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Haptic Devices Evaluation for Industrial Use

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Abstract

The current study concerns the Assembly/Disassembly (A/D) process. Despite the latest improvements, the creation of a fully realistic VE is still challenging because of the complexity of the physical processes involved and the current limitations of the available VR technology. In this context, the main purpose of this research is to improve the A/D process simulation by proposing a new method and associated tools, as well as a better integration with haptic devices. To this end, the first objective, regarding the software application, is to develop and evaluate the impact of a mobility module based on predefined kinematic constraints between the assembly components, able to guide user's movements when performing A/D operations simulation. This can be achieved through the intelligent management of the assembly components relative mobilities in contact situations. The second objective, regarding the hardware aspects, is to determine if the described approach, along with a new moderate cost haptic system, could represent an interesting solution for industrial use. In this sense, a comparison between the A/D simulation qualities provided by two commercial haptic devices (basic equipment with 3 DoF force feedback versus an expensive system with 6 DoF force feedback) was performed and it is presented in this paper. Conclusions were drawn after series of tests conducted by a target group composed of 20 people with engineering background.

Categories and Subject Descriptors (according to ACM CCS): Categories and Subject Descriptors (according to ACM CCS): H.5.2 [User Interfaces] - Haptic I/O

1. Introduction

Realtime simulation platforms play an increasingly important role in our everyday life. These tools were initially used in immersive video games where players are put in scenarios allowing them to develop skills useful also, sometimes, in managing real life situations. The same type of approach is now transferred to domains like engineering or medicine, virtual training environments being created and implemented for developing and improving a diversity of skills.

In many VEs (Virtual Environments), emphasis is mostly given to visual and auditory displays [ZFS*05], little tactile feedback information being provided. Therefore, haptic technology can represent, in some way, the third dimension of any immersive platform, essentially contributing to the user's perception of immersion. In recent years, many applications have been developed, ranging from portraying an unfolding (open) story [LBS13], training of complex products assembly [XLR*12], nanoscale phenomena simulation [MLB*08] to simulations in neurosurgery [CCS*13].

As known, the use of haptic devices usually involves collision detection in realtime, and effort generation where the collisions are taking place. In a significant number of cases this leads to an exponential increase of the required computing resources or to a relatively low quality simulation. Thus, there is a strong need for new development paths for the existing software, as well as for new and more affordable hardware solutions, especially for mechanical engineering applications, of interest in our research.

In the engineering field, one of the most prolific research areas is represented by the A/D process simulation. Great challenges pertain to this area due to the growing concern of environmental impact of the product in the latter phases of its lifecycle. Here two types of approaches are prevalent:

- Virtual manual assembly: methods that allow users to manipulate virtual components in a natural and effec-

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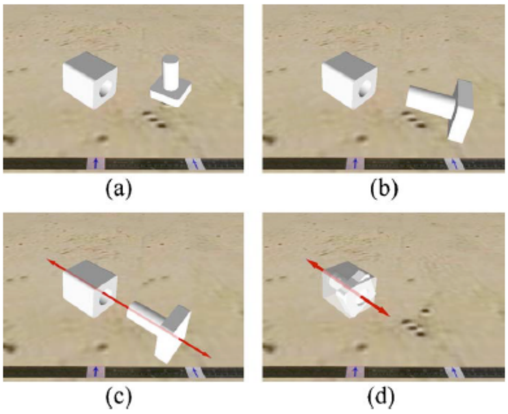

Figure 1: *Assembly using geometric constraints [SVO10]*

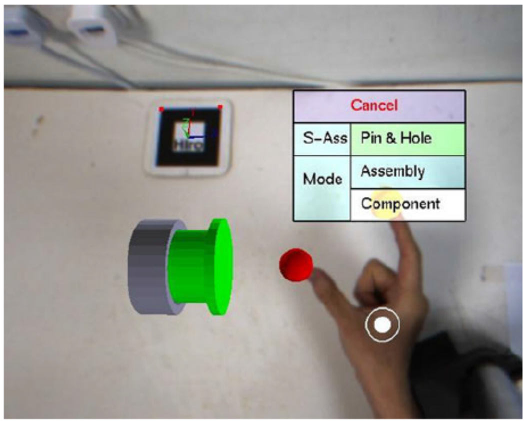

Fig. 1 Control of virtual panel using 3DBHI

Figure 2: *Virtual 3D bare-hand interaction tool [WON13]*

tive manner using basic movements and devices [SVO10], [WON13].

- Haptics based assembly: immersive applications that integrates a complete haptic effect for components mounting and dismounting operations [TDP10], [XLR*12].

Currently, as far as we know, despite the vast amount of research related to the immersive simulation environments, there are several unsolved issues. Among these issues, the most difficult one is the simulation using haptic devices of detailed A/D operations such as the insertion (extraction) phase of a component into (from) an assembly. Despite the fact that real-time simulation platforms have evolved tremendously, the final element which could render the simulation closer to reality, is still unavailable. This situation complies with the 80-20 implication rule introduced by Vilfredo Pareto and developed later by Joseph Juran [Jur51].

Regarding the hardware aspects, the existing haptic devices are either expensive and offer high quality feedback effects [Per14], or they have a very limited working space [Sen08] at a lower price. Thus, there is no affordable haptic system that could provide a set of features suitable for immersive simulations. In this context, the main purpose of this research is to set the basis for developing an integrated tool - hardware and application, to aid engineers in the design process, ergonomics evaluation, training etc., through a set of functions currently unavailable. This tool will represent a natural and smart choice for any mechanical design engineer that uses 3D CAD or immersive software.

In this paper, we will first review some of the existing immersive A/D platforms and haptic devices (Section 2). Then, we present the research questions (Section 3), followed by a description of the test protocol (Section 4). The next two sections describe the results (Section 5) before concluding (Section 6).

2. A/D immersive simulations

The immersive simulation platforms are based on 3D component models. In case of A/D operations, in order to generate realistic movements, simulations should extensively rely on kinematic constraints through the use of component mobility. The relative mobility of the assembly components is based on interface information that contains data about the contact type and the geometric nature of its corresponding surfaces. They can help characterizing the nature and the kinematic parameters between two components of a mechanical assembly [IPC13].

As previously mentioned, one type of approach is related to virtual manual assembly. Seth et al. developed a novel approach to virtual assembly that combines dynamic modelling with geometric constraint-based modelling for supporting low clearance manual assembly of CAD models [SVO10]. This is made possible by using the boundary representation (B-rep) solid model data available in most contemporary 3D CAD representations, which enables accurate collision/physics calculations on exact model definitions and access to geometric features. The application of constraints aids the designer during the assembly process (Figure 1). This approach is interesting, but it lacks an automatic geometric constraint recognition method to enable the system to define, during the run-time, the necessary geometric constraints based on the predicted assembly intent of the user, in order to offer a more intuitive interaction with the environment.

A similar method was used by Wang et al. for a manual assembly design system [WON13]. They have implemented an hybrid approach that allows users to simulate a manual assembly without the need for additional computer-aided design information in assembly design. A methodology for 3D bare-hand interaction was integrated with the

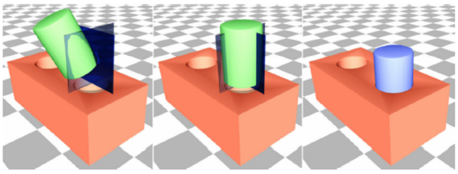

Figure 3: *Peg-in-hole insertion using VCG [TDP10]*

interactive manual assembly design system for the users to manipulate the virtual components in a natural and effective manner (Figure 2). The geometric information required for assembly modelling is extracted using SolidWorks and stored in a tri-layer assembly data structure: the first layer stores the geometric information; the assembly sequence is stored in the second layer; the information of the completed assembly model is stored in the third layer.

The developed system is useful, but limited due to a direct dependence of proprietary software - 3D models are created only in SolidWorks. In addition, the spatial mating constraints considered include only three elements: planar fit, cylindrical fit (plus conical fit) and spherical fit.

In order to ensure a good assembly of virtual objects using haptic devices, Tching et al. created a method of interactive assembly that uses both kinematic constraints and guiding virtual fixtures. Modelling a haptic assembly task as a combination of mechanical joints, they focused on the guidance of objects and on the activation cues of kinematic constraints in physical simulation. The proposed method for haptic guidance VCG (Virtual Constraint Guidance - Figure 3) decomposes a task in two independent steps: a guiding step, which use geometries as virtual fixtures to position objects, and a functional step, which use kinematic constraints to perform the assembly task. This approach, where the component kinematic mobility become an additional parameter of the digital model involved in the A/D simulation and control, is the first one that offers the possibility to obtain a more realistic simulation of A/D operations. However, the proposed method is limited because the kinematic constraints should be manually defined at the beginning of the simulation and it seems that the presented application can manage only one type of joint: cylindrical fit.

A new type of haptics-based VE system for assembly training of complex products is developed by Xia et al. [XLR*12]. They designed a low-cost motion simulator for the integration with the VE, to realize free walking by humans, and an automatic data query interface to transfer geometry, topology, assembly, and physics information from a CAD system to the application. Also, a hierarchical constraint-based data model was built to construct the virtual assembly environment and physics-based modelling and haptics feedback were undertaken to simulate the realistic assembly operations (Figure 4). This VE system represents

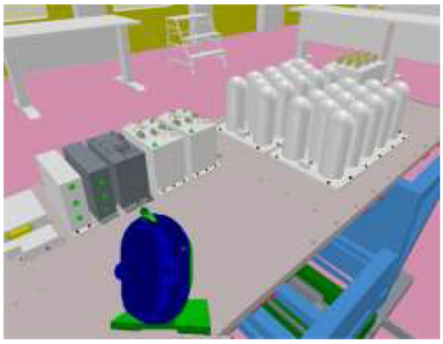

Figure 4: *Part assembly with geometry constraint [XLR*12]*

a complex simulation environment, but it is unclear how the application retrieves all the assembly data from the base 3D product model using multiple API toolkits.

An immersive simulation environment is composed of two main elements: hardware and software. Given that several existing applications were detailed in previous paragraphs, thereafter different haptic devices suitable for immersive simulations will be analysed.

Since the development of the first feedback device integrated in a robotic tele-operation system for nuclear environments, different commercial force feedback interfaces have been developed. These can be divided in two main categories:

- basic-haptic - defined as having a limited haptic effect through a vibro or thermo method;
- complete-haptic - defined as providing a complete haptic effect actively generated by a device through a frame system.

Currently, the most used tactile technology is deployed through the vibration effect. Almost all of the mobile phones and communicating devices have a simple vibrating mode. Other inexpensive devices like: joysticks, gamepads etc., use the same technology. Although the haptic effect used is a very basic one, it is very popular because of a really low price.

Having a price far more elevated, the tactile gloves are more appropriate when VR simulation requires dexterity - multiple contact points, freedom of motion, and information on object grasping state and mechanical texture, but not weight. A well-known example is the commercial CyberTouch produced by CyberGlove Systems that uses electromechanical vibrators placed directly on the glove. The existing tactile gloves offer a set of limited haptic effects for a high price, which limits their spread. More, their further integration in a complex immersive system is very difficult. Though, the tactile feedback research domain is still dy-

Figure 5: *Geomagic Touch.*

Figure 6: *Haption Virtuose 6D35-45.*

namic and it can offer further interesting approaches through innovative concepts.

The equipment offering a complete haptic effect is more complex, reliable and expensive. These devices can be further divided in two categories based on the mechanism type: parallel and serial.

The Omega series is built around a parallel kinematic structure by Force Dimension and it provides a good haptic effect through a high rendering degree of contact forces. Three similar devices sharing the same platform are currently commercialized: Omega.3 (3 active translations), Omega.6 (3 active translations and 3 active rotations) and Omega.7 (3 active translations and 3 active rotations plus 1 active grasping). The haptic devices based on parallel kinematic structures or on spherical mechanisms are robust and provide good haptic effects, but their workspace is very limited and their cost is high.

A different type of haptic interfaces relies on the linkage-based system, which consists of a pen attached to a robotic arm tracking the position of the pen and being capable of exerting a force on the tip of this pen.

In order to meet the haptic demands required for providing the user the sense of touch, complex hardware and software are used to set the correct values for joint angles and torques which can determine a single point of force at the tip of the pen. As a result, a high quality linkage-based force feedback can be really expensive.

Based on the robotic arm architecture, Touch (former Phantom Omni) is one popular and inexpensive device on the market (Figure 5). This device is produced by Geomagic (former Sensable) and it offers 6 DoF positional sensing, only 3 DoF force feedback and very limited workspace [Sen08].

An example of a high premium haptic device is Virtuose 6D35-45 (Figure 6). This device is developed by the French company Haption and offers a large workspace and substantial force-feedback on all 6 DoF [Per14]. Although these type of haptic equipment offer an excellent haptic feedback, their workspace is still limited and their cost is high.

3. Research objectives

As presented in the previous section, haptic technology represents a new and straightforward dimension of the immersive simulations, the haptic devices being used more frequently in different domains. Although this technology has evolved impressively in the last years, many improvements are still needed in the hardware zone coupled with software advance, in order to render the simulation environment more accessible and truly immersive. The latest trend in the field is to offer haptic devices with bigger workspace and new modules for a smarter management of immersive simulations [Per14]. In order to improve the A/D process simulation, two objectives are pursued in our research.

The first objective is to evaluate the impact of a mobility software module, based on predefined kinematic constraints, able to guide the user's movements, when performing A/D operations simulation, through an intelligent management of relative mobilities of the assembly components in contact situations.

The second objective is to find out if it is feasible to create a moderate cost system (i.e. hardware plus software) for industrial use. It is important to note that the price of such a system is prohibitive for many SMEs and universities, limitating the penetration rate of such equipments and thus the advances in the practice.

Using the price list from a main VR equipment distributor - Engineering Systems Technologies [EST14], we have computed an average price of a haptic system. Thus, we can conclude that the haptic device price represents more than four-fifths from the system price. In this context, a rapid way to decrease the total cost would be to use a low cost device, if the simulation quality remains good enough for a set of predefined activities.

4. Test protocol

The core application used to fulfil the research objectives was CVE - Collaborative Virtual Environment, developed by the G-SCOP Laboratory. This software can manage the interaction between the virtual scene and human through a stereoscopic display and a haptic device.

CVE is basically an event propagator between several clients (modules). The clients can be executed on the same computer or on several ones through network connection. Every client is in charge of its own task and does not care about what is executed by others. It just publishes a shared model, which refers in a more or less complex organization to a set of concepts that can be evaluated by attributes. Whenever this model is changed, the client is in charge of updating a local device and simultaneously, whenever a local device is activated by the user, its new state values must be propagated to any other interested client.

A mobility software module dedicated to modeling contact relations between elementary components of a product and responsible for managing the relative mobilities of the assembly components was integrated in CVE. This one can efficiently contribute to the real-time simulation process, when it is performed with haptic devices, by by-passing the complex collision detection algorithms and their unrealistics effects when caught with multiple contacts. This way, A/D operations can be naturally simulated in real-time for their most critical part.

In order to perform the evaluation tests, a number of elements have been set in a preparation phase. In the first place, test equipment was chosen using two criteria: devices from completely different ranges (price and performance) and, obviously, their availability in the VisionAir infrastructure. Thus, Geomagic Touch (Figure 5) and Haption Virtuose 6D35-45 (Figure 6), already presented in the previous chapter were used respectively as a basic equipment and a premium equipment.

In order to have relevant evaluation data, the analysis is deployed through a series of tests conducted with a group of 20 people with the following characteristics:

- Gender mix: males and females.
- Different ages: [20 - 60]. Average: 35 years.
- Different status with background in engineering: professors, researchers, engineers, bachelor & master & PhD students.

Test was divided in two sequences (S-3 and S-6) of two task (T1 and T2). Each sequence was dedicated to a specific device (3DoF and 6DoF) half of the participants started with the 3DoF equipment - Geomagic Touch (S-3), and the other half started with the 6DoF equipment - Haption Virtuose (S-6), thus avoiding a progression effect that might have appeared by using the same order of sequence. For each sequence, two tasks were proposed in the same order: a same mounting operations on different supports. The first task was performed on a simple Mounting Flange assembly (Figure 7) composed of 7 components and 12 contacts: planar fit and cylindrical joint type. The main component (aka the flange) has 14 holes (of which 6 counterbore holes), the user being free to choose any of them to mount any screw, thus ensuring the interactivity of the VE. This assembly follows a specific scenario:

- main (base) part is fixed - colour: red;
- participant selects, using a haptic device, any free part - screw (colour: green) and explores the virtual scene;
- user reaches a privileged position when the final insertion is to begin and the manipulated part changes its colour: orange;
- part is inserted, using the activated kinematic constraint, in the hole and, in the final position (colour: red).

Participants were asked to mount, as quickly as possible, all the screws in the base part. This task was mainly intended to allow participants to familiarize with the scenario and gain a first experience with the haptic device. The second task was performed on a mechanism made of X parts. Several types of joints were implemented (list of joints) and the participants had to assemble as much part of the mechanism as possible following a provided flow process grid detailing the assembly operations order. This task was also to be held in a limited time.

In order to have a meaningful evaluation, different types of assessments were deployed:

- Real-time quantification elements: number of assembled components, average time for a component assembly, and

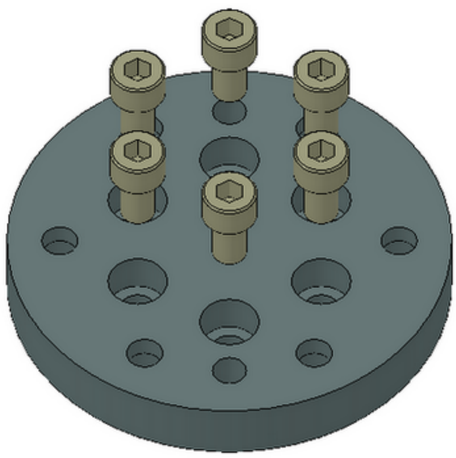

Figure 7: *Mounting flange assembly.*

average number of clicks - objective assessment. They where wether collected by the observer or captured by the software;
- Questionnaires: pre-activity (held before the beginning of any manipulation), post-activity questionnaire (for both 3DoF and 6DoF devices)held at the end of each sequence and the final questionnaire for subjective assessment held at the end of the test.

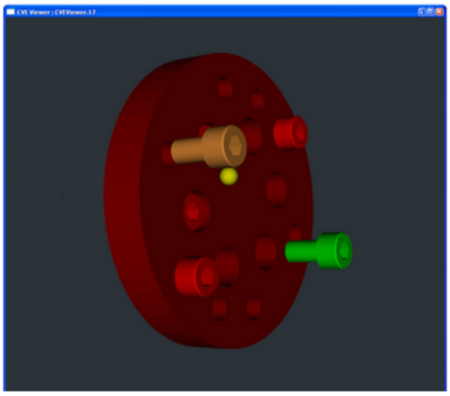

Figure 8: *Assembly operation in CVE.*

Each test session was recorded. Thus, three types of elements were measured (extracted) in real-time. This data was corroborated with the questionnaires results for a global analysis. The main part of the questionnaires was based on a standard Likert scale: 1 - absolutely not to 5 - absolutely. Thereby, the questionnaires answers provided a fast evaluation of the users' satisfaction when using the application: ease of use, usefulness of stereoscopic view, utility of the haptic cues etc., and a comparison of satisfaction in using the two haptic devices.

5. Results

Investigation and testing of VE for design and assembly tasks have been carried out for many years [LRD*07], [PDS*12]. This research is a complementary approach having as purpose to find an answer to the following questions:

- Q1. Does a mobility software module contributes substantially to increase the immersion (reality) of a real-time A/D simulation?
- Q2. Is an haptic device with average performance sufficient for A/D simulation?

Before discussing the experiment results, we consider that it is important to present a description of the average user. This way the results and opinions may be reported to the character created for statistical purposes. However, for a number of specific comments, the particular profile matters. Thus, the average user is 35 years old, right-handed and of average corpulence. He has a master's degree and is attending an additional university training program. He has good knowledge of industrial engineering and has already practised at least two CAD systems and an assembly module. He occasionally used stereoscopic view and haptic equipment.

Related to the first question (Q1), the following conclusions can be enumerated from the questionnaires analysis:

- application was perceived as useful, the functions well defined and the 3D graphics accurate enough for performing the task;
- parts were easy to assembly using the kinematic guidance - the insertion phase;
- problems were mentioned in some configurations, when the collision detection was used.

Interpretation of participant responses in relation with Q2, allowed the next conclusions to be drawn:

- users have the tendency to say that it is easier to perform the assembly tasks with the basic device;
- although the haptic effect was perceived as real and useful, due to the collision detection problems, the 3 additional degrees of freedom with force feedback offered by the premium device seem unnecessary;
- an important aspect mentioned is the existence of a sufficiently large working space (human size).

6. Discussion and conclusion

The sense of touch is an important medium of communication and information exchange primarily between people, from the very first years of life, and, nowadays, to a clear certain extent, between man and computer (immersive simulation environments). Fields like Artificial Intelligence (AI), robotics, VR know an important evolution, but despite their advances, we believe that the future belongs, though, to the humankind and creativity.

Even the importance of haptic feedback for different applications is a recognized fact, it is still under-represented in the everyday computer interface. Mainly, there are two reasons: the commercially available haptic devices are still relatively expensive and the existing immersive software is not offering robust functions for real-time simulations.

In A/D immersive applications, currently there are two types of approaches for constraints generation: the interactive specification and the semi-automatic enumeration of these constraints during the simulation, depending on the configuration of components. In both situations, difficulties related to the analysis of the constraints consistency exist. Related to the hardware, although many haptic devices are available, they are either expensive or they offer low quality force feedback effects.

In this context, the current research had the following main objectives: to validate a mobility software module for enhancing the user experience of A/D simulations, and to assess the impact of haptic devices' performances on the user experience. To these purposes, the developed mobility module was integrated in an immersive environment and several evaluation tests were carried out by a group of 20 potential haptic users, by means of two haptic devices (3DoF and 6DoF). The results comparative analysis, allowed drawing two main conclusions: 1. the mobility module increases the level of immersion, although the collision detection algorithm plays also an important role; 2. results clearly outline that some characteristics of the haptic device stand out in the context of A/D operation simulation: hence, we can consider that there's a strong opportunity for the development of more affordable haptyc systems that would favour an extended workspace over the number of DoF or the level of haptic feedback. This work should be extended to a larger range of applications in order to verify if this perception of immersion experience is specific to A/D operation or shared among a wider range of engineering activities.

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References

[CCS*13] CHAN S., CONTI F., SALISBURY K., BLEVINS N.: Virtual reality simulation in neurosurgery - Technologies and evolution. Neurosurgery vol. 72, no. S1 (2013), A154-A164. Doi:10.1227/NEU.0b013e3182750d26.

[EST14] Engineering Systems Technologies website: http://www.est-kl.com/products/haptic-feedback.html.

[IPC13] IACOB R., POPESCU D., CARUTASU N.: Development of assembly/disassembly process simulation platform. Proceedings in Manufacturing Systems vol. 8, iss.1 (2013), 15-24.

[Jur51] JURAN J.: Directions for American Society for Quality Control. Industrial Quality Control vol. 8, no. 3 (1951), 30-34.

[LBS13] LLOBERA J., BLOM K.J., SLATER M.: Telling stories within immersive virtual environments. Leonardo vol 46, no. 5 (2013), 471-476. Doi:10.1162/LEON_a_00643.

[LRD*07] LIM T., RITCHIE J.M., DEWAR R.G., CORNEY J.R., WILKINSON P., CALIS M., DESMULLIEZ M., FANG J.J.: Factors affecting user performance in haptic assembly. Virtual Reality vol. 11 (2007), 241-252. Doi:10.1007/s10055-007-0072-8.

[MLB*08] MILLET G., LECUYER A., BURKHARDTS J.-M., HALIYO D.S., REGNIER S.: Improving Perception and Understanding of Nanoscale Phenomena Using Haptics and Visual Analogy. In Haptics: Perception, Devices and Scenarios, Ferre M. editor, pp. 847-856, Springer Berlin Heidelberg, (2008).

[PDS*12] PONTONNIER C., DUMONT G., SAMANIZ A., MADELEINEZ P., BADAWI M.: Designing and evaluating a workstation in real and virtual environment: from digital mock-up to realization. International Conference on Cognitive InfoCommunications (2012), 249-254. Doi:10.1109/CogInfoCom.2012.6421988.

[Per14] PERRET J.: Haptic trends by Haption: larger, stronger, faster. EuroHaptics Conference (2014).

[Sen08] SensAble Technologies: Force reflecting haptic interface. United States Patent no. US7.411.576.

[SVO10] SETH A., VANCE J.M., OLIVER J.H.: Combining dynamic modelling with geometric constraint management to support low clearance virtual manual assembly. Journal of Mechanical Design vol. 132 (2010).

[TDP10] TCHING L., DUMONT G., PERRET J.: Interactive simulation of CAD models assemblies using virtual constraint guidance - a new method to assist haptic assembly tasks. International Journal on Interactive Design and Manufacturing vol. 4 (2010), 95-102.

[WON13] WANG Z.B., ONG S.K., NEE A.Y.C.: Augmented reality aided interactive manual assembly design. International Journal of Advanced Manufacturing Technology vol. 69 (2013), 1311-1321.

[XLR*12] XIA P., LOPES A.M., RESTIVO M.T., YAO Y.: A new type haptics-based virtual environment system for assembly training of complex products. International Journal of Advanced Manufacturing Technology vol. 58, iss. 1-4 (2012), 379-396. Doi:10.1007/s00170-011-3381-8.

[ZFS*05] ZHANG Y., FERNANDO T., SOTUDEH R., XIAO H.: The use of visual and auditory feedback for assembly task performance in a virtual environment. Conference on Information Visualisation (2005), 779-784.