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Assessment of Virtual Reality Environments for design activities

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Abstract
The aim of this research is the performance assessment of 3D visualization and interaction devices for design activities. Experiments are expected to determine the virtual environments that best fit the dedicated activities. Classification of technologies is proposed on the basis of its apparent relevance to reach intuitive support to the design activity but a method to provide a more complete and objective assessment is proposed. To check the proposed assessment method, a simple assembly activity has been selected as a use case where the use of stereoscopic screen versus classical 2D display on one hand and an haptic arm with versus without force feedback on the other hand must be compared. Experimental measures are performed by the use of objective sensors: duration and gesture instability along the task are tracked. The comparison was done on the assembly of the jig and fixture system. The experimental measures are analysed both with their absolute values and their evolution when training users. This paper is a positioning paper where the intention is to build a framework where more abstract qualification of virtual environments may be extracted: intuitiveness, tangibility, ergonomic and by the end utility should be the final assessment.

keywords: Virtual Reality, Design, Intuitiveness, Tangibility, Usability, Utility.

1. Introduction

Virtual reality demonstrated applications in professional fields, especially in design and manufacturing. One critical point is to propose and build virtual environments useful rather than usable. This paper identifies a process for performance assessment of virtual reality (VR) devices when used for design activities. Designers mainly use CAD systems to create virtual 3D model [EAM*13] and manufacturing expert use this digital mock-up to assess the manufacturing process [CGA*12], but both do not practice so much virtual reality tools. While virtual environment should allow manufacturers and designers to collaborate around the mock-up by assembling, disassembling, painting, viewing, and assessing product performance, a low deployment of VR technology is observed, due to technology cost but also to the difficulty to prove the technology added value. That may be because the technology is not mature enough or because it is not perceived as useful. It is thus necessary to go towards a performance analysis process. If a lot of studies try to demonstrate the usability, there are less result about utility assessment.

Manufacturing industries face a global competition which leads to a growing pressure about launching new products in ever shorter cycles especially[TJJ*07] (but not limited to) the automotive and aircraft industries. Virtual reality could potentially lead to lower cost [CAM*13], higher quality product, and shorter time-to-market, thus it could improve the competitiveness [YAN07] of innovative companies. In the current study a basic virtual assembly process is used to organize the assessment process. Virtual assembly process remains one of the key applications in advanced design of manufactured [JTR*07] products. It is a promising application of VR within the manufacturing sector. The study organises an experiment to evaluate the assembly of a system with collision detection [DAS09] and kinematics joint constraints through basic objective criteria: docking finalization, duration of the task and gesture instability. An analysis module was developed to trace these sensors during a virtual reality activity by linking the sensors to specific state values of the virtual environment. Four VR configurations for the same design task were assessed.

But comparison of performance measured by sensors is

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not enough. The basic measures must be consolidated into more abstract assessment, as intuitiveness [FAS12], tangibility, ergonomic of the virtual environment for the corresponding task. It is thus discussed how raw sensor results could be mapped to an abstract assessment level, creating a new classification of devices respect to a design task utility. Such a classification of technologies may be proposed on the basis of its apparent relevance [Fre12] to reach useful support to design activities.

2. Use case definition

Within Design, the increasing variety of models and product complexity is accompanied by rising requirements in terms of quality and by the constraint of cost savings. This research was initially conducted to improve the design of the jig and fixture system (as shown in Figure 1) intensively used in the automotive industry. The overall task is to check the assembly process for such a system by the use of virtual reality. As manufacturing companies pursue higher quality products, they spend much of their effort monitoring and controlling dimension variations. Dimensional variation in production parts are statistically accumulated, and propagated through kinematic joints, causing critical feature of the final product. Such dimension variations can cause expensive issues during assembly, requiring extensive rework or scrapped parts. It can also cause unsatisfactory performance of the finished product, drastically increasing warranty cost and creating unsatisfied customers. In the current use case, the multiple involved experts expect designs that will not fail downstream in the manufacturing process.

Within such a use case, our research question is: **how visualization and interaction technologies may be assessed to identify which virtual environments is useful for collaborative design activities?**.

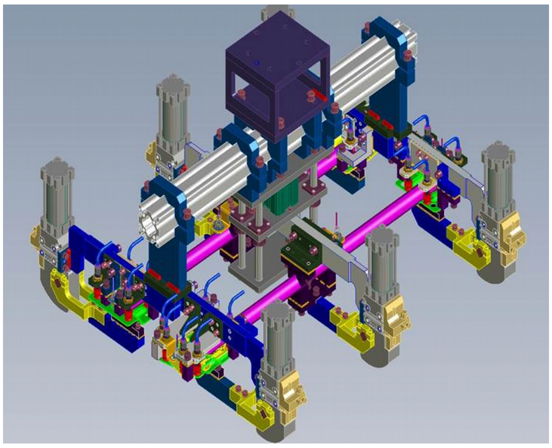

Figure 1: *The Jig and Fixture system for performance assessment of virtual reality devices*

3. CAD to VR process

The potential of 3D visualization techniques to become the right support instrument for design is explored. Both 3D visualization techniques and internet communication networks [WFC11] provide new opportunities. To achieve a good support to designers, the overall process starting from the design tools and leading to virtual reality applications must be drawn. The process of Figure 2 is proposed. A designer uses computer aided design software to create the jig and fixture model dedicated to clamp the workpiece of the car door for the welding process in an automotive industry. When the model is complete, it is sent to the manufacturing expert and both should collaborate around the DMU. They basically expect to visualize the assembly, to measure it, to perform various analyses including complex simulation, and to save design decisions. These functions should be realized with the support of VR.

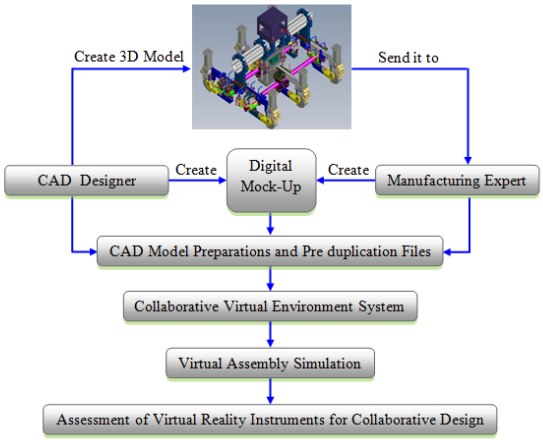

Figure 2: *An overall process for design activity with virtual reality environment*

First the 3D model must be translated and sent to the VR environment. In our research, the 3D model was created within SolidWorksTM. As most CAD system, SolidWordksTM can export the CAD model in other formats (STL, STEP AP203, VRML, etc.). For direct conversion towards VR, the CAD parts were individually exported into STL files. Then the mesh module of SolidWordksTM was used to reopen the STL file merge nodes and to export the meshes into OBJ files. The main reason to use obj file format is to get a good level of compression and it is available to import into most virtual reality viewers. But several CAD systems do not export directly into obj file format. Therefore an intermediary step is performed through the STL to OBJ conversion. In addition, for assembly simulation, the virtual environment expects the definition of potential kinematic joints [EAM*13]. As transferring 3D geometry of parts is not enough [GHT13], the kinematics constraints were rebuilt from scratch directly in the virtual environment in our case.

Some works are made to automate this process and to make it transparent for designers. Here it is just considered that each part is represented by a single polyhedron in the virtual reality environment, and that the assembly refers to potential kinematic joints which can be activated when parts are properly aligned.

4. Experimentation framework

The collaborative virtual environment software (CVE), developed and used at the laboratory, consists of a server, a configuration editor, a 3D viewer enabling virtual reality usage, an analysis module, and various tracking extensions. The server dispatches events between the various modules. The primary purpose of this research is the assessment of performance of VR to achieve a use case (the jig and fixture system), with the potential use of an haptic arm to interact with VE. The Figure 3 shows the various CVE modules [XRM*10] used in our experiment.

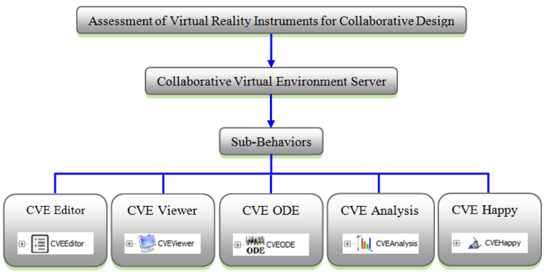

Figure 3: *The experiment framework*

CVE is a multi-agent based system dedicated to collaboration within a virtual/augmented environment. A socket communication system is employed to ensure the communication between agents. Every agent is in charge of a behavior of the global virtual environment. In the current experiment, the expected sub-behaviors correspond to five modules:

- CVE-Editor enables to modify the scene and provide access to any state value of the scene.
- CVE-Viewer is in charge of rendering and of sending the scene to the final display which can be holographic, stereoscopic or a simple 2D screen. CVE Viewer opens 3D windows which can be displayed diverse imported 3D objects (as obj files).
- CVE-ODE is an agent in charge of collision detection and simulation based on the open source Object kinematic Dynamic Engine (ODE).
- CVE-Happy is a module to take in charge the connection with an haptic arm. It can survey the position of the human operator's hand and it activates the arm actuators to apply a force feed-back [RAS07] during virtual assembly.
- CVE-Analysis is an agent surveying some state values evolution and consolidating them as basic sensors. CVE Analysis records the trace of basic sensors on a running activity.

4.1. Description of the tested environments

The analyzed devices are a stereoscopic screen (2D wall screen: crystal eyes 3D glasses + Christie digital mirage HD3 projector) versus classical 2D display (the same without activation of stereoscopy). An haptic arm (haption virtuose 6 d35 enhanced to 6 dof) was employed for interaction. The haptic arm [CJJ11] may be employed with or without force-feedback. The Figure 4 shows the research environment.

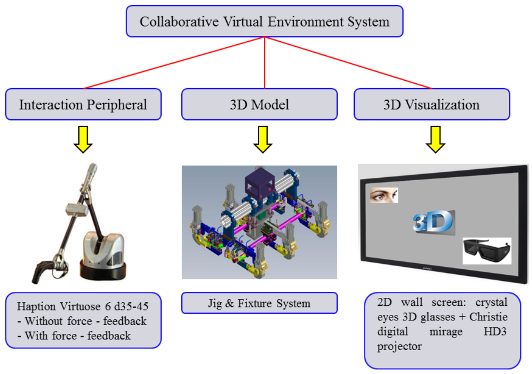

Figure 4: *The environments to assess the performance on CVE*

This selection of devices creates four environments as follows:

Env1: The first environment consists of an haptic arm without force-feedback + 2D wall screen.
Env2: The second environment consists of an haptic arm without force-feedback + 3D glasses + 2D wall screen.
Env3: The third environment consists of an haptic arm with force-feedback + 2D wall screen.
Env4: The fourth environment consists of an haptic arm with force-feedback + 3D glasses + 2D wall screen.

The virtual assembly of the jig and fixture system was used to compare the selected environments. Intuitively it was anticipated that environment 4, using which integrates both 3D stereoscopy perception and force feedback must best fit design activities. It was expected to check this intuition with an objective exprimental process and to discuss how utility of this environments may be discussed.

4.2. Sensors

Several basic sensors were developed in the analysis module which can be selected and adjusted from the CVE-editor as

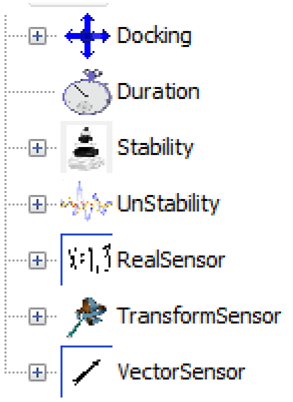

Figure 5: *The sensors in CVE Analysis on the CVE*

illustrated in Figure 5. As a first step, in the current experiment, two sensors have been employed: the "duration" and "un-stability" sensors.

"Duration" sensor records the overall duration of a task: the interval of the time between the event launching the analysis and the event stopping the analysis.

"Un-Stability" sensor evaluates the gesture instability. The position of two points in a frame defined by a transformation matrix is permanently analyzed. The trajectory of these points is linearized by small intervals of time and the sensors compare the real path length of the point respecting to the linearized trajectory per interval. The ratio gives an idea of the oscillation of the trajectory around a more efficient path. It depicts the gesture shivers. This ratio is recorded by the analysis module for every conducted experiments.

A task can be defined, processed and repeated several times. A file records the raw result of these basic sensors.

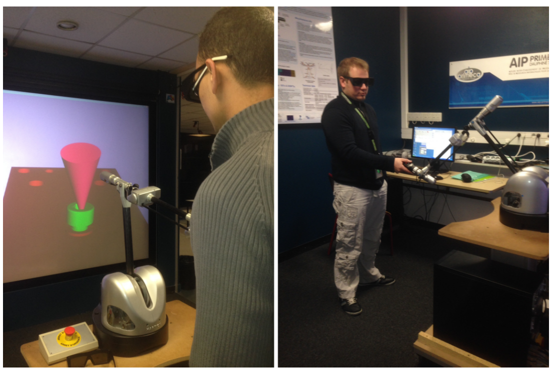

Figure 6: *The participants work in a comfortable stand postures*

5. Experimentation description

5.1. Description of the participants

The eleven participants to the experiment are all male PhD students of our laboratory. They have engineering design knowledge but they never experienced our internal virtual reality system. Moreover it is their first time to employ virtual reality equipment. It has been elucidated to the participants how to employ the devices and the assembly procedure to be performed in the experiments. They first tried to employ the system and understood how to perform the experiments. The participants were conducted in a comfortable postures by standing about 2 meters away from the screen. Figure 6 shows the gestures of participants for assembly simulation. No participants dropped out in the middle of the experiment [YAN07] and all of them went through the experiment smoothly.

5.2. Experimentation protocol

As already discussed, a virtual assembly task of a Jig and Fixture system was selected in our research since assembly simulations involved a lot of interaction and real-time simulation. The system was simplified and a few parts to be assembled were selected to keep a reasonable experiment time. It was decided to limit the experimentation task to the insertion of a single screw in its corresponding hole. Every participant was expected to repeat the task 15 times (for 15 equivalent screw insertions). A longer task was thus forbidden for a reasonable experimentation time.

Each participant was thus expected to perform insertion of 15 screws. The Jig and fixture system has several components which were imported as the main component (in turquoise color). The screws were imported and highlighted in several colors: red, blue, and yellow. They defined the direction of insertion as visualized on Figure 7. The task is quite simple: selecting the screw and inserting it in the right hole. Anyway, every participant repeated it 15 times within the four environments. This leads to about 15 minutes of work on every environment configuration (they were solicited during about one hour).

The researcher/observer loaded the virtual environments and opened the analysis manager. The analysis manager, shown in Figure 8, has a simple text field to identify a test and a single button to start or stop the experiment. When the experiment is started, every part is assigned at an initial position such that every test is driven in the same conditions. Only devices are parameters making difference in the operation. Every participant tested the four environments in the same sequence (from environment 1 to 4). Participants can lead and manipulate screws by using an haptic arm to assemble screws into the holes. When the observer had launched the analysis, the raw sensors values were recorded automatically into a comma separated value file format and can be processed afterwards for more complete analysis.

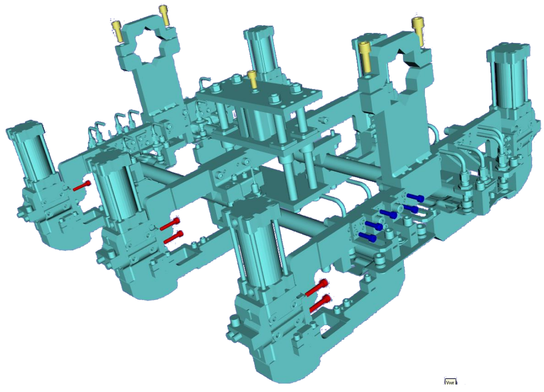

Figure 7: *The 3D model for assembly task*

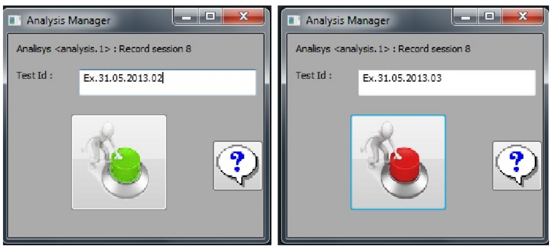

Figure 8: *The analysis manager in CVE Analysis*

5.3. Experimental results

The raw recorded files have been processed with basic statistics to get duration and gesture instability. The experimental data obtained include the following: minimum, mean, maximum, and standard deviation of all participants for the four environments for every inserted screw. The curves of average duration and instability for every repetition step are in Figure 9 and Figure 10.

Each screw is a learning opportunity for the operator. The evolution along the repetition steps is of primary importance to make a real comparison of the environments. One can observe that the absolute value may change at each step and a kind of convergence may be expected after few repetitions. This learning stage makes sense and if the instability is lower and the duration is optimized after few steps, the environment becomes operational. Without repetition, this statement cannot be observed. The curves of Figure 9 indicates that duration to insert one screw is increasing screw after screw. It may be interpreted as tiredness activity. The used protocol following the same sequence to test the environments appears as a real drawback since environment Env4 will always be evaluated the later when the user is already tired but also already trained. This must be corrected in a future series of experiments and it is a first conclusion of the conducted work. Currently this statement forbids any relative comparison between environments.

By analyzing the results, one can imagine that convergence tends to prove that the environment will be usable and useful after a learning stage. Oscillations about duration can be related to non-intuitive or not tangible systems where users cannot process twice the same strategy and improve it. Gesture instability will be related to lack of ergonomics: stability is a side effect which should be measured to discuss the easiness. If the handle is vibrating, it means that the actor is not so comfortable because of a wearing 3D handler. Then a second conclusion must be also highlighted: the shapes of curves (convergence, divergence, oscillations) are also significant for more abstract assessment.

Another analysis can be proposed by observing the correlation between raw sensors as drawn in Figure 11. Instability is drawn in respect of task duration for a specific environment. The correlation coefficient between duration and instability for the second environment is shown in Figure 11 through the interpolated line. The abstract conclusion here is that a rapid action (low duration) leads to less instability while a more quite action will come with increased instability. The utility of the environment may thus be considered depending on the expected rapidity or expected sharpness.

As previously justified, no definitive conclusion may be drawn yet since the sequence protocol should be revised first. Our experimental results can be summarized by considering both criteria of duration and instability of which global average values are summarized in table 1. A raw conclusion could be that providing 3D glasses or/and force-feedback leads to improve (shorter) duration of the manipulation. However, another hypothesis could be that this decreasing duration between environment 1 and other may be explained by users' training during the series of experiments from 1 to 4. Further experiments with the various order of environment tests should be conducted. On the other hand when concerning instability, we cannot conclude as the differences are not so significant from one environment to the others.

Environment	1	2	3	4
Average duration	22.53	17.12	17.81	16.64
Average instability	0.009	0.011	0.009	0.011

Table 1: *Correlation between instability and duration*

6. Discussion and conclusion

In this positioning paper, a traditional assembly process was used as a use case to assess and compare various configurations of a virtual reality environment. Raw sensors were employed to record the activity of eleven users repeating 15 times an equivalent task. Virtual environment can be employed to simulate, analyze and optimize manufacturing processes including assembly, leading to a more intuitive and natural way to simulate the assembly process during the

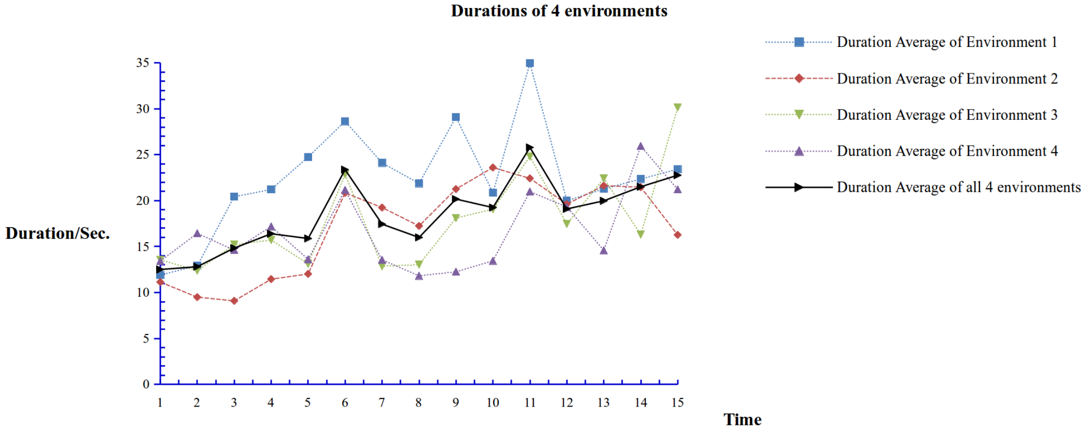

Figure 9: *The curves of average duration each repetition step (y axis : duration in s and x axis repetition step)*

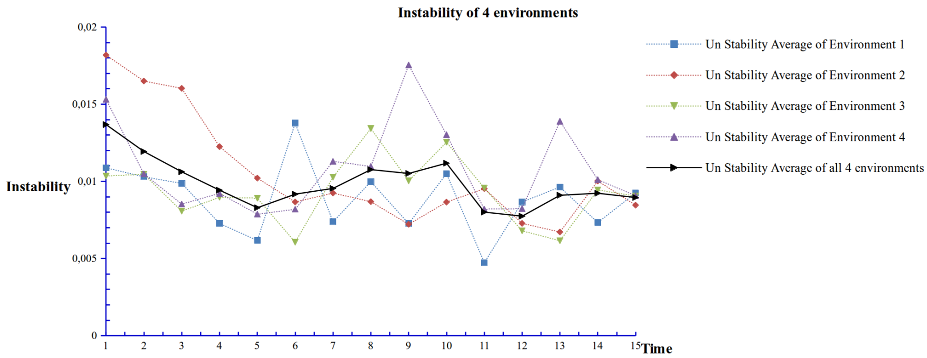

Figure 10: *The curves of average instability (y axis : instability level and x axis repetition step)*

design phase of new components even before any physical prototype is created. Significantly, we should find a way to compare environments about their capacity to provide natural interaction and professional added value. This study is a first step to reach utility assessment. Not only the first experiment which highlighted some attention points about the experimental protocol which must be improved, but also a good starting point to identify an analysis method to acquire abstract knowledge from raw sensor records. The next steps will first conduct new experimentation to validate the analysis protocol, then apply this protocol to more design dedicated activities. A clear experimental scenario allowing design to achieve tolerance evaluation of the system (such as the jig and fixture system) is the second step. In such step the condition of VR deployment in industrial design offices will pass through the demonstration of utility of VR for such activities.

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References

[CAM*13] CHARLES PONTONNIER., AFSHIN SAMANI.,MARWAN BADAWI., PASCAL MADELEINE., GEORGES DUMONT. Assessing the ability of a VR- based assembly task simulation to evaluate physical risk factors. IEEE Transactions on Visualization and computer (2013)

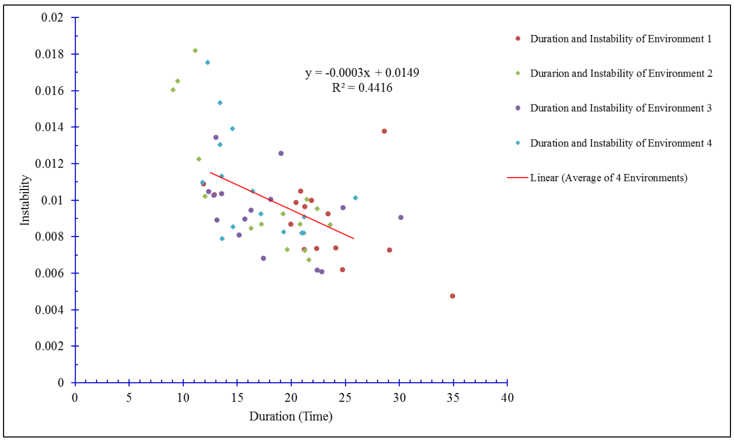

Figure 11: *The average duration and instability of 4 environments*

[CGA*12] CHARLES PONTONNIER., GEORGES DUMONT., AFSHIN SAMANI., PASCAL MADELENE., MARWAN BADAWI. Designing and evaluating a workstation in real and virtual environment: from digital Mock-up to realization. IEEE International Conference on Cognitive Infocommunications (Dec. 2012).

[CJJ11] CAROLINE CHABAL., JEAN-FRANÃğOIS MANTE., JEAN-MARC IDASIAK. Virtual reality technologies: a way to verify and design dismantling operations. IARIA Journal (2011), vol. 4 no 3&4, pp. 343-356.

[DAS09] DAWEI JIA., ASIM BHATTI., SAEID- NAHAVANDI. Design and evaluation of a haptically enable virtual environment for object assembly training. IEEE (2009).

[EAM*13] EMAD S. ABOUEL NASR., ABDULAZIZ M-El-TAMIMI., MUSTUFA H. ABIDI., ABDULRAHMAN M. AL-AHMARI. Virtual assembly in a semi-immer- sive environment. World Academy of Science, Engineering and Technology. (2013), vol.74-02-26.

[FAS12] FREDERIC NOEL., ANH NGUYEN BA., SAMIRA SADEGHI. Qualitative comparison of 2D and 3D perception for information sharing dedi- cated to manufactured product design. VISIONAIR (Sep. 2012).

[Fre12] FREDERIC NOEL. From integrated to intuitive design thanks to new technologies. MITIP (2012).

[GHT13] GERMANICO GONZALEZ-BADILLO., Hugo I. MEDELLN-CASTILLO., THEODORE LIM. Development of a haptic virtual reality system for assembly planning and evaluation. Science Direct Journal (2013), pp. 265-272.

[JTR*07] J.M. Ritchie., T. LIM., R.S. SUNG. Generation of assembly process plans and associated gilbreth motion study data. (2007).

[RAS*07] R. LGLESIAS., A. URIBE., S. CASADO. Assembly simulation on collaborative haptic virtual environments. (2007).

[TJJ*07] T. LIM., J.M. RITCHIE., J.R. CORNEY. Assessment of a haptic virtual assembly system that uses physics-based interactions. IEEE, International Symposium on Assembly and Manu- facturing (July 2007).

[WFC11] WESSEL W. WITS., FREDERIC NOEL., CEDRIC MASCLET. Exploring the potential of 3D virtualization techniques for usage in collaborative design. CIRP Design Conference (2011).

[XRM*10] XIANGCHUN CHENG., RONG GU., MIN CHEN. A virtual assembly system on automobile engine for assembly skills training. American Society for Engineering Education (2010).

[YAN07] YING ZHANG., ADRIAN R L TRAVIS., NEIL COLLINGS. Evaluation of multi-sensory feedback on the usability of a virtual assembly environment. Journal of Multimedia (Feb. 2007), vol. 2 no. 1, pp. 38-47.