the obtained results are described in Section IV and discussed in Section V. Finally, conclusions and future works are presented in Section VI.

II. Related Work

Even if VR experiences in which users can share a first-person view have been explored in the past, there are still few studies about the control of a single avatar by multiple users. Recent studies explored co-embodiment usage in VR and proved its potential in training scenarios as motor skill learning and retention can be improved. Firstly introduced by Fribourg et al. [3], the co-embodiment enables users to share the usage of a single virtual avatar with other users, robots, or autonomous agents. The proposed co-embodiment implementation is based on tracking the positions of multiple users' limbs and averaging them to control an avatar. The authors proved a positive correlation between the degree of control of the shared avatar and the SoA and a positive influence of tasks restricting the participant's choices on the SoA.

Kodama et al. [14] investigated the benefits of an initially strong SoA in training activities with variable levels of control performed by co-embodiment and its effectiveness for motor skill learning. The problem of performance drop after learning motor intention by co-embodiment despite the strong sense of agency was explored in [15]: to address this problem, Kodama et al. proposed to assign a greater influence to the trainer in the early stages of learning, and decreasing the influence according to the learning level. Kodama et al. further explored motor skill transfer by applying virtual co-embodiment and compared it with first-person perspective approaches in [16].

Takita et al. [24] investigated and proved the positive effects of co-embodiment training on skill retention. However, the use cases proposed in the papers discussed so far are limited to the selection of virtual spheres floating in front of the users in a given order or turning on candles. The maze task discussed in [14] is the only use case requiring some accuracy to properly move the stick without touching the walls or other obstacles. Katsumata et al. [10] investigated the usage of co-embodiment for sign language learning and proved the benefits in enhancing usability and matching speed during movement imitation in [9]. Hapuarachchi et al. proposed a different approach to virtual co-embodiment, called body-part-segmented VC, whereby multiple users control separate limbs as a single avatar: in [6], the authors investigated the effects of indirect movement and haptic feedback on embodiment by assigning the control of different sides of a joint avatar to two users: the authors verified that even in a total absence of control, connection induced upper body movements synchronized with the visible limb movements positively affect the sense of embodiment towards partner-controlled or autonomous limbs.

Another approach to virtual co-embodiment allows multiple users to control different sections of an avatar separately, thus allowing two users to collaborate, for example, in the control of a robotic arm [5]: Hagiwara et al. proved that this approach enables an expert to support a beginner trying to practice stable movements effectively.

Pinkl and Cohen [19] investigated the usage of co-embodiment for learning to drum by comparing it with a more traditional action observation approach. Rather than multiple users sharing control of a virtual avatar, the control is shared between a single user and an autonomous agent, as per the definition provided by Fribourg et al. [3], represented by a drumming program. The proposed task, learning to drum, completely depends on the timing of the notes, with the exemplar avatar's performance and the user's performance compared in real-time, selecting a tolerance equal to the 25% of a note duration. Even if the task proposed in [19] relies on timing accuracy, to the best author's knowledge, the other use cases discussed in the literature neither require accuracy nor rely on temporal demand; research studies aimed at evaluating the usage of co-embodiment in high-accuracy tasks have not been published yet.

III. The Proposed System

Based on existing VR welding applications [7] and co-embodiment research discussed in the previous section, an application was designed and developed with the Unity Engine [25], enabling two users to interact in real-time in the same virtual environment through the usage of Virtual Reality Headsets. Two approaches are provided: a traditional multiplayer mode, with each user embodying a different avatar, and a co-embodiment mode, with two users controlling the same avatar. The virtual environment consists of the inside of a welding workshop, with a work table, welding machines, and a blackboard displaying information about the welding process. Figure 1 represents the learning-by-imitation approach: the

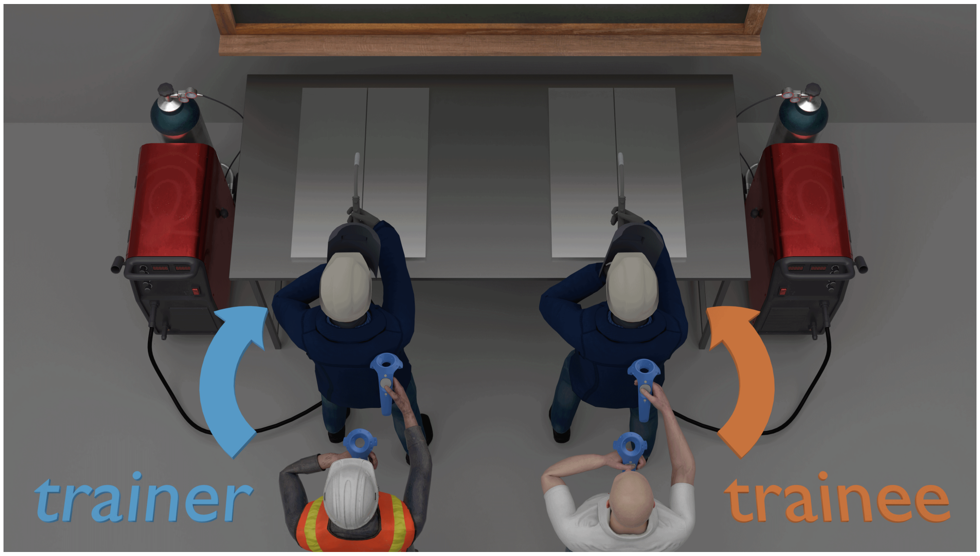

Fig. 1. The traditional learning-by-imitation approach: the trainer (on the left) and the trainee (on the right) each control one avatar in the virtual environment.

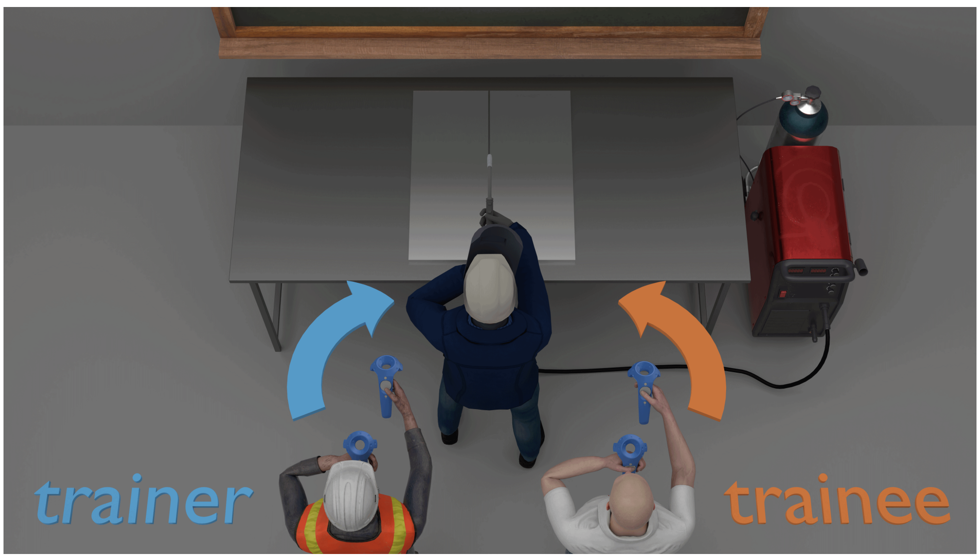

Fig. 2. The proposed co-embodiment approach: trainer (on the left) and trainee (on the right) control the same avatar.

trainer (on the left) and the trainee (on the right) each control one avatar in the virtual environment. The trainee can observe the trainer performing the welding procedure and replicate the task afterward. Figure 2 represents the co-embodiment approach: trainer and trainee control the same avatar. At the beginning of the training procedure, the trainer has full control of the avatar and shows the task procedure to the trainee, who will observe the avatar doing the task by itself. Afterward, the trainer shares the avatar's control with the trainee: then, the trainee should try to repeat the trainer's task, whereas the trainer should be able to correct the trainee influencing the avatar itself.

Unity Netcode for GameObjects has been used to add the multiplayer and the network features necessary to deploy a multi-user, networked, shared environment. The trainer's computer acts as a host and owns the virtual environment whereas the trainee connects to the server. The avatar embodiment is based on AvatarGo [21], a Unity package that proved to be effective for incorporating self-avatars in any VR application [20]. The hardware setup is based on two desktop computers with the same specifications: an Intel i7-7700 CPU, 16 GB RAM, and an Nvidia 1070ti graphic card. Each user wears an HTC VIVE Pro head-mounted display (HMD), with two controllers to track the hands and interact with the virtual interface, one VIVE Tracker (3rd generation) to track the waist, and two VIVE Trackers (3rd generation) for the feet. AvatarGo computes the input of the VIVE devices to track the user movements and embodies the virtual avatar by an inverse kinematic (IK) approach. Following recent studies on the SoE in virtual environments [18] and previous studies on co-embodiment [3], a photorealistic avatar and a first-person perspective have been chosen. As per the design approach detailed in [3], the head position and orientation of the HMDs were not shared to avoid motion sickness. The weighted average of the real-time position and orientation of the VIVE devices (controllers and trackers) is computed by the system and applied to the shared avatar to enable the co-embodiment. The trainer can change the level of control on the avatar in the 0 to 100 continuous range. The system requires the users to specify the welding parameters (welding current, arc voltage, and electrode diameter) before starting the welding procedure. Moreover, the system has been designed to display the welding only if the user complies with the welding parameters defined by the trainer. While the user presses the torch activation button, the system records the torch's angle and position at each frame. The trainer's user interface is augmented to show these data in real-time: this allows him to monitor the trainee's task in the learning-by-imitation approach effectively, or to correct the trainee in the co-embodiment approach.

After completing the deployment, three usability experts assessed the proposed system. Usability experts have been selected among scholars whose research mainly concerns human factors and extended reality. The experts provided their feedback by voice while experiencing the virtual environment and after performing welding tasks with both approaches. This preliminary evaluation unearthed the most meaningful problems that had been fixed before involving other testers. The experts greatly appreciated the avatar embodiment in the standard scenario, as it allowed them to observe the trainer's actions while performing the welding procedure, as expected in a learning-by-imitation approach. On the other hand, the trainer's perspective allows him to assess the trainee's actions effectively. Pertaining to the co-embodiment approach, the system was perceived as robust in averaging the movements of the two users over a single avatar.

IV. The Experiment

An experiment to assess the usability of the co-embodiment approach in high-accuracy tasks and compare this approach with a traditional learning-by-imitation approach has been designed. The learning-by-imitation approach has been chosen as it is the standard learning approach in real-world welding training procedures.

A. The Proposed Tasks

Participants had to perform two linear weldings between two metal plates:

- T_1 a square groove weld (90°);
- T_2 a fillet weld (45°).

In the learning-by-imitation approach, the trainer first shows the user how to perform the welding; then, the trainee repeats the task. In the co-embodiment approach, the trainer sets the control percentage to 100% and shows the user how to carry out the welding task. Then, the trainer decreases the control percentage to 50%, informs the trainee that both will share the control of the avatar and asks the trainee to repeat the task. The 50% control value has been chosen for this preliminary evaluation because previous studies demonstrated that the avatar's hand movements become straighter and less jerky than the participant's hand movements in the weighted-average-based virtual co-embodiment with 50% weight [4]. Moreover, existing co-embodiment studies show that the user can prioritize the movement of a co-embodied avatar rather than their own body, indicating that the trainer may be able to control the co-embodied avatar to correct the trainee even when the learner's incorrect movement is reflected [15].

B. Participants

Eight participants enrolled in the master's degree or Ph.D. in computer science volunteered for the experiment. They had normal or corrected-to-normal vision and gave written and informed consent. The experimental protocol followed the declaration of Helsinki [1]. Data were recorded in conformity with the European General Data Protection Regulation 2016/679, stored in local repositories with anonymized identities and used only for the post-processing aggregate evaluation procedure. No sensitive data were recorded. All users were volunteers, and they did not receive any reward for participating in the tests. The participants were split into two equal groups to avoid learning bias: the first group started the test procedure with the co-embodiment approach, and the second began with the learning-by-imitation approach.

C. Measurement

A questionnaire based on the user experience (UX) evaluation factors for wearable devices [13] has been used to gather subjective evaluations of the proposed system in terms of Ease of Use, Learnability, Wearability, and Utilitarian value on a 1 to 7 Likert scale, not considering the Hedonic and Aesthetic values which were out of scope for the proposed study, similar to [8]. Moreover, detailed insights about the user experience were gathered by user interviews.

D. The Test Procedure

The overall test procedure can be summarized as follows:

1) introduction: The user is introduced to the research project, and the test procedure is explained in detail;
2) user data: The user signed the informed consent form and fills out a preliminary form used to collect general information about the participant;
3) system setup: The user is assisted in wearing the HMD and the trackers, performs the calibration procedure, and is prompted into the virtual welding workshop, waiting for the trainer;
4) tutorial: The trainer briefly introduces the user to the virtual interface;
5) task demonstration: The trainer shows the trainee how to perform the welding task;
6) task repetition: The trainee tries to perform the welding task;
7) steps 5-6 are repeated for both tasks;

TABLE I

RESULST OF UX EVALUATION: AVERAGE SCORES AND STANDARD DEVIATIONS FOR THE LEARNING-BY-IMITATION (A_1) AND CO-EMBODIMENT (A_2) APPROACHES.

UX evaluation factor	**No.**	**Statement**	**Avg.** A_1	**Std.** A_1	**Avg.** A_2	**Std.** A_2
Ease of Use	Q1	The control interface was easy to use.	5.88	1.36	5.00	1.31
	Q7	It was easy to concentrate on the assigned task rather than on the control interface used to perform those tasks.	5.63	1.60	4.88	1.73
Learnability	Q2	Control principle was easy to learn after short training tasks.	6.13	1.36	5.88	1.36
Wearability	Q4	The interface was convenient to wear and use.	6.25	1.39	6.13	1.36
	Q6	I was tired from operation with the control interface.	1.50	0.76	1.38	0.52
Utilitarian Value	Q3	I think the control interface provide a natural and intuitive motion control mechanism for the proposed tasks.	5.75	1.16	5.38	1.60
	Q5	I think the interaction with the environment during the task was natural.	5.38	1.06	4.50	1.07

8) questionnaires: The user has to fill out the user experience questionnaire;
9) steps 5-8 are repeated for both approaches, learning-by-imitation (A_1) and co-embodiment (A_2).

E. Results

All the users involved in the tests claimed to have previous knowledge of the VR domain. Only one of them had some earlier experience with welding procedures. Regarding previous VR experience, one had no prior experience, whereas the others considered themselves skilled or very skilled. The gender distribution is similar, with five males and three females. The average age was 25.5 ± 1.5.

All the participants completed the welding process for the two tasks. Six participants rated both approaches positively (score ≥ 5) on all the evaluation factors. Two participants who were less enthusiastic about the system rated the Utilitarian value poorly (score ≤ 3) for the co-embodiment approach and average (score $= 4$) for the other one. One rated the Ease of Use of the co-embodiment approach poorly, whereas the other rated both poorly. Table I shows the questionnaire evaluation factor results in terms of average scores and standard deviations for each statement for the learning-by-imitation (A_1) and co-embodiment (A_2) approaches.

V. DISCUSSION

A. Results Analysis

Based on the task completion rate, results suggest that co-embodiment can be used as a training approach in virtual reality for accuracy tasks, such as welding. Based on the subjective evaluations, both approaches were rated positively, with less than one point of difference on the average scores for each statement between A_1 and A_2. However, the users preferred the learning-by-imitation method. Based on these preliminary data, we can positively answer the first research question, whereas the two systems are comparable in terms of user appreciation.

The users' interviews revealed two focal aspects:

- the users appreciated the avatar embodiment in the learning-by-imitation approach, whereas it was considered a source of distraction in the co-embodiment one;
- it was difficult for them to understand their contribution to the task with the co-embodiment approach, even if they were conscious that the avatar control was shared with the trainer on a 50% base.

In the learning-by-imitation approach, the trainer was represented by a different avatar in the virtual environment, whereas the trainees could look at the trainer without caring too much for their own avatar. In the co-embodiment approach, the trainees can only look at themself even when referring to the trainer. For this reason, the avatar was generally perceived as a distraction in the co-embodiment approach since the task focused on the welding torch's position, angle, and speed, whereas the user's overall posture was irrelevant to determining the task's success. Moreover, some of the testers suggested improving the system by clearly displaying the trainer's and trainee's contributions to the avatar's movements. Thus, to improve the trainee's focus on the welding torch instead of the avatar posture, a different approach should be pursued: the avatar should be hidden in the co-embodiment approach, and the only 'shared' object visible in the scene should be the welding torch, whereas the trainer and trainee controllers, depicted with different colors, should be displayed to allow the users to understand each others' intentions. Based on this preliminary feedback, it is possible to conclude that a different approach to co-embodiment may be necessary for high-accuracy tasks compared to those envisioned in the state of the art. Thus, the system should be improved to exploit the capabilities of the co-embodiment approach further.

B. Limitations

Due to the limited sample size, a statistical analysis of the questionnaire's results does not highlight any statistically significant difference between the two approaches.

Moreover, the proposed research does not investigate the trainees' performances with respect to the proposed task. This choice depends on verifying the feasibility of the proposed approach before assessing its impact on learning technology. Otherwise, even statistically significant results based on a high number of testers may be distorted by a wrong design of the co-embodiment approach for the specific task.

VI. CONCLUSION AND FUTURE WORKS

In this paper, a virtual reality, multi-user application for welding tasks has been designed and developed, which supports two learning approaches: in the learning-by-imitation approach, two users control their avatars and see each other as they work in a shared environment. In the co-embodiment approach, two users control the same avatar to accomplish a task.

The system has been designed to record the welding torch's angle at each application frame while welding occurs. The trainer's user interface is augmented to show these data in real-time to monitor the trainee's task in the learning-by-imitation approach, or to correct the trainee in the co-embodiment approach. An experiment has been proposed to assess the usability of the co-embodiment approach in high-accuracy tasks and compare this approach with a traditional learning-by-imitation approach. Questionnaires and user interviews have been used to obtain subjective measures of the system's usability. Preliminary tests allowed us to formulate tentative answers for two of the proposed research questions, whereas further investigations are required for the third one. Overall, users' evaluation and feedback allowed us to define other possible approaches for designing co-embodiment interfaces for teaching high-accuracy tasks.

Future research will be aimed at improving the proposed system by experimenting with a different co-embodiment approach, hiding the avatar and considering the welding torch as the only 'shared' object visible in the scene; the trainer and trainee controllers, depicted with different colors, should be displayed to allow the users to understand each others' intentions. Moreover, the temporal dimension of the co-embodiment could be investigated. The trainee may start the learning task with 100% control on the avatar; then, the trainer may 'activate'the co-embodiment when needed to correct the trainee, varying the control percentage only for a limited amount of time, and with compelling visual clues to give the trainee a clear comprehension of the trainer's suggestion. This approach may effectively simulate physical interaction in teaching tasks, especially for high-accuracy tasks that preclude physical interaction.

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