



HAL
open science

Operators' accessibility studies for assembly and maintenance scenarios using virtual reality

Cephise Louison, Fabien R Ferlay, Delphine Keller, Daniel R. Mestre

► To cite this version:

Cephise Louison, Fabien R Ferlay, Delphine Keller, Daniel R. Mestre. Operators' accessibility studies for assembly and maintenance scenarios using virtual reality. *Fusion Engineering and Design*, 2017, 124, pp.610-614. <10.1016/j.fusengdes.2017.03.017>. <hal-01691171>

HAL Id: hal-01691171

<https://hal.science/hal-01691171v1>

Submitted on 30 Mar 2026

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License

Operators' accessibility studies for assembly and maintenance scenarios using virtual reality

Céphise Louison^{a,b,*}, Fabien Ferlay^a, Delphine Keller^a, Daniel R. Mestre^b

^a CEA, IRFM, F-13108 Saint Paul-lez-Durance, France

^b Aix-Marseille University, CNRS, Institute of Movement Sciences, Marseille, France

The development of fusion plants is more and more challenging. Compared to previous fusion experimental devices, integration constraints, maintenance and safety requirements are key parameters in the ITER project. Components are designed in parallel and we must consider integration, assembly and maintenance issues, which might have a huge impact on the overall design. That also implies to consider the operator's feedback to assess the feasibility of accessibility or maintenance processes.

Virtual reality (VR) provides tools to optimize such integration. In 2010, the CEA IRFM decided to upgrade its design tools, by using VR during the life cycle (from design to operations) of a fusion component. The VR platform is intensively used in the design and assembly studies of WEST components. In particular, feasibility of the assembly scenario is assessed by the operators involving in the real assembly work.

To study this aspect, the use of static manikins is quite frequent in the industry. However, more complex studies, like the feasibility of assembly and maintenance tasks in complex and very confined environments, require enhanced features such as dynamic and biomechanically realistic virtual humans. We also study the contribution of tactile feedback to improve physical presence and interaction in the virtual environment (VE), which is very important for the validation of a given task's feasibility and the ergonomic evaluation of the posture and gesture of the operator. In particular, we show that adapted behavior in respect to physical elements of the VE can be obtained using a dynamic co-localized representation of the subject's body and a pseudo-haptic tactile feedback. In this paper, we present integration studies involving operators and recent advances in the assessment of maintenance feasibility.

* Corresponding author at: CEA, IRFM, F-13108 Saint Paul-lez-Durance, France.
E-mail address: cephise.louison@cea.fr (C. Louison).

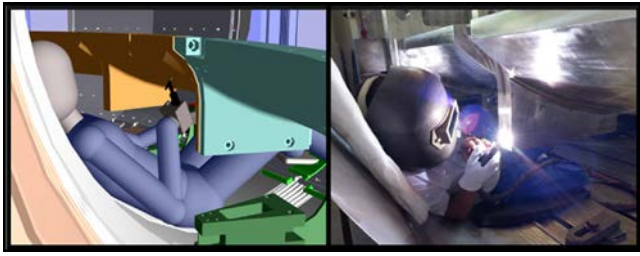


Fig. 1. Welding task simulation in Virtual Reality and with a real mockup.

1. Introduction

Since 1990, industry has seen the interest of Virtual Reality (VR). By creating interactive and versatile environments and mock-ups, VR allows, *inter alia*, to evaluate the accessibility, feasibility and ergonomics problematic of assembly and maintenance tasks, in early stages of the design process. It could have a very positive impact, in terms of cost and time, by reducing the need for physical mock-ups and validating (or not) early designs. In the context of fusion plants, the integration constraints, maintenance and safety requirement are key parameters for the design. VR technologies are very efficient to optimize such integration, integration within parallel designing processes while taking into account assembly, maintenance and safety issues.

The role of operators in future facilities also needs to be studied. The human factor takes an important role, since the operator often has to interact with elements in a very tight and confined environment. Due to that simulation in VR has to take into account this specificity. However, if visual rendering of a complex confined space is nowadays satisfying, haptic rendering remains difficult, if not impossible. This is a problem, since, to validate a maintenance task, the operator has to maneuver in a confined environment, to pay attention to his/her whole body and adopt a correct posture with respect to the environment (see Fig. 1). Without haptic feedback, the user will not feel contact/collision with the virtual environment (VE). This deficiency might lead to a lack of the user's presence in the VE, and be one reason for inappropriate behavior, with respect to reality. Studies like the feasibility of assembly and maintenance tasks in complex and very confined environments require enhanced features such as dynamic and biomechanically realistic virtual humans (also called avatars) and need a substitute for the missing haptic feedback.

2. Approach

The haptic perception combines the kinesthetic and the tactile perceptual information. The kinesthetic perception gives both the relative positions and movements of body parts, and muscular effort. Tactile perception combines the feel of different types of stimulus on the skin, such as thermal properties, vibration, pressure, and pain. Kinesthetic/force feedback is importance in constructing a spatial mental model of the world. While obtaining a force feedback is relatively straightforward using a haptic force device, these systems cannot be applied to all types of scenarios. They are not satisfactory to interact with a complex Virtual Environment (VE), in particular when the whole body is involved. Two



Fig. 2. A. Subject doing the task in the physical environment. He wears the HMD and a full-body tracking markers suit. B. Global view of the virtual environment and the avatar passing the door. C. Subjective view inside the HMD.

other interaction metaphors can be studied to “replace” haptic perception. The first one is the addition of a tangible interface, such as physical elements within the user's workspace, creating a mixed reality [1,2]. However, that can be difficult to implement in the case of complex environment. The second one is lighter pseudo-haptic systems for representation of localized information such as contact points, without restriction of mobility (they can be wearable). This last metaphor can be implemented using vibrotactile interfaces. We propose to use vibrotactile feedback as a substitute for force feedback, to make users aware of impending or actual collisions in highly constrained spaces. This type of feedback has shown interesting result in the case of guidance [3,4] and also in collision awareness [5–7].

The democratization of VR HMD (Head Mounted Displays) in particular with the release of the HTC Vive and Oculus Rift, raises the problem of subject's body representation. By default with these devices the user doesn't have a representation of his own body. We propose to use a co-localized and dynamic avatar of the subject's body to improve the operator's behavior regarding physical elements of the VE.

We experimented these factors (virtual body and pseudo-haptic feedback) in two experimentations that cover the two main kinds of situations we encounter: displacement in a confined environment and manual operation from an almost static position (limited displacement of the operator).

3. Experimental study

3.1. Adaptive behavior

We realized a first experimentation to analyze the factors needed to obtain an optimal adaptive behavior. The lessons that can be learned from this simple scenario are intrinsically linked to some of our studies involving an operator's displacement within a confined environment. Our first hypothesis was: the use of a virtual self-representation when user wears a HMD, favors the perceptual calibration of the body/environment relationships (and the processing of body-scaled information [8]). The second hypothe-



Fig. 3. Two radar (represented here by the spheres) were placed on the shoulders side. The spheres' centers matched with the vibrotactile actuators position on the subject. The size of the sphere is the spatial area of activity of the feedback.

sis, based on previous study [7], was: vibrotactile feedback (used as an alert of impending or actual collisions) contribute as self-representation to behavioral calibration. In the following section we will summarize this experimentation, please refer to [9] for details.

In this experimentation we asked to subjects (twenty male subjects voluntarily) to walk in a three meters wide corridor. The VE was composed of a corridor with at the middle a two panel sliding door (Fig. 2C and D). The door could be opened with five different width apertures: 40, 50, 60, 70, 80 cm. We studied the instinctive behavior (affordance) of rotating our shoulders to pass through a narrow aperture; the rotation should depend on the aperture width.

During the experimentation subjects wore an Oculus Rift DK2 device and a vibrotactile device that we developed previously [7]. Two vibrators were placed on the shoulders side. The subject's all-body movements were obtained and recorded by an optical tracking system (ArtTrack[®]) (Fig. 2A). These positional data could be connected in real-time to a co-localized virtual representation of the subject's body (Fig. 2B).

We studied two aspects. First, the feedback use: only visual or augmented with vibrotactile feedback. The vibrotactile feedback operates as a radar: when the subject's shoulder approaches from a part of the VE (for example, a door side) a vibration is sent to the corresponding actuator (with intensity inversely proportional to the distance) (Fig. 3). Secondly, the rendering (or not) of a virtual body representation also called "Avatar".

Results show that, in all conditions, subjects exhibited an adaptive behavior. They rotated their shoulders when try to pass through narrow apertures; in the same proportion as the outcome of previous studies [8,10]. The behavior is defined by the critical point when the subjects marking the transition from frontal walking to body rotation. This point is determined by the critical aperture-to-shoulder-width ratio (A/S). In previous studies, the critical point in free walking occurred around $A/S = 1.3$. Our result approximately $A/S = 1.4$ is coherent with these previous results. It confirms that adaptive behavior, previously observed in natural conditions and in a CAVE setup (4 screens VR rooms). The adaptive behavior is similar when wearing a HMD.

The results from the analysis of the collision percentage between avatar and the door shows are interesting. In the absence of any feedback (Fig. 4, *noA-noV*), subjects collided in almost 50% of the trials for small apertures. Fewer collisions were observed when the vibrotactile feedback or avatar (Fig. 4, *AV*) factors were present, with the fewest number of collisions when both factors were present

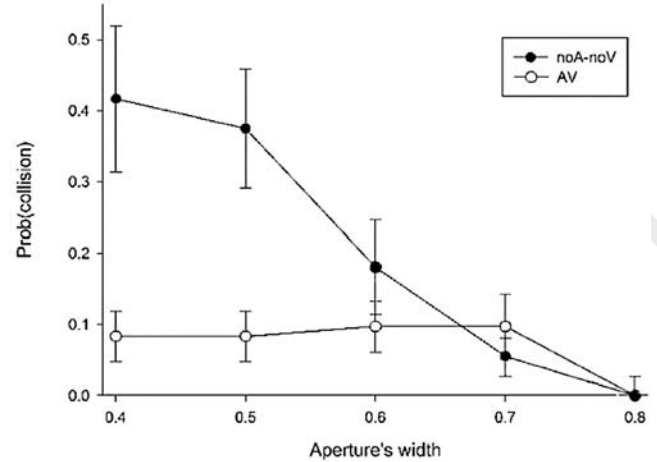


Fig. 4. Average probabilities of a collision between the body and door (with standard deviation), as a function of the aperture width.

(~75% less). The avatar and the vibrotactile feedback allow subject to calibrate the perception of body-environment relationships.

3.2. Feeling of contact

An important part of our studies involve manual operation with limited displacement of the body. The second experimentation was based on that kind of scenario. In this experimentation, we deepened the study of vibrotactile feedback. Our general hypothesis is vibrotactile feedback and especially multi-localized vibrators, contribute to enhance visuo-proprioceptive consistency. We use the term visuo-proprioceptive consistency to refer to the spatio-temporal coherence between the operator's and avatar's kinematics. This concept can be linked to the concept of kinematic symmetry proposed by McMahan [11]. Spatio-temporal coherence describes a bi-directional link of interaction. The avatar must adopt the same posture as the user, being co-localized with the user. Conversely, the user must integrate the posture limitations imposed on the avatar by the virtual environment (VE).

The experimentation is based on a study case from the CEA WEST assembly. Subjects (twenty-eight subjects voluntarily) were asked to reach targets (semi-transparent sphere) that appear in the VE with their right hand. We asked them to adopt the more fluid and natural movement as possible. The environment represents a part of a WEST facility, it was composed of a platform to access the back of an ICRH antenna (Fig. 5B). We studied several Vibrotactile conditions: without activation of any actuator, with a single vibrator on the upper side of the right hand or with ten vibrators along the right upper limb (Fig. 6).

Subjects wore an Oculus Rift DK2 device and a vibrotactile device. Ten vibrators were placed all along his arm. Subject's all-body movements were tracked (Fig. 5A) and used to connect to a co-localized morphological valid avatar in real-time (Fig. 5B).

In this experimentation, the avatar cannot pass through elements of the virtual environment. The avatar's members are blocked at the surface of the object, but nothing prevents the subject from continuing his movement. These situations create a visuo-proprioceptive inconsistency: the avatar and the subject do not have any longer the same posture. To analyze the visuo-proprioceptive consistency, we compute the co-localization Root Mean Square Error (RMSE): the distance between the real subject's 3D positions (obtained from the tracking system) and the avatar's positions. We next measured the mean contact time with environmental objects during a trial. This indicator was meant to analyze

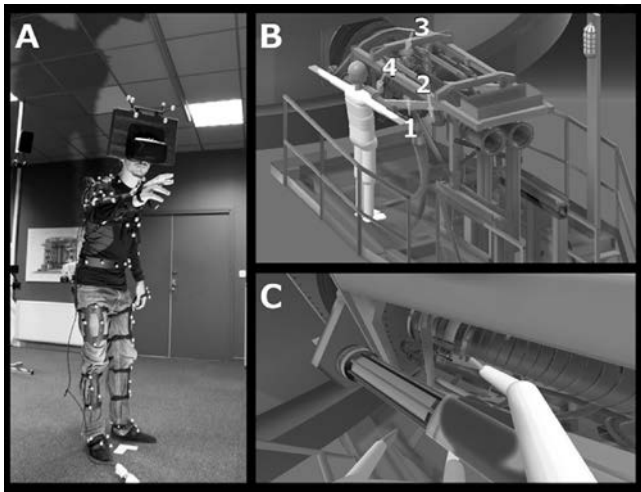


Fig. 5. A. Subject doing the task in the physical environment. He wears a HMD, and a full-body tracking markers suit. B. Global view of the virtual: avatar in the initial position and targets C. First person subjective view inside the HMD.

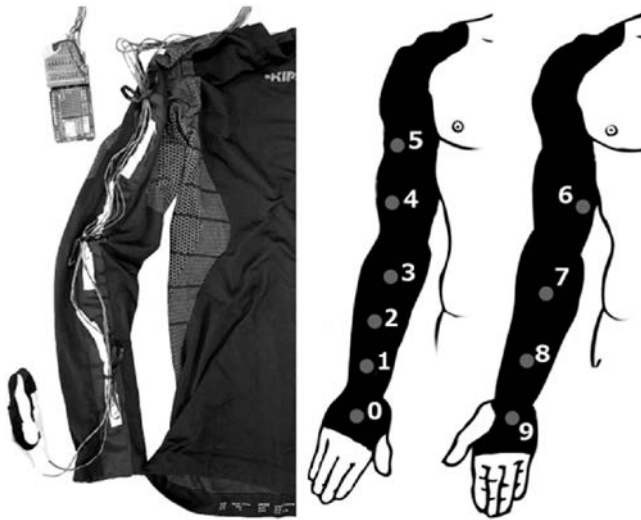


Fig. 6. Vibrotactile arm suit device with ten actuators (left). Vibrators' position along the arm. In the condition with a single vibrator only the vibrator '0' is used (right).

how subjects dealt with the occurrence of contacts, as a function of experimental conditions.

Preliminary result from the RMSE shows significant reduction of the visuo-proprioceptive inconsistencies with the vibrotactile feedback (Fig. 7, left). Also, mean contact time during a single trial analyze shows a trend of decreasing contact time with increasingly localized vibration conditions (Fig. 7, right). This is supported by subjective data (post-hoc open interview) the majority of subjects found that the extra information given by the multi-localized vibrotactile device is relevant. It allows a fast location of contact points without visual feedback.

We also asked for participation in the experiment to CEA operators, who have several working years of experience with the ToreSupra/WEST facility. Their feedback was positive and they estimated that the setup: VR device, a co-localized avatar and multi-vibrotactile feedback is a very useful tool to evaluate accessibility.

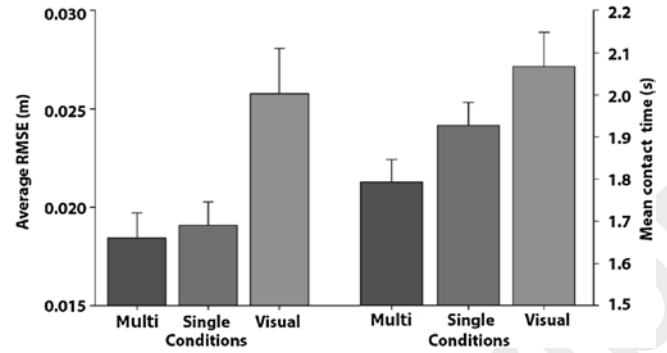


Fig. 7. Average values (with standard error) of RMS error (left) and of the mean contact time in a single trial (right), as a function of experimental conditions.

4. Conclusion

Within the frame of the use of VR simulations for assessing complex assembly tasks performed for the WEST project, one approach mixing a dynamic and co-localized representation of the subject's body with a multi-localized vibrotactile feedback as substitute of contact tactile clue has been tested. Results show that these two factors allow calibrating the perception of the operator's body-environment relationships and enhance visuo-proprioceptive consistency. The extra information, offered by a localized vibrotactile feedback, allows a fast location of contact points without overloading the visual sense and preserve a visuo-proprioceptive coherence. We conclude that associating these two aspects to enhance the validity of assembly and maintenance simulations realized in virtual reality.

Funding

Céphise Louison is supported by a doctoral grant from CEA.

Acknowledgements

The authors wish to thank the CRVM (www.crvm.eu) team for decisive assistance in the experimental process. They also acknowledge the contribution of Jean-Claude Lepeccq from Aix-Marseille University to this line of research. We also thank the CEA LSTD and LSI teams for their involvement in the project.

References

- [1] P. Milgram, F. Kishino, A taxonomy of mixed reality visual displays, *IEICE Trans. Inf. Syst.* 77 (1994) 1321–1329.
- [2] H.G. Hoffmann, Physically touching virtual objects using tactile augmentation enhances the realism of virtual environments, in: *Virtual Real. Annu. Int. Symp.* 1998 Proc. IEEE, IEEE, 1998, pp. 59–63, http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=658423. (Accessed 3 July 2014).
- [3] G. Flores, S. Kurniawan, R. Manduchi, E. Martinson, L.M. Morales, E.A. Sisbot, Vibrotactile guidance for wayfinding of blind walkers, *IEEE Trans. Haptics* 8 (2015) 306–317, <http://dx.doi.org/10.1109/toh.2015.2409980>.
- [4] J.B. Van Erp, H.A. Van Veen, C. Jansen, T. Dobbins, Waypoint navigation with a vibrotactile waist belt, *ACM Trans. Appl. Percept.* TAP 2 (2005) 106–117.
- [5] A. Bloomfield, N.I. Badler, Virtual training via vibrotactile arrays, *Presence Teleoperators Virtual Environ.* 17 (2008) 103–120.
- [6] R.W. Lindeman, R. Page, Y. Yanagida, J.L. Sibert, Towards full-body haptic feedback: the design and deployment of a spatialized vibrotactile feedback system, in: *Proc ACM Symp. Virtual Real. Softw. Technol.*, ACM, New York, NY, USA, 2004, pp. 146–149, <http://dx.doi.org/10.1145/1077534.1077562>.
- [7] C. Louison, F. Ferlay, D. Keller, D. Mestre, Vibrotactile feedback for collision awareness, in: *Proc 2015 Br. HCI Conf.*, ACM, New York, NY, USA, 2015, pp. 277–278, <http://dx.doi.org/10.1145/2783446.2783609>.
- [8] W.H. Warren, S. Whang, Visual guidance of walking through apertures: body-scaled information for affordances, *J. Exp. Psychol. Hum. Percept. Perform.* 13 (1987) 371–383.

- [9] D.R. Mestre, C. Louison, F. Ferlay, The contribution of a virtual self and vibrotactile feedback to walking through virtual apertures, in: M. Kurosu (Ed.), *Hum.-Comput. Interact. Interact. Platf. Tech.*, Springer International Publishing, 2016, pp. 222–232, http://dx.doi.org/10.1007/978-3-319-39516-6_21.
- [10] J.-C. Lepecq, L. Bringoux, J.-M. Pergandi, T. Coyle, D. Mestre, Afforded actions as a behavioral assessment of physical presence in virtual environments, *Virtual Real.* 13 (2009) 141–151, <http://dx.doi.org/10.1007/s10055-009-0118-1>.
- [11] R.P. McMahan, Exploring the Effects of Higher-Fidelity Display and Interaction for Virtual Reality Games, 2011, <https://vtechworks.lib.vt.edu/handle/10919/30123>. (Accessed 29 July 2016).

Accepted Manuscript