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AN ANALYSIS OF HUMAN-BASED ASSEMBLY PROCESS FOR IMMERSIVE AND INTERACTIVE SIMULATION

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ABSTRACT

Assembly simulation, with the help of Virtual Reality (VR), becomes a very challenging technology due to its highly interactive context, imposed by a number of functions and the need for realism. This study focuses on the development of an interactive simulation prototype for use in human-based assembly operations. The design aims at improving the easiness and efficiency of VR when used, in the early stages of a product's lifecycle, by engineers that can exploit its benefits, without having an expertise in the VR field. The development of this prototype is tested and evaluated through its implementation on a use case, found in the daily practice of an aerospace industry. The development is made in a platform independent architecture, in order for its possible integration with different VR platforms to be facilitated and it is based on usability guidelines and a taxonomy-based classification. Based on the requirements, provided by the aerospace industry, a validation part is compiled for the evaluation of the interactive prototype developed, in relation to human-centred specifications.

KEYWORDS

Engineering Simulation, Process Simulation, Virtual Assembly

1. INTRODUCTION

The manufacturing industry has turned to the Virtual Reality (VR) technology, in order for the time and cost of their PLM activities to be reduced and particularly, the cycle time and cost, starting from the conceptual phase of the product or process development up to its production phase. In general, VR is described as a computer-generated environment that simulates the real world besides imaginary worlds. Virtual Reality (VR) provides the means by which humans visualize, manipulate, and interact with computers and extremely complex data (Chryssolouris, 2006). These computer-generated environments, called Virtual Environments (VE), consist of three-dimensional objects. VR users interact with the VE or its content (e.g. virtual objects) through 3D Interaction techniques (3DITs) (Flasar, 2000).

VR is used in many engineering applications such as product and process design, modelling, manufacturing, training, testing and digital validation. Virtual Manufacturing (VM) is a technology that mimics real manufacturing processes with models, simulations and artificial intelligence (Lin et al, 1995). Another type of use of VR in manufacturing is Virtual Assembly which is defined as the use of computer tools in assisting with assembly-related engineering decisions through analysis, prediction models, visualization, and presentation of data without creating the product or the support processes (Mujber et al, 2004). The VR technology is also very popular for validating through experimentation the ergonomics of products and processes (Bi, 2010).

Traditionally, the verification of an assembly process is performed in wooden or high-fidelity scale model mockups. This can be a time and labour intensive procedure. With the use of VR, more realistic computer generated assembly environments can be created and by using 3D Interaction Techniques (3DITs), products can be manipulated, assembled and disassembled as required (Wan et al, 2004). The application of immersive virtual reality in a virtual model of the assembly environment, can help design and evaluate manufacturing tasks and different possible sequences, and choose the best alternatives (Zhao and Madhavan, 2006). Also, by immersing a real person into the virtual environment, which interacts directly with the elements of a simulated virtual world, ergonomic data can also be acquired (Chryssolouris, 2006).

Assembly simulation, through the use of VR, is very challenging due to the fact that the interactions should be as natural as possible. In other applications, the intuitiveness, or easiness to perform the interaction, is usually preferred but of course that is not the case when the goal is to simulate a real process. During a VR session, the user does not only interact with the virtual environment but also with the system (Zachmann and Rettig, 2001). The development of natural interactions is a big challenge, because their purpose is not just to facilitate the human-computer interaction but also to ensure that the interaction imitates the real function or operation, as realistically as possible. This means that during the design and development of a 3DIT, the designer should respect the constraints that apply to the real world and at the same time make the technique as robust as possible. In (Chryssolouris et al, 2002), a virtual experimentation environment was developed as a planning and training tool for machining processes. This approach involved the virtual modelling of machining processes within a Virtual Machine Shop environment. This environment enabled an immersive and interactive process performance and showed the potential of the approach to provide significant advantages in this field of applications against current desktop simulation approaches. A study by (Rubio et al, 2005) presented a methodology of virtual models being developed for manufacturing simulation.

According to the authors of (Connacher and Jayaram, 1997), the acceptance and success of a Virtual Assembly (VA) simulation application is dependant on five factors. The first factor has to do with the capacity of the application to enable engineers in gaining perspective on assembly issues. The second factor implies that the system should support the engineers’ decision making activities. The third and fourth factors suggest that the technology should be applicable in real production and easy enough so as to be used on a daily basis. The fifth and final factor that should be taken into consideration refers to the accuracy and fidelity of the information derived from the simulation.

There is a broad spectrum of interaction metaphors for manipulating objects in VEs but none of them is considered as the “ideal” or “dominant” 3D manipulation technique. The reason for this is that even if a technique is perfectly suited for a specific application, it may not necessarily be the best one for another. In almost all cases, any choice of a 3DIT is the result of trade-offs, such as realism over usability and ease of use in respect to the accuracy of the simulation. Managing these trade-offs for a more desirable outcome is one of the keys to a good 3D IT design (Ottosson, 2002). Natural user interactions play a key role in virtual assembly because high interactivity is an intrinsic characteristic of any assembly process and therefore, in virtual reality, this feature is of the outmost importance (Wan et al, 2004). In assembly simulations, the most common techniques are the ones that have to do with grasping and manipulating a virtual object. When it comes to grasping, Pitarch (2010) classifies the actions concerning grasping objects into pre-grasp, grasp and after-grasp. In (Jones, 1997) a distinction is made between five types of grasping; Precision, Cigarette, 3-point pinch, Power and Gravity grasping. However, using many techniques can be confusing to the user and thus prevent realism In (Wan et al, 2004) the authors divide the types of grasping to Power grasping and precision grasping. A mechanism was developed that could recognize grasping actions by using auxiliary virtual objects (Pappas et al, 2003). According to the study, this technique resulted in improving the user interaction realism within the virtual process environment and the minimization of the necessary time for a task to be executed. There are other studies, also focusing on the simulation of the grasping task, (Holz et al, 2008, Weber et al, 2006), however, all have come to the conclusion that no matter how affluent literature may be, there is no perfect modelling for grasping simulation. It is a very complex task, which in most cases, is adjusted to the requirements of the application.

There are cases in assembly simulation that objects should be placed accurately and in respect to a certain time-frame. In such cases, it is almost impossible for all natural limitations to be respected, mainly due to the absence of haptic feedback and the inherent inaccuracy by which multimodal devices are controlled, resulting in a poor performance during the positioning or removal of virtual objects. On top of that, feedback of the product's weight and collision with other objects (when moved object collides with another object) is still a problem for the VR technology (Ottosson, 2002). Consequently, the parts can hardly be placed in their exact fitting position. In (Mavrikios et al, 2006) a solution to this problem was proposed through the development of a function, which released the virtual object from the user's hand as soon as a good position had been achieved.

2. INTERACTIVE ASSEMBLY FEATURES

The classification of user interaction techniques and a survey on the existing technologies and methods in that field, are mandatory for the design and development of advanced interaction metaphors. The classification, followed in the conceptualization and design of this study, is based on a common categorization, provided by technical literature (Bowman et al, 2004). Referring to this, preselected, common interaction techniques are divided into main categories such as travel, selection, manipulation, system control and symbolic input techniques.

For use in this study, has been employed the concept of the decomposition technique (Bowman et al, 2004). In this method, the techniques for a particular task can be decomposed into sub-techniques, which are called technique components (TC). The formalization methodology followed in this study for the development of the interaction metaphors, is proposed by (Bowman and Hodges, 1999, see Figure 1) and suggests that in order for the differences in modelling between 3DITs to be better comprehended, the designer should arrange them into categories based on various parameters.

The most important advantage of this approach is the summative evaluation that compares technique components rather than holistic techniques. After the decomposition, each subtask can be translated into functional components of its implementation code. These components are designed to be functions that can be easily facilitated by various VR platforms so as for the techniques to be platform independent.

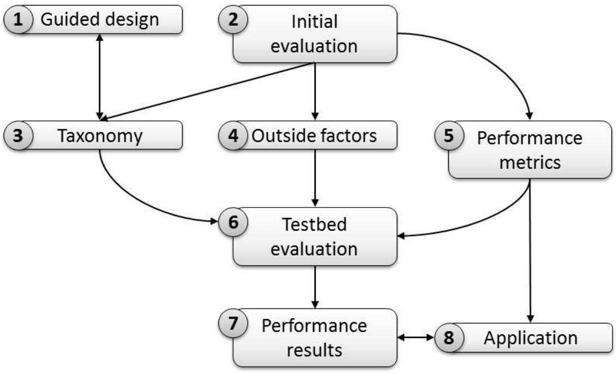

Figure 1 – Methodology of design, evaluation and application of the 3DIT proposed by (Bowman and Hodges, 1999)

2.2. DRILLING PROCESS METAPHOR - DP

The Drilling Process interaction metaphor (DP) is a specific technique used for the drilling process simulation that allows an immersed user to virtually drill holes on a virtual work-piece. The user can modify certain parameters of the drilling process by using a multimodal device. The device's structure allows the user to dynamically change the values of those parameters while the process is being executed and the values can be simultaneously modified.. Ultimately, the user controls the tool's velocity when it is inserted into the work-piece.

The device used for this technique is the Wii Nunchuk®, which is basically a 3D mouse with two buttons and a joystick. A tracker is also attached to the device so that its position and orientation can be tracked. The two buttons are used for adjusting the spindle rotational speed, while the joystick on the for modulating the actual velocity of the drill tip when it is inserted into the object. The lower value of this parameter is zero and the maximum is calculated depending on the spindle rotational speed. The hole in the model is represented with a cylinder and is modified according to the input from the technique. The metaphor can be activated after the tool is near, in the right position and has the proper orientation. If the tool stops being in the proper pose (position and orientation) the Drilling metaphor is deactivated.

2.2.1. Task decomposition

The drilling task is divided into three sub-tasks. The first task has to do with the definition of the drilling spot on the work-piece. The second task has to do with the testing of the tool's position and the third one with the modification of the model (in this case hole-drilling) using various inputs from the user. The architecture of the metaphors is generated from the description of the tasks. For the definition of the working spot, a common "raycast" interaction technique (a technique where a ray is casted from the user's hand or tool) can be used with an intersection test incorporated. A position control technique is used for testing the tool's placement relative to the spot to be drilled. This is done by calculating the gradient of the surface at the specific point. Finally, for the model's geometrical modification, another technique is created that modifies the model by translating the input from the user's peripheral device. The task decomposition of the drilling process metaphor is graphically depicted in Figure 2.

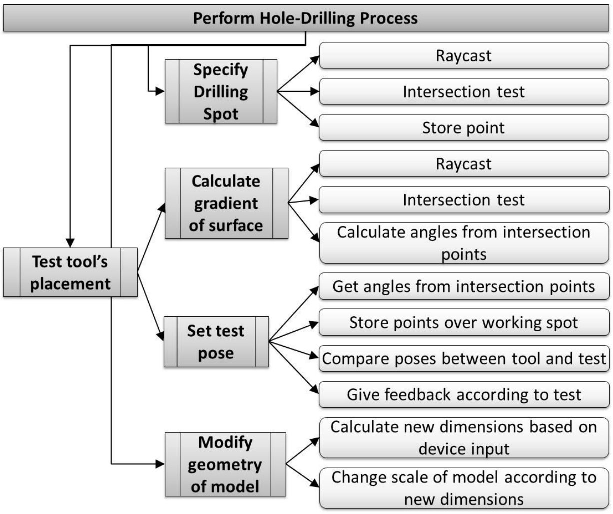

Figure 2 – Drilling process task decomposition

2.2.2. Implementation

The DP works by translating signals, received by an input device (representing the virtual drill) into modifications of the hole-geometry. The IM is initiated when it receives a positive input by the Magnet Metaphor (see 0), which checks whether or not the tool is in the right pose to perform the drilling operation. The device used in the application comprises two buttons and a small joystick as shown in Figure 3.

The upper button of the device is used to increasing the value of the spindle rotation parameter and the lower one to decreasing it. The joystick when moved forward increases the value of the insertion velocity and decreases it when moved backwards.

For a given type of drilling simulation, the predefined amplitude of spindle values can be used. Values inside this amplitude are given to the parameter, from 0 to a maximum rotational speed. The spindle rotational speed is controlled by the two buttons of the device (see Figure 3).

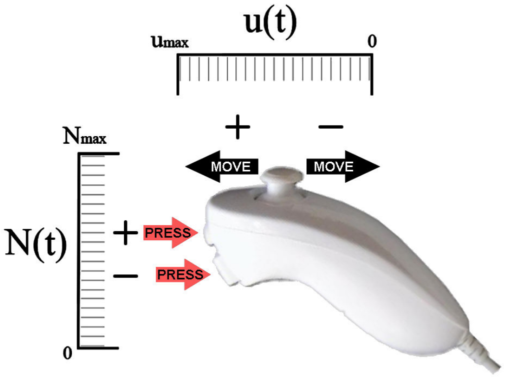

Figure 3 – Mapping of functions on the device

The second parameter adjusted by the user is the actual velocity that the drill tip is inserted into the object. The minimum value of this parameter is zero ($u_{min}(t)=0$) and the maximum is calculated as shown in Equation (1).

$$u_{\max}(t) = F \cdot N(t) \tag{1}$$

Where:

- F(mm/rev): is the feed rate being the velocity at which the tool is fed into the work-piece, expressed in millimeters per revolution of the spindle. The feed rate varies depending on the drill and has a constant value.
- $u_{max}(t)$ (mm/min): is the maximum velocity that the drill tip can be inserted into the work-piece, expressed in millimeters per minute.
- N(t) (rpm): is the spindle rotational speed expressed in revolutions per minute.

The depth of the hole is calculated as shown in Equation (2).

$$d(t_k) = \sum_{i=0}^{k} u(t_i) \cdot t_{const}$$

(2)

Where:

- i = 0, 1, 2……k
- $d(t_k)$ (mm): the depth of the hole at a given time t_k.
- $u(t_i)$ (mm/s): the velocity at which the drill bit inserts the hole at any given time t_i.
- t_{const} (ms): time constant $t_{const} = t_{i+1} - t_i$ represents the step followed in order for the calculations to be made.

The geometry of the space in the hole is represented by a cylinder whose length $b(t_k)$ is changed as shown in Equation (3).

$$b(t_k) = 1 - \frac{d(t_k)}{L} \tag{3}$$

Where:

- L (mm): the initial length of the hole geometry.

The geometry of the hole is scaled down in its main axis according to the values of the $b(t_k)$. When the depth reaches its maximum value and the $b(t_k)$ reaches zero, the geometry stops scaling down and is deleted.

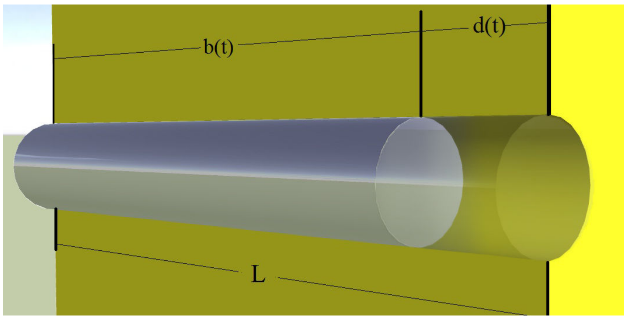

Figure 4 – Hole geometry modification

2.3. MAGNET METAPHOR

2.3.1. Task decomposition

The Magnet metaphor is an interaction metaphor designed to test when a predefined acceptable position and orientation have been achieved for the placement of an object in a Virtual Environment. For example, in the case of hole-drilling, the tool should be placed in the right position, relatively to the drilling spot. A virtual object is moved inside a virtual environment, based on the tracking data translated into coordinates, received by the corresponding VR peripheral device found in the hand of the immersed user (e.g. wand). When the distance between the object and the predefined position is within a certain threshold, the object's texture is set to blue so as to inform the user of his approaching the "magnet" spot. When the object's orientation and that of the test are also close, the tool's texture is set to green and the interaction technique places the object in the magnet's position (see Figure 5). The above algorithm of the metaphor is presented in Figure 6.

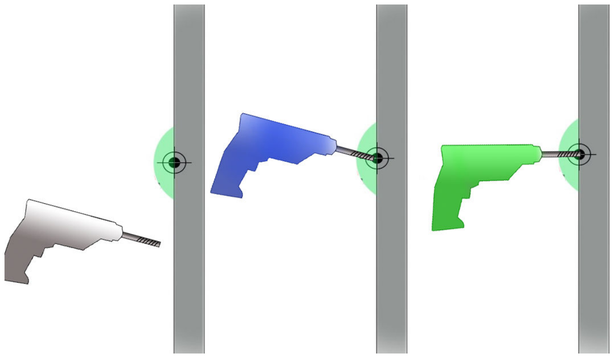

Figure 5 – Magnet metaphor concept

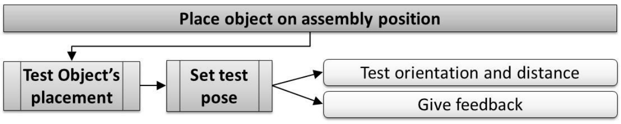

Figure 6 – Magnet metaphor task decomposition

2.3.2. Implementation

The Magnet Metaphor, which is used for the precise positioning of virtual objects in assembly applications, works by testing the pose of an object relatively to a predefined one, called the "magnet" pose or test pose.

The first test that the metaphor executes is the distance test, which calculates the distance between the object and the magnet's position. If the distance is under a certain threshold, the orientation test is initiated. Following the logic of the previous test, if the orientation is under a certain threshold (fixed vector), the object is placed in the desired position.

This metaphor is more suitable for operations such as for positioning objects (e.g. parts to be assembled) in virtual mockups. It also has to do with placing the tool that the user is using (e.g. screwdriver) in the proper position to perform a task. Part positioning works when the object is controlled by the movements of the user's hand. While the object is being moved, the proximity test runs and when all conditions are satisfied (proper position and orientation) the part is snapped to the magnet position. In order for the object to be released, the user needs to perform either a release gesture, when a virtual hand is used, or to release the button when a 3D mouse is used.

2.4. ADAPTIVE FINGER GRASPING METAPHOR - AFG

2.4.1. Task decomposition

The Adaptive Finger Grasping interaction metaphor (AFG) simulates the process of real objects being grasped with one's hand. The immersed user, by giving input through a data-glove can select and manipulate objects in the VE.

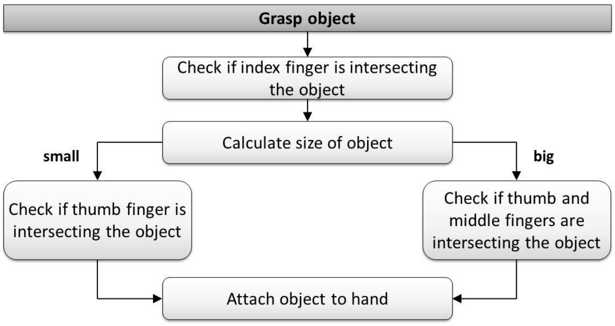

Figure 7 – AFG task decomposition

The AFG requires different conditions for grabbing small objects (e.g. screws) and bigger ones (e.g. tools), as it is illustrated in the decomposition of the AFG algorithm in Figure 7.

2.4.2. Implementation

The geometries that compose the virtual hand are usually more complex and thus intersection tests between those components and the virtual objects will be computationally intensive. Instead of executing direct collision tests, simpler geometries can be used to make the process simpler and more effective. Invisible cylindrical geometries are attached to the fingers of the user's hand (Figure 8). The collision detection test takes place between these geometries and the virtual objects. That also makes it easier for an object to be selected and helps overcome the difficulties that data-gloves usually bear with their signal mapping.

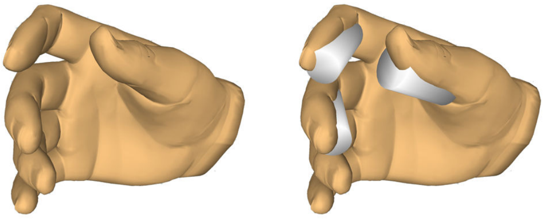

Figure 8 – Virtual hand with invisible cylinders

When intersection occurs between the index cylinder and one of the objects in the VE (the ones defined as movable), the technique calculates the volume of the object's bounding box so as to get a rough estimation of its size. A value defined by the user is used as the threshold between small and bigger objects. If the object is defined as a small one (volume under threshold value) the 3DIT will require one more intersection to take place from the thumb cylinder in order for the selection to be activated (see Figure 9) and if it is defined as a bigger object, the technique will require intersection from both the thumb and the middle finger cylinder (Figure 10). Once the collision requirements have been met, the object is being attached to the virtual palm and starts following the user's hand. If one or more of the intersection tests gives negative output (thumb cylinder and/or middle finger cylinder) then the object will stop following the user's hand.

The external cylinders are very useful for the picking up of smaller objects since any contact between them and the objects of the virtual environment happens more easily than when the virtual hand's geometry is being used.

Figure 9 – AFG for small objects

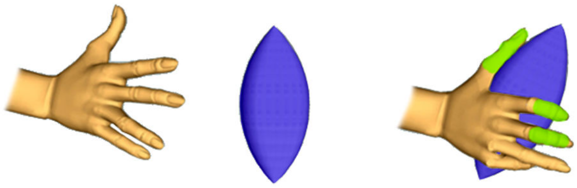

Figure 10 – AFG for medium sized objects

2.5. POOL TO HAND INSTANTIATION METAPHOR - PHI

2.5.1. Task decomposition

The PHI metaphor is designed for use in cases that the immersed user needs to select and manipulate small objects in relation to the size of the virtual hand. In addition, this problem becomes more complex when the virtual objects beside their small size are also great in population and in a condensed space. In such cases, the intersection mechanism usually used for the manipulation of virtual objects does not work properly. For example, in a case that an assembly operator wants to pick rivets from virtual bags containing such objects, it is difficult to execute a realistic manipulation mechanism because of the great number of intersection tests that will take place when the virtual hand will collide with the volumes of the objects. The Pool To Hand Instantiation metaphor (PHI) concerns the picking of a virtual object from a geometry that exists as a pool of such objects. To pick an object from the pool the user simply puts two fingers into the virtual bag (so as to cause an intersection) and then pulls them out. When the fingers and the bag stop intersecting (as the user removes his fingers from the bag), the object is created on the virtual hand (see Figure 11 and Figure 12).

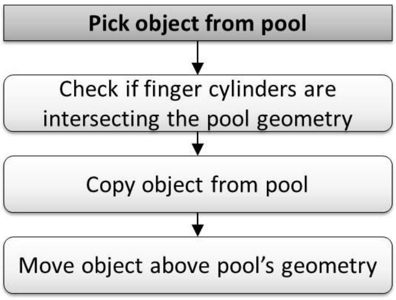

Figure 11 – Pool to Hand instantiation metaphor decomposition

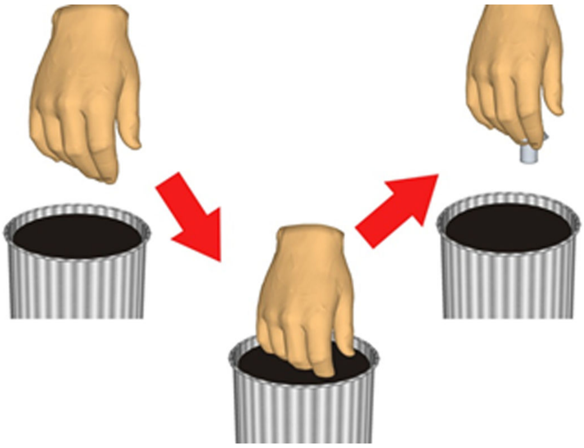

Figure 12 – Pool to Hand Instantiation Metaphor

2.5.2. Implementation

The Pool To Hand Instantiation metaphor (PHI) runs an intersection test between the geometry representing a pool (e.g. bag) and the index finger of the virtual hand. When the output of test is positive (as the user puts his hand in the virtual bag a file from a resource folder is copied to the VE, which is the geometry of a small object such as a rivet. In order for the metaphor to finalize the procedure, the user needs to pull his virtual hand out, thus providing to the intersection test a negative output.

2.6. 3D ANNOTATIONS

2.6.1. Task decomposition

The 3D Annotations metaphor (see Figure 2) serves the user by providing information about various parameters of the scene, or the actions of the user, in the VE. The annotations are pop-up screens that follow the user's movements and are stable when the user is performing an operation. For example in a drilling process, the 3D Annotations metaphor is used to providing the user with information, regarding the process parameters (e.g. depth of the hole, velocity of the drilling or the spindle speed). The decomposition of 3D annotations is shown in Figure 13.

2.6.2. Implementation

The information is shown on small white screens as shown in Figure 14. Those screens are three-dimensional and serve as tablets providing titles, values and if necessary, units (e.g. mm/sec). The 3d object that is used for the screen follows the user's movement and is always perpendicular to the user's viewing plane. The 3D Annotations are more useful than normal data communication techniques are, when it comes to executing operations immersed into a VE, because in contrast to most of the techniques, the screen isn't always in the user's point of view, unless the user chooses to and it is not stationary but moves as the user does so.

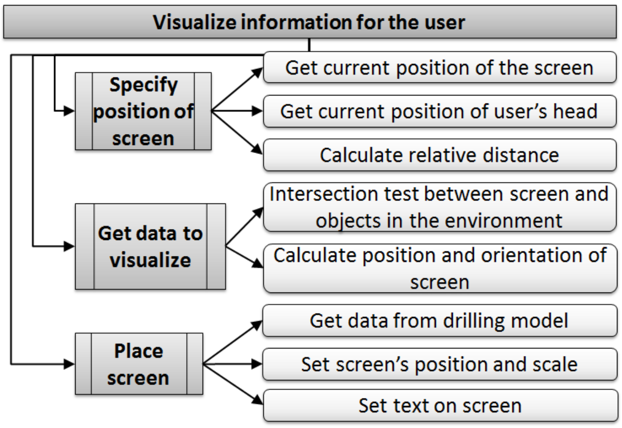

Figure 13 – 3D Annotations task decomposition

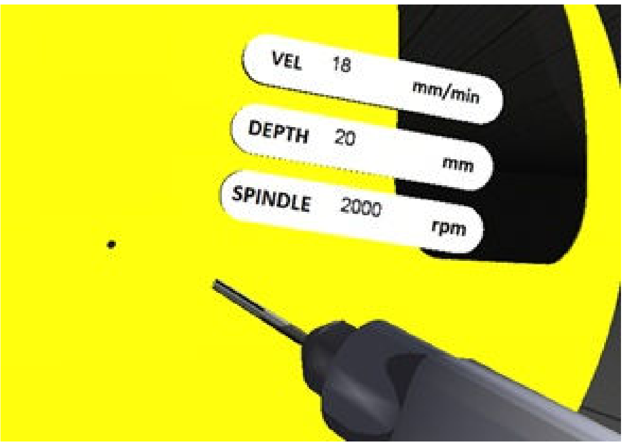

Figure 14 – 3D Annotations during a drilling process

3. AIRCRAFT ASSEMBLY TEST CASE SIMULATION

The test case scenarios, used for the validation of the metaphors developed, were provided by the aerospace industry. The use-cases involved two very common assembly operations in the everyday practice of human-based aircraft assembly manufacturing. These operations are the hole-drilling and riveting tasks. Both of these assembly tasks are performed in the junction areas of the fuselage components of the aircraft. In the drilling use case the operator needs to drill holes in the fuselage. It takes about 30 seconds to drill one single hole and the operator has to respect an established drilling sequence. Therefore, the virtual simulation model should provide a suitable environment for testing both the operation of the drilling task and the sequence through which it is executed. In the riveting task, there are two operators cooperating for the execution of this assembly process. The point of this task is that rivets be used for the mechanical fastening of the fuselage components. In this task, outside the fuselage, there is an operator, who is responsible for putting the rivet (lock-bolt) in to the hole. The second operator is located inside the fuselage and is responsible for putting a ring in the rivet-gun for swaging the rivet after the latter has been inserted into the hole by the first operator. In the use case, there has to be a cooperation between the two operators in order for them to finalize the riveting process in the holes previously created by the hole-drilling process. In this use-case, therefore, it is important that a simulation environment be created so as for t the trainees to be able to exercise their cooperation abilities while a process engineer will be able to validate the sequencing and ergonomics characteristics of the process.

3.1. HOLE-DRILLING USE-CASE

For the hole-drilling operation simulation, two interaction techniques were utilized; the Magnet and the DP interaction metaphors. In the sequence described, these interaction techniques allowed the user to drill holes in the fuselage and by controlling the drilling process parameters the user had a direct influence on the time that the process required. The workflow of the operation along with the utilized techniques can be seen in Figure 17.

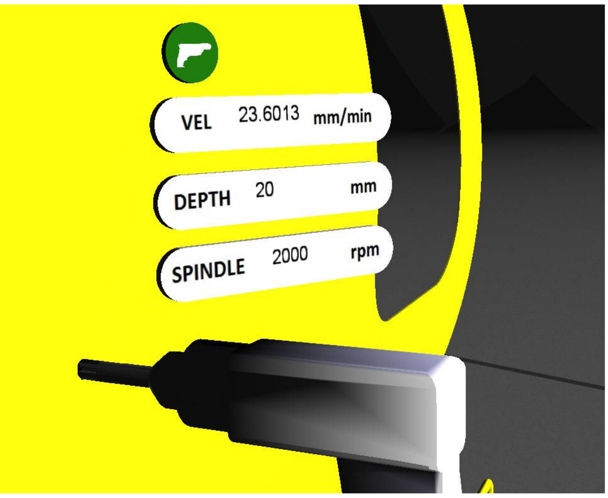

Figure 15 – Drilling test-case, executed on a virtual aircraft fuselage.

The user places the tool on to the drilling spot and performs the operation. Then he/she is able to move to the next drilling spot or define a new one, upon completing the previous hole-drilling.

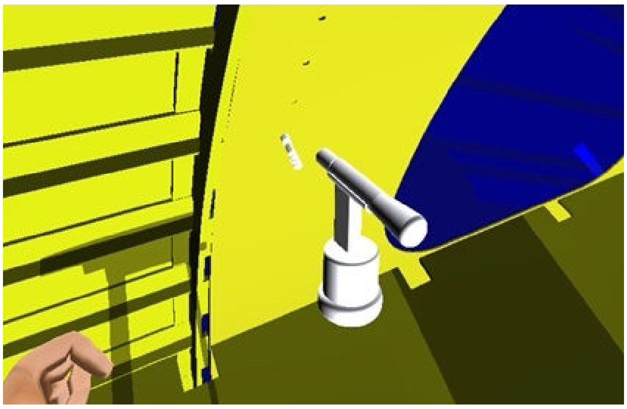

Figure 16 – Riveting test-case on the junction section of the fuselage.

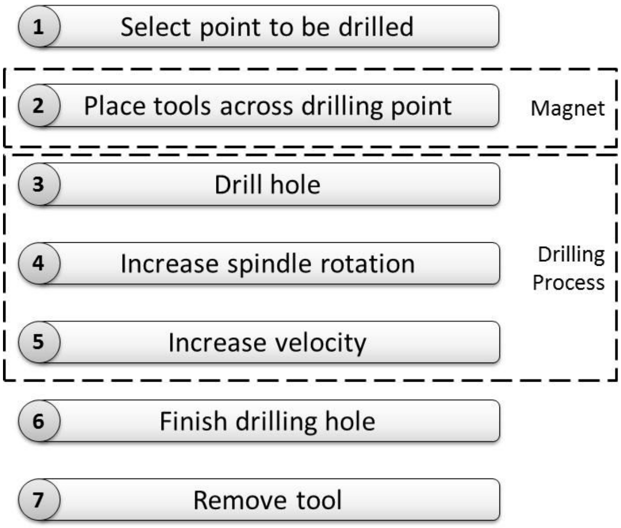

Figure 17 – Workflow diagram for the hole-drilling process task, along with the corresponding IMs.

3.2. RIVETING USE-CASE

During the riveting task, the operators work in pairs: one operator is located inside the aircraft while the other one is outside. In the riveting operation the outside operator uses the PHI, AFG and Magnet interaction metaphors to perform the rivet installation and the inside operator uses the PHI, AFG and Magnet interaction metaphors to finally swag the rivet. The swaging of the rivet and the collection of the queue is performed automatically by pressing a button. When the button is pressed the rivet's geometry is modified accordingly. In order for that to be done,, the user should first bring the tool to the right position for which he receives visual feedback from the Magnet metaphor as to whether the pose of the rivet gun is proper for the operation to be carried out. The workflow of the assembly operation can be seen in Figure 18.

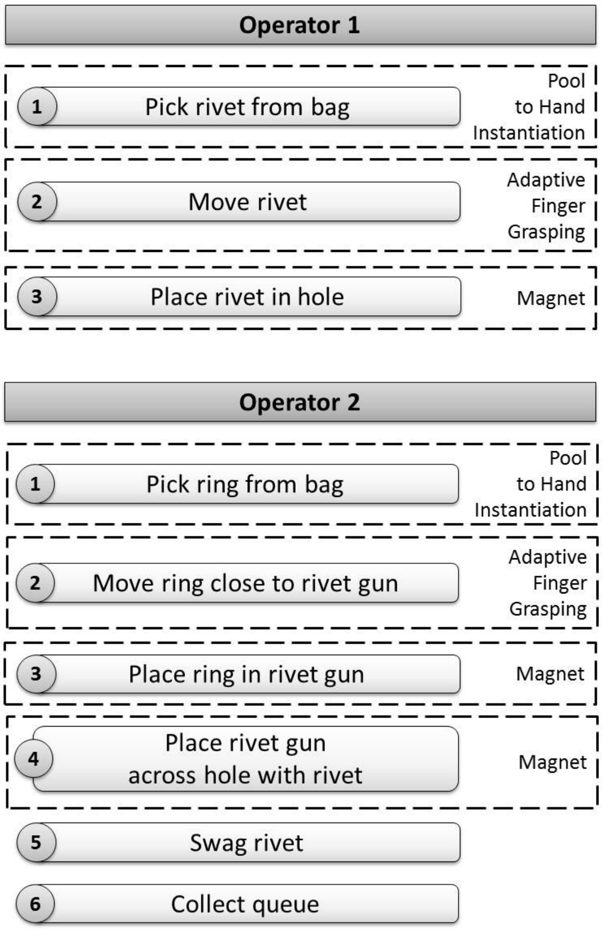

Figure 18 – Workflow diagram for the riveting process task, along with the corresponding IMs for both operators.

3.3. EVALUATION AGAINST INDUSTRIAL REQUIREMENTS

The evaluation, based on the requirements having been set by the aerospace industry, is adapted to the specific applications of the IMs developed and are applied to the certain scenarios. Since the techniques are developed for carrying out certain tasks in virtual environments, the results are qualitative because the tasks are predefined and have only one outcome. There is a list following with the industrial requirements and the evaluation of the respective interaction metaphors, used in the use-case scenarios:

Table 1 – Industrial requirements and evaluation of interactions used in the test case simulation

Place object in proper position/orientation	The Magnet metaphor successfully helps the user place an object in a predefined position/ orientation.
Grasping object	The requirement of grasping a virtual object is satisfied through the AFG technique by adapting the selection conditions of the technique's algorithm so that the user can grasp and manipulate objects of different sizes.
Direct manipulation, natural interaction with objects	The PHI simulates with success the process of picking a small object from a bag/box with many similar objects and the AFG is also used for grabbing and moving bigger objects in the environment.
Intuitive transformation of objects	The drilling metaphor successfully helps the user modify geometry by drilling a hole.
Integration of human body for interaction visualization	All the tasks that are carried out through the use of the techniques require the use of the user's hands. The user either controls the virtual hand with a data-glove or a tool through a tracked input device (e.g. wand). Both ways require the integration of the human body since the tracking data come from the movement of the user's body.
Interaction metaphors must work for head mounted displays (HMD) and projection walls	All the techniques can be utilized with the use of HMD or projection wall displays since none of them depends on the devices used for visualization purposes.
One hand manipulation	The AFG technique provides one hand manipulation of objects through selection and movement.
Intelligent interactions with objects	AFG can be characterized as intelligent technique since it uses algorithms that recognize object size so as to adapt the interaction behavior.
Facilitate the execution of complex interactions	The Drilling metaphor helps VR users perform an immersive simulation of the drilling processes which requires complex interaction mechanisms.

4. CONCLUSIONS

The interaction metaphors developed in this study, were successfully implemented into use-case scenarios, having derived from the everyday practice of the aerospace manufacturing operation whilst certain assembly processes were simulated for validation purposes. The techniques were similar or identical to those for the real-world interactions in the form of natural behaviour of the interaction and the duration of operations.

The techniques were designed and developed based on the aerospace industry's requirements and under a formal framework allowing for future use in different industrial applications. Their design concept was not task-based but based on modelling and interpreting the subtasks of each process. For example, the Adaptive Finger Grasping metaphor is a technique that can be used in many industrial applications where the user has to grab and move objects of varying sizes with one hand.

The main goal of the design and development of the techniques was to provide realistic interactions with a VR system in the form of simulating real world interactions. That goal was accomplished through following two basic guidelines. The first one was that the techniques were conceptually designed by having decomposed each task into sub-tasks and the second that the techniques were developed so as to provide realism, in the form of time and naturalness in interacting with the environment. Instead of creating techniques for the major tasks, natural techniques were implemented that could be used as building blocks for satisfying the requirements of bigger tasks when combined.

Although the techniques presented in this study, aimed at a realistic representation and simulation of human-based assembly processes, there is still a lot of work that has to be done in order for an exact representation of the real processes to be accomplished. Future research should be distributed to the fields of advanced visualization, interaction techniques and in the development of new VR peripheral devices that provide realistic feedback without limiting the user's movement. Haptic feedback is the most realistic but it still has many drawbacks such as the weight of the devices and their being stationary. Research carried out in the field of interaction, should focus on developing isomorphic techniques, since they are more suitable for the simulation of real interactions.

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REFERENCES

Bi Z.M., "Computer integrated reconfigurable experimental platform for ergonomic study of vehicle body design", Int J Computer Integrated Manufacturing, 23/11, 2010, pp. 968-978

Bowman D.A., Hodges L.F., "Formalizing the Design, Evaluation, and application of Interaction Techniques for immersive Virtual Environments", J. of Vis. Lang. & Comp., 10, 1999, pp. 37-53

Bowman D.A., Kruijff E., LaViola Jr. J.J., Poupyrev I., "3D User Interfaces: Theory and Practice", first ed., Addison Wesley Longman Publishing Co., Redwood City, 2004

Chryssolouris G., "Manufacturing Systems: Theory and Practice", 2nd ed., Springer-Verlag, New York, 2006

Chryssolouris G., Mavrikios D., Fragos D., Karabatsou V., Pistiolis K., "A novel virtual experimentation approach to planning and training for manufacturing processes-the virtual machine shop", Int. J. of Comp. Integr. Manuf., 15, 2002, pp. 214 - 221

Connacher H., Jayaram S., "Virtual Assembly Using Virtual Reality Techniques", Comp.- Aided Des., 29, 1997, pp. 575-584

Flasar J., "3D Interaction in Virtual Environment", Proc. of the 4th Cent. European Semin. on Comp. Graph., 2000, pp. 21-31

Holz D., Ulrich S., Wolter M., Kuhlen T., "Multi-contact grasp interaction for virtual environments", Journal of Virtual Reality and Broadcasting, 5/7, 2008

Jones L., "Dextrous hands:Human, prosthetic, and robotic", Dep. of Mech. Eng., Massachusetts Inst. of Tech., 1997.

Lin E., Minis I., Nau D.S., Regli W.C., "Contribution to Virtual Manufacturing Background Research", Inst. for Syst. Res., Univ. of Maryland, 1995

Mavrikios D., Karabatsou V., Fragos D., Chryssolouris G., "A prototype virtual reality-based demonstrator for immersive and interactive simulation of welding processes", Int. J. of Comp. Integr. Manuf., 19, 2006, pp. 294 - 300

Mujber T.S., Szecsi T., Hashmi M.S.J., "Virtual reality applications in manufacturing process simulation", 2004, J. of Mat. Process. Technol. 155-156 (2004) 1834-1838.

Ottosson S., "Virtual Reality in the product development process", J. of Eng. Des., 13, 2002, pp. 159 -172

Pappas M., Fragos D., Alexopoulos K., Karabatsou V., "Development of a three-finger technique on a VR Glove", Proc. of the 2nd Virtual Conc. Conf., 2003, pp. 279-283

Pitarch E.P., "Virtual Human Hand: Autonomous grasping strategy", Uviversitat Politecnica de Catalynia, 2010

Rubio E.M., Sanz A., Sebastian M.A., "Virtual reality applications for the next-generation manufacturing", Int J Computer Integrated Manufacturing, 18/7, 2005, pp. 601-609

Wan H., Luo Y., Gao S., Peng Q., "Realistic Virtual Hand Modeling with Applications for Virtual Grasping", Proc. of the 2004 ACM SIGGRAPH int. conf. on Virtual Reality contin. and its appl. in ind., 2004, pp. 81-87

Wan H., Peng Q., Dai G., Gao S., Zhang F., "MIVAS: A MULTI-MODAL IMMERSIVE VIRTUAL ASSEMBLY SYSTEM", ASME 2004 Des. Eng. Tech. Conf. and Comp. and Inf. in Eng. Conf., 4 (2004) 113-122.

Weber M., Heumer G., Amor H.B., Jung B., "An Animation System for Imitation of Object Grasping in Virtual Reality", Advances in Artificial Reality and Tele-Existence, 16th International Conference on Artificial Reality and Telexistence, ICAT, 2006, pp. 65-76

Zachmann G., Rettig A., "Natural and Robust Interaction in Virtual Assembly Simulation", 8th ISPE Int. Conf. on Concur. Eng.: Res. and Appl., 2001

Zhao W., Madhavan V., "Virtual Assembly Operations with Grasp and Verbal Interaction", Proc. of the 2006 ACM int. conf. on Virtual reality appl., 2006, pp. 245 – 254