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SERVICEABILITY ANALYSES IN VIRTUAL ENVIRONMENT FOR THE AUTOMOTIVE INDUSTRY

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1. Introduction

Virtual Reality (VR) is commonly used throughout the design phase in automotive industry, starting from the styling review in the conceptual design phase to the Digital Mock-up (DMU) validation in the advanced stages of the design process. In fact, many design tasks take advantage of the full-scale stereoscopic visualization typical of the Virtual Environments employed in the automotive industry.
Since 1996, Fiat and Elasis adopted the Digital Mock-Up (DMU) approach for the development of future car models. The goal of this methodology was to reduce the number of PMUs (Physical Mock-Up) used to validate the design of a new car. The most important consequence of the application of this methodology is time and cost reduction. In 1999 Elasis researchers began to introduce VR technologies in car development processes, using their capacity to visualise large data sets that represent the outputs of digital simulations [Monacelli 2001], [Monacelli 2003]. Currently many design tasks such as crash test simulation, study of complex assemblies by means of clearance analysis, visualisation of inner sections and ergonomic analysis are conducted making use of the instruments and typical methodologies of Virtual Reality (VR).
This paper describes an industrial application of VR techniques in the field of DMU analyses, reporting the results obtained with the development of a software application that allows Elasis engineers to evaluate important design parameters in the serviceability studies. These analyses can be conducted during the early stages of the design process using DMUs and finding the difficulties related to the serviceability tasks. Using VR techniques it is possible to simulate the entire operative context in which the human operator works during the assembly/disassembly task. In this way a designer can directly verify some potential difficulties in component reachability, in posture and visibility [Bruno 2003], [Bruno 2005].

2. Previous work

Gomes de Sa and Zachmann [Gomes de Sa 1999] have investigated the steps needed to apply VR for virtual prototyping (VP) to verify assembly and maintenance processes. They present some interaction paradigms and functionality that a VR system must implement in order to be suitable for Virtual Assembly. They also report a user survey that has been performed at BMW with a representative group of key users. The result of their survey indicates that the use of VR for VP will play an important role in the near future in the automotive (and probably other) industries. In particular, the response of the user survey has been very encouraging and optimistic. It seems that VR/VP does have the potential to reduce the number of Physical Mock-Ups and improve overall product quality, especially in those part of the business process chain where humans play an important role. The survey was made using a HMD, a electromagnetic tracking system and a CyberTouch data glove with tactile feed-back.

Jayaram et al. [Jayaram 1997] present a feasibility study for using VR in design for assembly, the design of a Virtual Assembly environment and preliminary results from the use of this environment. Their system uses a HMD, an electromagnetic tracking system, the Cyberglove and the Tactools feedback system that provide a sensation of touching at the fingertips. During the assembly process the user can store the path that was created or reject it and reassemble the part. Collision detection methods warn the user of interference and tolerance problems.

Bao et al. [Bao 2002] present a framework and prototype system of an immersive virtual product design (IVPD) which enables users to navigate and interact with the display system by using 3D peripherals. Participants may passively view the virtual world revolving around them while others control navigation and simulations, and may interact with other members. A virtual assembly application of this framework is also presented, it allows the users to identify interferences and design conflicts, check the movement of parts, verify the fitness of interrelated parts and almost eliminate physical prototypes. It is also possible to visualize and interact with every part of a complex design, grasp, move, and rearrange virtual objects.

Jayaram et al. [Jayaram 2004] present a method that improves the ability to use the virtual assembly environment to simulate real world assembly sequences in complex models where there are significant differences between the subassembly and hierarchy representations in the design CAD model and the component assembly sequence in the factory floor.

Ye et al. [Ye 1999] compare non-immersive and immersive environments for assembly planning. They present the benefits of virtual reality environments in supporting assembly planning. Sun et al. [Sun 2002] present real-time planning in virtual environment using two-handed interactions.

3. The serviceability analyses in the automotive industry

Success of new car models generally comes from customers judgement. Products must have satisfying performances and reliability and must need very short maintenance time, in order to make the operational costs competitive. In order to reach this target it is necessary that, starting from the first phases of a car design, engineers must respect some requirements known as “serviceability criteria”. These recommendations, coming from operating experience, emphasize to the designer the vehicle parts that require particular attention in order to guarantee the pervious characteristics.

Starting from this considerations, the authors developed a virtual maintenance application employing VR techniques and technologies. Virtual Maintenance simulations are becoming a very important step during a new vehicle project development. Car manufacturers have, in fact, recognized the importance to study the feasibility of these operations during the early stages of the project in order to avoid that their analysis in the subsequent phases of the project could bring to heavy modifications that could also affect the car performances (for example during crash test).

Usually, virtual maintenance simulations are performed by means of Digital MockUp software. Engineers verify that the car project satisfies the “Maintenance Criteria” that are a set of rules which allow a correct maintenance operation. Such very general criteria are based on procedural (disassembly operation sequences) and geometrical (minimal distances, available volumes, etc.) tests and are easily possible with Digital MockUp software. Elasis experience has shown that this solution isn’t complete because, even if a project satisfies the “Maintenance Criteria”, the operation could not be successfully completed. It could happen, for example, that the worker cannot reach (with his hand or with support hardware) the component to change. In the same way, the components lay-out could not allow simple movements to do the operation. For example, two different project solutions could both satisfy the “Maintenance Criteria” but the first one could be better than the second because the interested parts are more easily visible.

Generally speaking, the main problem of a Digital MockUp exclusive approach is that “Human Factors” cannot be analyzed although, as previously said, they effect the feasibility, the time of the operation and the costs too (that for in warranty cars is in charge of the car manufacturer).

Elasis approach to Virtual Maintenance simulations is based on Digital MockUp software for geometrical test and on Digital Human Models (Virtual Manikins) for Human Factors. Thanks to virtual manikins, the project team can check human factors too, so the maintenance operation can be verified not only by the normative point of view but also by the workers point of view.

According to Elasis procedural flow, the first step for the project team to simulate a virtual maintenance operation is to prepare, a virtual environment with all the simplified CAD models of the car components potentially interested by the operation. Then it is necessary to place the manikin in a posture very closed to the worker's posture during the real operation. Furthermore it is possible to simulate the maintenance operation moving the manikin in the most realistic way. For some kind of operations, it could be also necessary to place, in the virtual scene, a set of tools with realistic dimensions to be used during the simulation.
Virtual manikins allow, as previously said, to do reach-ability analysis, checking also if near the interested components there is enough free space to perform the operation. Besides, using the possibility to look the scene by the manikin point of view, it is possible to check if the worker has a full visibility of the components to move.
Following the research line based on the "Human Centred Design", Elasis is now developing an immersive environment for Virtual Maintenance Simulations. Elasis designers have checked the benefits coming from this technology that allow the user to be fully immersed in the virtual work place. By this way, simulations become more and more realistic and interactive. The Virtual Environment is used to improve virtual manikins simulations when designers need to do quick and easy feasibility analysis of the maintenance simulation. It can be also used in the final phase of the project when it is necessary to check the final lay-out with maintenance experts. Usually, these people are not familiar with simulation software but their feedback is very important in order to understand the real effort of each operation. The Virtual Maintenance Environment allows to easily involve these people thanks to its natural and interactive nature.

4. Virtual environments for serviceability analyses

The virtual maintenance application described in the following sections has been implemented so that it can be easily ported on several hardware configurations. In fact, the application is used both in a immersive environment, made by an HMD and two datagloves, and in various semi-immersive environment based on retro-projected screens. The immersive environment employs an HMD with adequate field of view and graphical resolution that provides the user a realistic three-dimensional scene of the car model. The tracking system is the IS-900, a hybrid (acoustic-inertial) 6 DOF position and orientation tracking system with 3 sensors. The first sensor is connected to the HMD to show exactly what the user should see if he/she were in the real working environment, so the real visual of the operator while he is performing the maintenance task can be simulated. Other two sensors are connected to a pair of Cybergloves that allow the user to directly control the virtual hands that grab and move the components of the assembly. The immersive environment offers the possibility to simulate the working conditions, the visibility and the reach-ability of the components but it is less ergonomic than the semi-immersive one because of weight of the HMD and the complete immersion of the user in the virtual environment. The semi-immersive environments allow users to perform long working sessions without particular strain. These are also more appropriate for collaborative working and DMU analyses because allows several users to stay in front of the screen seeing a wide image at a very high resolution. Two different semi-immersive environments are installed in Elasis and are used for DMU analyses and maintenance simulations. The first system is based on a Tanorama™ Powerwall which is a large multi channel rear projection screen up to 6.9 m wide and 2.2 m high where users can visualize a complete car in a 1:1 scale. An Ascension Flock of Bird tracking system is employed to track the user head position, so the system can update the virtual scene accordingly with the user head movements. Other sensors track the position and the orientation of two input devices: the Neowand or the Sticky Mouse. Both the devices are supplied with buttons that have been customized to perform various tasks such as navigation, picking and sectioning.
The second semi-immersive environment is based on a single retro-projected screen and it is completely dedicated to the virtual maintenance. In this configuration the user wears only one glove on the right hand, and holds the 3D mouse with the left one. The absence of the second glove prohibits to have an articulated model for the left hand, but the presence of the buttons on the 3D mouse is very useful for the user to quickly activate some functions and to easily control the navigation in the scene.

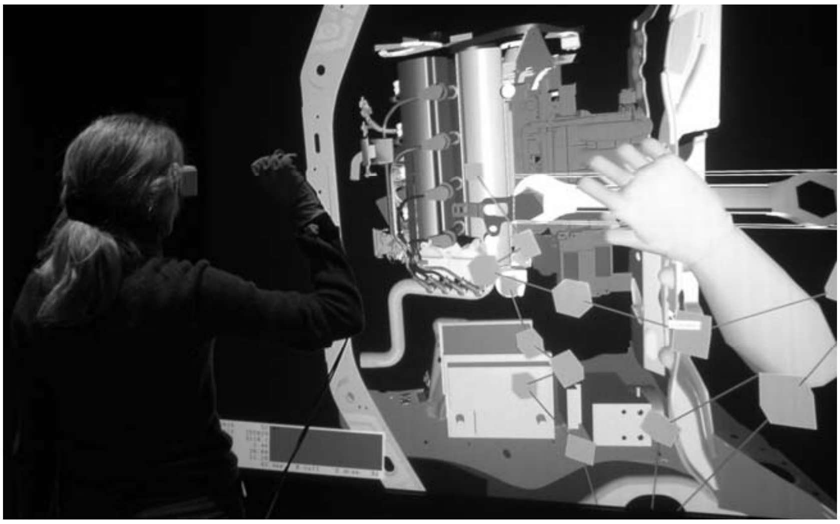

Figure 1. A simulation in the virtual environment

The need to develop a platform independent application, able to run on different operating systems, with various visualization systems and with several input devices has been one of the crucial aspects in the choice of the SDK used to implement the application. In fact, dv/Mockup, through the dv/Toolkit, allows the developers to implement new input device drivers and to properly configure the visualization parameters to adapt the application to every possible display like HMD or retro-projected screen. The implementation of new device drivers has been conducted employing the Virtual Reality Peripheral Network (VRPN) library that provides a device-independent and network-transparent interface to virtual reality peripherals. VRPN is public domain, open-source software with a user community in academia, industry and the research labs. The set of supported devices is continuously updated and new drivers can be easily implemented. The implementation of a VRPN interface in dv/Mockup allows us to quickly change the hardware configuration and also to support input devices connected to other computers present on the network.

5. Interaction techniques for objects manipulation

Several interaction techniques have been investigated to determine how the user can optimally perform the serviceability analyses. The technique for picking the components depends on the hardware configuration adopted and it is different if the component has to be picked with one or two hands. During the picking process the user has a visual feedback of the contact between the various parts of the hand and the component.

The Ghost paradigm has been employed to avoid the penetration between the selected component and the other objects. The “Ghost” is a semi-transparent object with the same geometry as the picked one. When the user drags a component the application moves the ghost object first, checks the collisions, and, only in the case of absence of collisions, it moves the component. In this way, during a collision the user controls the ghost, while the component continues to stay in the last valid position. When the ghost occupies a non-colliding position, the component is moved toward that position and the ghost disappears. The ghost paradigm has been employed also for the movement of the hands.

The user can freely drag not all the components. Some of them, in fact, are subject to particular constraints defined during the preparation of the virtual environment. These constraints can simulate the function or the mechanical behaviour of some elements like doors, hinges, etc. or can help the user to assembly/disassembly particular components like bolts, screws, oil filter, etc.. Constraining the motion of virtual objects, which are interactively manipulated by the user, facilitates precise positioning in the virtual environment, which otherwise would almost be impossible. This is because the user’s real hand always moves in free space without any physical points of reference.

The presence of motion constraints becomes essential in some cases in which a component is precisely fitted into another, (eg.: a gearwheel on a shaft) or when two components are connected with a screw-thread like in the case of the oil filter.

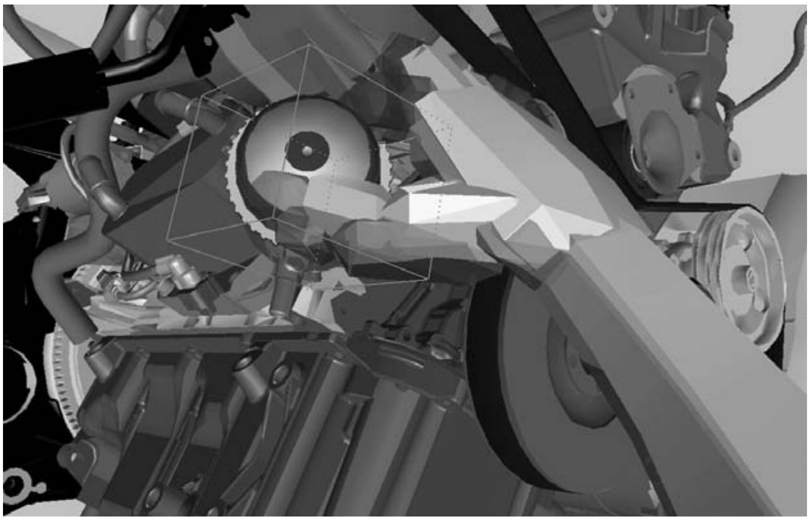

Figure 2. The user picks the oil filter with the virtual hand

The second case in which the user needs some aids to disassembly the components is related to the presence of screws, bolts and other components coupled with a screw-thread. Since it is very difficult to precisely unscrew a component, the disassembly becomes impossible because the object cannot be moved without going in collision. During the preparation of the virtual environment it is possible to define some disassembly rules that allow the user to overcome this problem. The components with the screw-thread can be preliminary identified so they can be easily disassembled moving them along the constraint axis without considering collisions.

Another important application of the motion constraints in maintenance simulation is to verify that there is enough space to perform a certain operation with a certain tool. Very often, this is some kind of screwing operation (with a screw driver or wrench, for instance). Two problems arise when investigating this in VR: it is difficult for the user to hit a screw exactly with the wrench, for instance, and it is almost impossible to maintain the correct contact during the screwing operation. A solution for both problems is to constrain the tool's motion keeping its axis aligned with the screw axis and keeping the tool tip coincident with the head of the screw. In our implementation, a tool does not immediately snap to a screw when it is moved close to it, but it only signals the presence of a compatible screw by changing its colour. If the user presses the trigger of the 3D mouse the constraints becomes active, the tool is aligned with the screw axis and the screw can be unscrewed moving it out of the hole.

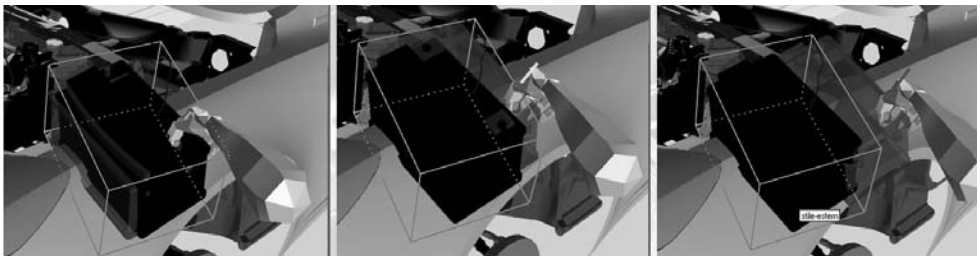

Figure 3. A coloured bar over the virtual hand signals the level of interference during a collision

When a component is moved, it traces a line that defines its assembly/disassembly path. The user can hide or show all the paths or only the path of a selected component and he/she can modify the paths enabling the visualization of the nodes, represented with little green cubes that can be dragged to modify the path. When a path is modified it is necessary to check that the component, moving along the new path, does not collide with some other components.
The "replay" functionalities are also useful when the user wants to check if a previously saved sequence is still valid after a modification of the DMU, or if he/she wants to visualize in virtual reality the sequence made on a desktop software application for DMU analysis. In fact, one of the results of the analyses is the set of paths that constitutes the sequence of operations needed to perform the maintenance task analysed. These sequences can be stored in the PDM and can be retrieved in any moment. If, for any reason, the DMU is changed, it is necessary to repeat some serviceability tests in order to verify if the change has invalidated the previous tests. In these cases the sequences, previously stored in the PDM can be retrieved and, with the "replay" functionalities these can be repeated to check if the tests are still valid.

5.1 Reach-ability and accessibility analyses

The verification of the reach-ability of the components involved in the serviceability test is a crucial aspect for designers, especially when the analyses regards the most common task in the engine bay like the substitution of a lamp or the oil filter. These kinds of analyses are efficiently performed in the virtual environment because the use of the data glove makes easier and quicker the manipulation of the virtual hand, compared to the software based on virtual manikins. Besides, the possibility to employ the ghost technique, allows the user to interactively search a correct and collision-free position for the virtual hand. The need to check if there is enough space to perform the maintenance task and if the various locations are easily accessible requires that the size of the virtual hand has to be standardized using appropriate percentiles. The user can easily change the size of the hand to perform the same analysis with several models of the hand, representative of a precise percentage of the human population, obtaining more general and objective results.

6. Support tools

In order to make the correct decisions, it is important that the user can get information about the parts involved in the virtual prototype currently being investigated. Different tools have been requested by designers to have the functionalities necessary to perform some of the most common analyses made on the DMU. One of these tool is the dynamic section plane that can help to inspect "problem areas" more closely. The second tool allows the user to quickly measure distances in the DMU. Four kinds of measurements are possible: minimal distance between two parts, distance between two points, distance between two vertices, position (expressed in the world coordinate system) of a point.
The last support tool allows the user to choose one of the standard views (left, right, front, rear, top, bottom) from the menu. This function, usually included in every CAD or DMU application, is useful in an immersive environment because it allows the user to set a precise alignment of the view, that is not easy to obtain by the 3D navigation, and to restore a proper view of the DMU when the user is disoriented.

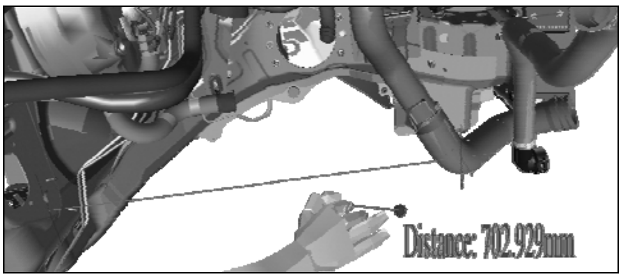

Figure 4. Application of the measurement tool

7. From CAD to Virtual Environment

The generation of virtual model dedicated to serviceability application and virtual prototyping deals with different kinds of problems related to data exchange and about the level of aggregation of the model to produce. The data exchange problems between CAD applications and VR environments, is extremely felt in the automotive world, because the vehicle time to market (TTM) trend is always shorter, and this happen because car companies wants to acquire competitive advantages to the comparisons of the contenders. Time employed for the generation of the virtual models become an extremely critical factor. In the Elasis experience, a typical example related to the mentioned problems regards the data exchange between Data Warehouse and dv/Mockup, the last one is an application dedicated to the visualization of Virtual Environments used in the virtual serviceability activities.
The components are organized in a typical trees structure that is really similar to organized structure of the vehicle. Inside this structure, components are collected in folders and subfolders that contain all the codified parts officially released. This structure remains optimized for the development of classic virtual verification like Packaging, CAE, Ergonomics, etc. and not optimized for verification through the use of Virtual Reality technologies, with particular attention to the data exchange. To such purpose the authors, on the base of the experiences carried out in Elasis, have developed some methods oriented to solve these problems, always keeping in mind the preparation time, and the data optimization, in order to produce models that supply interaction level compatibles with expectations of the customers employed in the serviceability area, in terms of high level of detail of the scene, chordal error, triangle welding, and of course the frame rate.
Another problem related to generation of interactive virtual environment, regards the managing of the aggregation of the components as in the case of info-telematics devices or meccatronic systems like column switch module, cruise lever, light lever. In this case the most important problems is that these components are considered by designers like single components and so released in the company's data warehouse. Interacting with these parts using devices like data glove and tracking systems became extremely difficult because the user cannot interact with joined assemblies. Also in this case the authors have developed specific methods that allow to generate model depending to the task specific needs. The models so developed can be characterized in order to allow a really dynamic interaction.
In order to completely exploit the advantages of the VE it is necessary to enrich the geometries of the model with some data that the system employs to perform some functionalities. For example data about constraints and joints can be associated to a component to make easier the disassembly phase or to simulate the behaviour of some objects like the engine cashing, doors, etc.. It is also possible to identify screws and bolts and to associate these to the proper tools, in order to allow the user to unscrew the component only with compatible tools.

8. Knowledge Base integration in the Virtual Environment

In the "Virtual Maintenance Environment" presented in this paper, a primary role has been assigned to "Knowledge". Usually, engineers involved in virtual simulations declare to take advantage in consulting, in real time, the "Company Knowledge" in order to check if project satisfies predetermined design and legislative rules. For the automotive industry, the problem is quite complex: each part of the car can be related (in direct or indirect way) to car performances and so it can be subject to specific rules. Besides, the "Knowledge Management Systems" of car manufacturers are very big, complex; usually, they have different architectures because each of them has been developed to manage a specific type of data.
One of the most important problem related to a Knowledge Management System, is the development of an easy and user-friendly graphical interface that allows information access also to not skilled people. The authors have found that Virtual Reality can be a very strong and quickly solution to this problem. In fact, thanks to three dimensional interaction devices (like CyberGloves, Neowand, etc.) and immersive visualization features, it is possible to hidden the operative core of the Knowledge Management System and to access directly to the desired information elements.

9. Conclusion

Since VR has been introduced in the product development process of the automotive industry it has represented an important tool in many decision making tasks, especially when the collaborative working plays an important role. Elasis has experimented different design activities in its VR laboratories, like CAE data exploration, ergonomics analyses for car interior, design review. The development of the Virtual Maintenance application opens new ways to approach the analyses performed on the DMU. In fact the application not only allows designers and technicians to simulate the maintenance task, but also offers a set of tools useful to analyze the DMU to discover possible modelling errors that can compromise the functionality of the product. All the analyses are supported by the on-line accessibility to the company knowledge-base and by a user transparent integration with the Knowledge Management System that make easier the access to the information, the interaction with the system and the analyses in general.

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