Ergonomics and Virtual Reality: VISIONAIR Project examples

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Abstract

This paper summarizes the developments realized as part of the VISIONAIR European Project in ergonomics applications based on virtual reality (VR). Thus, we first recall the context and the interest of the use of virtual reality for ergonomic purposes. Then the paper focuses on a study aimed at evaluating the ability of VR systems to properly mimic assembly tasks. A third part describes the framework we developed to involve in collaborative design sessions different actors of the design, i.e. the end user, design engineers and ergonomists. In conclusion, future works and developments are described.

Categories and Subject Descriptors (according to ACM CCS): Management of Computing and Information Systems [K.6.1]: Project and People Management—Life Cycle The Computing Profession [K.7.m]: Miscellaneous—Ethics

1. Introduction

VR is a wonderful and promising tool to enhance the design process of workstations and manufacturing processes. Within the frame of the VISIONAIR project [KWM*11], we proposed several studies and developments to enable a proper use of such a tool in industrial ergonomics. This article presents a summary of these developments and open questions about the future applications we consider for this work.

The use of virtual environments as a tool to support ergonomic assessments of workstations is an old and compelling idea [Wil99]. Wilson stated in his paper that such applications were still limited as technologies were limited. Now, thanks to the rise of new technologies and to the significative enhancement of the computational power, the use of such features in the early stage of workstations design seems natural since assessing ergonomics from the digital mock-up (DMU) is more cost-effective and convenient than doing it on a physical mock-up [JJS*06, BHV*07].

Figure 1 presents the ideal framework developed to perform collaborative industrial ergonomics. Basically, the end-user (industrial worker) is immersed in a virtual scene representing the workstation design and is asked to perform virtual tasks corresponding to the real ones. An ergonomist and a design engineer have access to informations coming from the simulation and the end-user activity. The ergonomist mainly analyses biomechanical quantities (e.g. postures, muscle activity, gaze) whereas the design engineer mostly deals with process indications (workstation features placement, productivity concerns). The three collaborative actors have the ability to modify the digital mock-up (DMU) of the workstation in order to enhance the workstation ergonomics, the user gestures and the productivity.

This ideal framework presents many issues that are not

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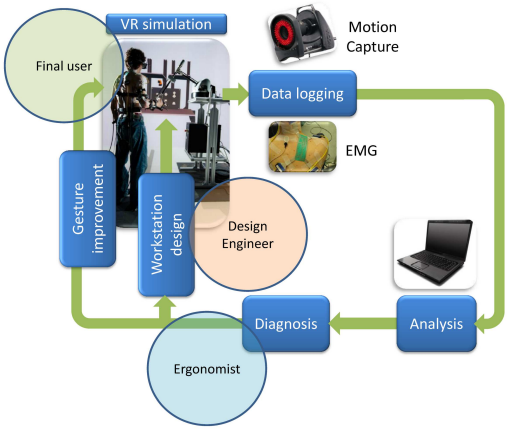

Figure 1: *Standard framework for collaborative ergonomic design sessions in VR. Adapted from [PDD13, PDD14, PDS* 14]*

solved yet. In this paper, we discuss only two of these major issues. First, the reliability of the ergonomic assessment remains contrasted, as differences exist in terms of motor control and sensory feedback between a real work situation and its emulation in VE. The first part of the paper deals with the assessment of such reliability and summarizes a study we conducted, comparing real and virtual assembly tasks in terms of biomechanical activity. It is inspired by a major contribution emerging from a Trans National Access (TNA) work proposed as part of the VISIONAIR project. This TNA has been done in collaboration with the Department of Health Science and Technoloy of Aalborg University. Then, the framework will be efficient for workstation design and ergonomics only if the different actors involved in the design process, i.e. design engineers, ergonomists and final users (industrial workers) have the opportunity to interact with each other and with the simulation in a convenient way. The second part of the paper deals with the proper definition of the roles of the actors in a collaborative virtual environment (CVE) for ergonomics. It summarizes two contributions we proposed in the context of the VISIONAIR project.

2. Assessing the fidelity of assembly tasks simulated in virtual environments

One of the main challenges of virtual reality simulation is its transferability or applicability to the real world. Especially in ergonomic studies, this issue remains widely unsolved. Actually, the objective evaluation of the virtual framework remains challenging. We proposed to evaluate the ability of a VR simulation of simulated assembly tasks to evaluate properly physical risk factors by comparing several biomechanical indicators of discomfort and fatigue recorded in a real environment (RE) and in a virtual environment (VE).

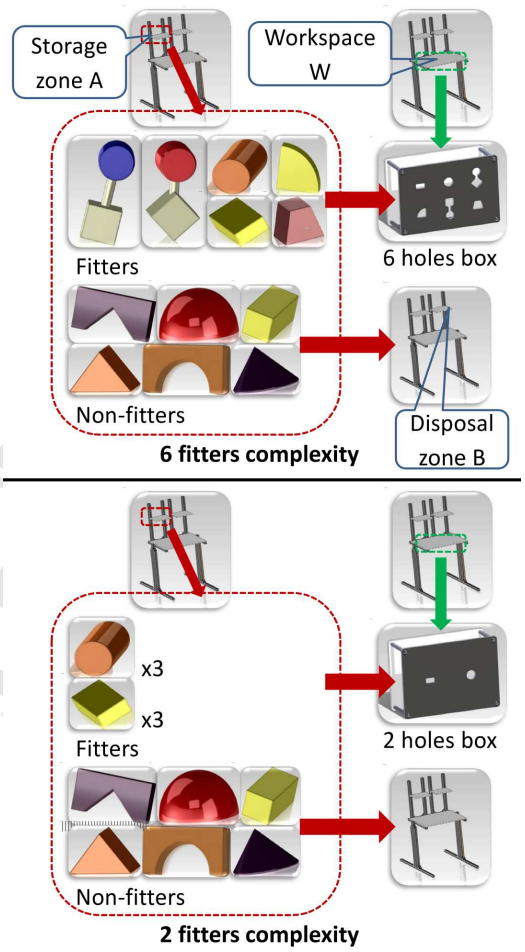

Figure 2: *Task description and complexity levels. Adapted from [PBD14]*

2.1. Task and Protocol

We decided to compare the performance of subjects realizing an assembly task in RE and VE. To do so, we designed a specific simulated task inspired from a child game: the holed box. The task consists in passing pieces with specific shapes trough holes exhibiting the complementary shape. Two levels of complexity were designed, as shown in figure 2. A condition on the timing regime was also designed to observe cases with "as fast as possible" behaviours (subjects grabbed pieces and place them as fast as possible) and cases with "time managed" behaviours (subjects grabbed pieces every ten seconds thanks to an auditory signal). For each trial, twelve pieces were used: six were fitting the holes and six were not. Subjects were asked to place non fitter pieces on a rebuttal zone, as shown in figure 2.

The RE consisted in a workspace fabricated with respect to an initial DMU. The same DMU has been used to

design the VE. The virtual system used a high resolution stereoscopic immersion room including a wall and a floor. Three dimensional glasses tracked with a tracking system equipped with 16 ART infra-red cameras (Advanced Real Time Tracking GmbH, Germany) were used to adapt the simulation to the user point-of-view. Only one object appeared on the storage shelf at a time and the subject had to grab the object using a wireless interaction device (Flystick2, Advanced Real time Tracking GmbH, Germany) co-localized with the VE. In the "as fast as possible" trials, a new object appeared on the storage shelf once the user had finished with the previous one. In the "time-managed" trials, the object appeared concomitantly with the auditory start signal.

The virtual coordinates of the flystick were linked to the physical ones by the mean of a standard proportional derivative control scheme for positions and a suboptimal control scheme with a quadratic cost for rotations.

Even though particular attention was paid to precisely mimicking the real task, several obvious differences existed between RE and VE: grabbing pieces consisted in clicking a trigger in VE, and no haptic feedback indicated collisions with the environment in VE to the user. Indeed, such differences in motor components cannot be afforded, and the current study aimed to evaluate whether or not they influence the results of an ergonomic study.

Sixteen subjects performed the simplified assembly tasks in RE and VE. Motion of the upper body and five muscle electromyographic activities were recorded to compute normalized and averaged objective indicators of discomfort, that is, Rapid Upper Limb Assessment (RULA) score, Averaged Muscle Activations (AMAs), and Total Task Time (TTT). Rated Perceived Exertion (RPE) and a questionnaire were used as subjective indicators of discomfort. The timing regime and complexity of the assembly tasks were investigated as within-subject factors.

2.2. Results and Discussion

The results revealed significant differences between measured indicators in RE and VE. While objective measures (RULA, AMAs, TTT) indicated lower activity and exposure in VE, the subjects experienced more discomfort than in RE (higher RPE in VE than in RE). Fairly good correlation levels were found between RE and VE for six of the objective indicators. This study clearly demonstrates that ergonomic studies of assembly tasks using VR are still challenging. Indeed, objective and subjective measurements of discomfort that are usually used in ergonomics to minimize the risks of Work-Related Musculoskeletal Disorders development exhibit opposite trends in RE and VE, whereas it has been proven that they should be correlated [KL12]. This means that a high level of subjective discomfort is generally associated with high scores in objective metrics. In the current study, reported RPE score was significantly higher in VE than in RE. As the RULA score and three of the five AMAs decreased significantly at the same time, the feeling of discomfort could not come from more awkward postures and is in contradiction with objective measurements. As only five muscles were monitored, the feeling of discomfort could come from an uncovered zone of the body solicited in a compensatory process. On the other hand, the increase of RPE confirms the longer TTT. These clues tend to confirm that cognition alteration tends to bias the physical risk factors evaluation in VE.

Then, such physical risk factors assessments can be performed if the offset between RE and VE is defined and taken into account. For example, fairly good correlations between objectives indicators (RULA and AMAs) recorded in RE and VE under the same conditions were found in the present study. Nevertheless, these correlations will be true for this specific task and environment. We are also currently investigating more in detail motor control strategies used in such situations in order to identify how different are the strategies between the two environments.

As a conclusion, a lot of improvements can be achieved to reduce the gap between RE and VE. For example, haptics is compelling to enhance the interaction fidelity and dedicated interfaces could be defined to achieve a more realistic grip and release of the objects. The study was also conducted on a relatively small population size and gave results for a very specific task. Further studies on fidelity evaluation are needed to enhance the transferability of VR results to the real world.

Most of this work has been published in [PBD14, PDS*14].

3. A framework for collaborative ergonomics design sessions

A compelling application of collaborative virtual environments (CVE) concerns ergonomics [PDS*12]. CVE consists in making collaborate distant actors in a shared environment with different interaction and display facilities. This fits exactly the requirements of a proper ergonomic design session. In such sessions, we want to enable a collaboration between a end-user (industrial worker) immersed in a high-end immersive facility, an ergonomist and a design engineer. The last two actors will be most of the time in front of a standard desktop with low immersive capabilities.

This is the reason why we developed specific tools for

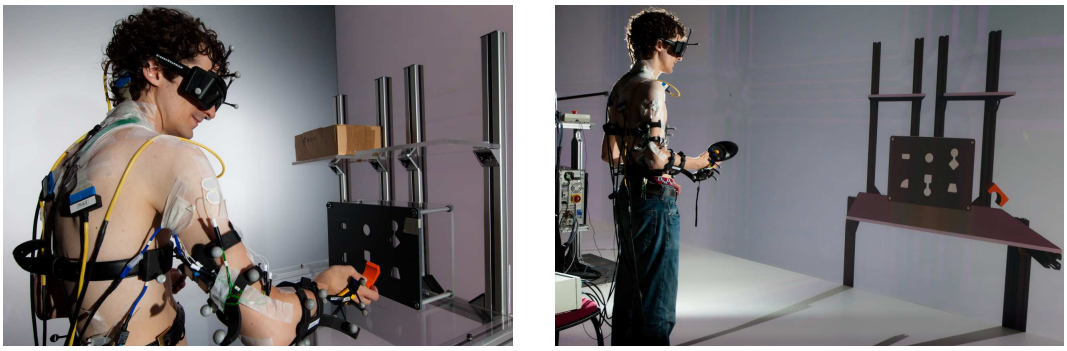

Figure 3: *Experimentation overview: simplified assembly task performed in real and virtual environments. Issued from [PBD14]*

ergonomic design sessions in a collaborative virtual framework named Collaviz [FDGA10]. The current section summarizes these developments and the future works we want to pursue in this direction.

4. Framework overview

A CVE can be considered as a major tool for workstation design, as it has the potential to enable real-time interactions between all of the actors involved in the design process. This statement is true only if the CVE is properly designed. As shown in figure 4, the DMU, used as a prototype during a design session, has to be manipulated by the main user - in most cases he is an industrial operator. In an ergonomic design session, ergonomists, as well as design engineers have a role to play. For example, a design engineer has to be able to modify the DMU directly and while preforming the experiment, and has to maintain the workstation workability and effectiveness with regard to the specifications previously defined by other actors (such as methods or process engineers). At the same time, an ergonomist has to be able to propose ergonomic recommendations to the design engineers as well as gesture recommendations to the main user. All of these features make possible an enhancement of the design of the workstation and the gesture of the user.

We currently developed these roles, as it is explained in the next section.

5. Ergonomist and Engineer Roles

Ergonomist and Engineers roles are specific and they both need specific interaction tools to be efficient. This is why, on the basis of the CVE shown in figure 4, we defined these two roles in a very different way.

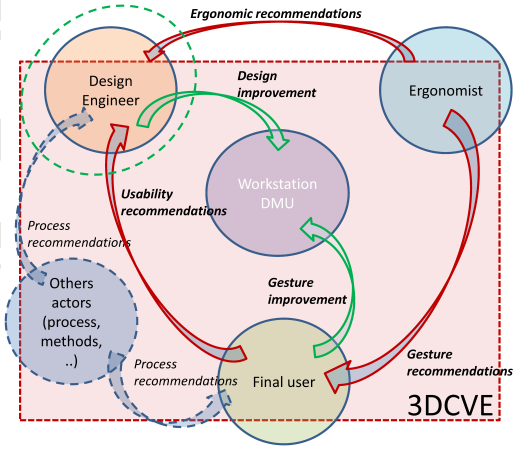

Figure 4: *Conceptual CVE for ergonomic studies. Only primary interactions are represented. All of the study actors have the opportunity to interact with the other ones. This configuration correspond to the "direct design" mode described in section 5.2. Issued from [PDD14]*

5.1. Ergonomist role

5.1.1. Operating modes

To enable an efficient interaction between the end-user and the ergonomist, we developed an original architecture using two similar virtual manikins represented in the virtual environment and seen by both users. A manikin A is used as a main manikin and can be animated either directly from the motion tracking or in replaying a previously recorded motion. Manikin B that can be considered as a ghost manikin can either mimic the manikin A or be manipulated by the ergonomist. Actually, manikin B is mimicking manikin A most of the time, but the ergonomist has the opportunity to stop this mimetic feature to indicate whatever he needs on the manikin. The combination of these animation modes define several work modes for the application:

- **Active-Passive:** Manikin A in direct tracking and manikin B in mimetic. This mode is mostly used by the ergonomist to observe, analyse and record the current work task;
- **Active-Active:** Manikin A in direct tracking and manikin B manipulated by the ergonomist. This mode is used for a direct evaluation of the current work task. The ergonomist asks the user to reach several postures involved in the task realization and propose via manikin B several recommendations;
- **Passive-Active:** Manikin A in motion replay and manikin B manipulated by the ergonomist. This mode is used for non direct evaluation of the current work task. The ergonomist replays a sequence, indicates during the replay the problematic postures and propose recommendations.

The manikins are the main vector of the ergonomic information provided to the ergonomist as well as the main vector for the gesture recommendations provided to the main user.

To provide a diagnosis, the ergonomist needs some analysis tools. As the only measured data available at this time consists in the tracked motion of the segments, two types of data are computed and proposed to the ergonomist:

- Postural scores: these information give a fair overview of the posture discomfort;
- Joint coordinates: these information enable a thorough analysis of the discomfort in giving an individual measurement on each joint.

5.1.2. Visualization and interaction features

The end-user (operator in situation) can see both manikins in superposition or separated. The postural scores are represented on the manikin A. Colour codes associated to the joints going from green (comfort) to red (discomfort) indicates to the user the situation of each joint in relation with the considered score. The whole manikin is also coloured from green to red as a representation of the global score.

When the manikin B is superposed to manikin A, the user can see changes and recommendations operated by the ergonomist in comparison with the initial posture, and then modify its gesture to fit the proposed recommendation.

At last, the ergonomist can see both manikins in superposition. The same information as the ones provided to the end-user (colour codes) are available. Moreover, the ergonomist has a dashboard to tune additional parameters. All of the non joint-related factors involved in the definition of the postural scores are accessible and tunable from the board. Moreover, the ergonomist can save/run sequences performed by the main user. At last additional outputs options are available. Indeed, the ergonomist can activate/deactivate color codes, display the global scores on his screen, and display the kinematical traces (global scores, local scores, joint coordinates) on curves if necessary. This way, the ergonomist has complementary representation tools of the same information (representation-bridging) to better analyse the current motion.

The ergonomist has also to be able to provide recommendations to the main user. At this point, the ergonomist can only modify directly the manikin B by clicking joints and displacing them in the environment. This interaction enables a simple recommendation metaphor, consisting in indicating the desired posture on manikin B with regard to the problematic one described on manikin A.

5.2. Engineer role

As shown in figure 4, a collaborative ergonomics design session consists in using a 3DCVE to simulate and evaluate the work task emulated from the digital mock-up of the workstation. The final user is asked to perform his work as he would do in real conditions. Measurements of biomechanical indicators (posture, muscle activity) as well as performance indicators are used by both ergonomist and design engineers to enhance the ergonomics of the workstation and maintain its specifications with regard to the industrial process.

The design engineer can have different roles, depending on the operating mode currently being used during the session. According to the figure 4, the design engineer has to be able to take into account recommendations coming from both final user and ergonomist, and to act on the DMU to indicate and to proceed to modifications in accordance with the process specifications. In this operating mode, the design engineer has an active role as he is the only one allowed to modify the DMU. We can call this operating mode "direct design" mode. In this operating mode, both ergonomist and final user need informative metaphors such as visual signals (arrows, spots, ...) and auditory signals (voice, bips,...) to highlight problematic parts of the workstation. Moreover, both final user and ergonomist need tools to show reachable positions and volumes to the design engineer. Then the design engineer has to be able to modify or move parts of the workstation with convenient manipulation techniques.

A second operating mode can be much more effective: in this case, according to figure 5, the design engineer is not acting directly on the DMU, but supervises, frames and validates with regard to its process expertise the changes made by the other actors. Here, changes are directly realized with regard to usability and ergonomic considerations, coming respectively from the final user's experience and from the ergonomist's analysis, and process specifications are guaranteed by the design engineer. In this operating mode, that we can call "supervised design", the design engineer needs tools, such as process information metaphors, to frame and indicate to the others actors if the modifications they plan to do are compatible with the process specifications. Such information metaphors will mostly consist in plans and volumes materializations.

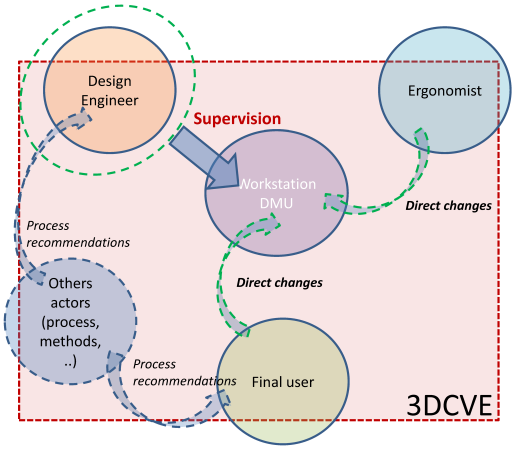

Figure 5: *A proposition of interaction definitions between the different actors involved in a collaborative ergonomic design session supported by a 3DCVE with a "supervised design" operating mode. The role of the design engineer is highlighted in green.*

6. Conclusion

Two specific issues relative to the use of VR for ergonomics have been explored in the context of the VISIONAIR project and summarized in the current article.

The first one, relative to the transferability and the applicability of the conclusions obtained from a VR-based simulation of a real work task, gave us compelling results. Even if it has been clearly established that the tasks performed in RE and VE were different, we were able to identify and quantify this difference. Current developments around these initial results are currently on going and we plan to investigate more practical cases in the near future.

The second one deals with the capability of CVEs to be used as a valuable tool for ergonomics. We already developed a strong basis of tools being able to handle the specific needs relative to such a use. We currently explore ways to evaluate these tools, using abstract cases and more applicative scenarions.

All of these contributions are giving serious credit to the use of VR as a reliable and efficient support for early-stage ergonomic design.

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