ASSEMBLY SIMULATION THROUGH A DIGITAL MOCK-UP APPLICATION

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Abstract: "Design for X" includes a set of techniques to realize the best product yet during the design avoiding re-works and loose of time and money. Among these, the design for assembly covers an important role and aims to design a product "thinking" to the physical assembling moment. Digital Mock-Up (DMU) is a process to enhance assembly feasibility and efficiency through specific design analysis and allow re-producing a product virtual assembling. Based on an action research based on a collaboration among company and university researchers, the paper aims to describe the development of a DMU application in a naval Italian aerospace company to improve a ship fuel system assembling. Technical features of the application are described.

1 INTRODUCTION

Different authors face the topics of the new product development phases (Clark, Wheelright, 1995; Crawford, Di Benedetto, 2003; Ulrich, Eppinger, 2007; Ribbens, 2000; Rosenau et al., 1996), everyone specify such phase that goes from the conceptualization until the production trough the engineering. Ulrich and Eppinger (2007) suggest five phases: 0. Planning, 1. Concept Development, 2. System Level Design, 3. Detail Design, 4. Test, 5. Production. Specially, the Design Phase defines the new product and prepares the work on which the manufacturing units will impact (Ulrich and Eppinger, 2007). The main objective in the product design is to create a product architecture directly linked with his functionalities. The creativity in the first phase of conceptualization has to be translated in a set of wished functions and blended in the product architecture through the design in order to facilitate and optimize the manufacturing and the following maintenance operations providing an optimized product. (Ribbens, 2000).

In the 'design for x' family, design for assembly (DFA) is a particularly relevant process/approach by which product assembly issues (mostly number of parts, their insertion and orientation) are addressed in the early design phase, with the goal to reduce overall assembly cost, time and complexity. Among company processes, the activities for assembling individual parts to obtain the final product are crucial as they use over 50% of total production time, with costs varying from 20% to 40% for a single unit. The use of DFA can improve significantly such performance and several methods have been developed at this purpose (Miyakawa and Ohashi, 1986; Boothroyd and Dewhurst, 1986; Holbrook and Sackett, 1988). The research on DFA is based on the premise that the lowest assembly cost can be achieved by designing a product in such a way that it can be economically assembled by the most appropriate assembly system. (Boothroyd and Dewhurst, 1986).

Digital Mock-up is used to support design for assembly providing assembly simulations that can be used to address changes in product design and support the physical assembly phase.

The naval industry is an interesting context of research. Particular dynamics and routine are peculiarities of this sector and cannot be found in other industry. The products are very complex and require high-technological knowledge and skills. Design for Assembly and Digital Mock-Up application can support the development of naval system improving the company performance.

Based on an action research carried by Università del Salento and Avio S.p.A., the commercial application Teamcenter Visualization Mock Up (VISMOCKUP) has been integrated in the

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company CAD system (NX). The paper aims to answer the question "How is characterized a Digital Mock-Up application in a naval company?". The paper shows criticalities and benefits from the integration of Digital Mock-Up and CAD environment in a unique Product Lifecycle Management System.

In the next section of the paper the Digital Mock-Up process is described, further insights from the research design are highlighted and the method used and application context are described. Another section is dedicated to the mock-up application description and finally, conclusions are provided underling the technological limits of the developed solution.

2 DIGITAL MOCK-UP

In the last years, there has been a great development of digital technologies to verify product lifecycle processes and reduce the need (and thus the costs) for physical prototypes. Information technologies can contribute not only to efficiency improvements but also to improved hypothesis creation capabilities in engineers and organizations through technical features such as full visualization, digital pre-assembly and simulation (Baba and Nobeoka, 1998).

In particular, digital mock-up (DMU) allows designers to investigate the assembly feasibility of a product and the constraints imposed by manufacturing processes. DMU allows the user to represent the structure of a product and the accurate position of its geometry, and enables a multidisciplinary presentation of assembly processes and analysis (design 'in context') such as insertion, view and collision.

Through DMU, it is possible to obtain a virtual representation of a product and simulate the shape and spatial positioning of its components or subsystems, as well as of the necessary production tools. By providing the basic representation of a product, DMU permits to share the core product data that the different company areas and disciplines use to collaborate.

DMU has been extensively applied in different industries such as automotive (Rooks, 1998) and aerospace. Ford Motor Company is today strongly involved in the adoption of virtual manufacturing tools and processes designed to catch possible manufacture concerns by simulating automotive performance. An optimized product development process based on the use of DMU and rapid prototyping has been defined in the automotive with the aim to fulfil goals of time and cost reduction, and quality improvement (Döllner, Kellner and Tegel, 2000).

Shipbuilding is another interesting field for applying virtual assembly features as it requires a sophisticated product information model to achieve the seamless flow of product information. A DMU system that builds a prototype in a computer has been proposed for consistent quality control. The system can simulate models and assemblies on-the-fly as well as project real-world manufacturability without the expense and time required to make a physical mock-up (Won Don, Jong-Ho and Ju Yong, 2007).

3 RESEARCH DESIGN

3.1 Research Method

The study is carried out through an action research based on an inductive approach in which problems and solutions have been deducted from observation of the organizational practices (Bryman, Bell, 2007; Thomas, 2006; O'Brien, 2001) and working together to develop the final application. Working with Avio in several research projects, the researchers of Università del Salento are very confident with the company problems and ICT used. The DMU project has been launched from Avio to improve its products design through the integration of VISMOCKUP and the NX CAD system in a way to work in the direction of a product lifecycle management system for the company. To develop the DMU system, three phases have been accomplished. In the first phase, an analysis has been done to evaluate how realizes the integration and its potentialities. A second phase has been of development and the two software tools have been integrated in order to guarantee the best performance for the company. In a last phase, the DMU/CAD integration has been tested. This phase has been concluded with a positive results and the application is widely used inside the company. This action research is carried out by a team of engineers of Avio S.p.A and researchers of University of Salento and the results are presented in the paper in the form of case study (Yin, 1994) to address the research question: "How is characterized a Digital Mock-Up application in a naval company?". It is a single case study that wants to express the experiences matured from the collaboration beetwenn Avio and Università del Salento in the context of DMU highlighting the importance and high relevance of this kind of system for the naval company. To answer to the research question has been developed a software solution and the related findings have described highlighting technological aspects and managerial implications.

3.2 Company Context

AVIO is a world leader in the design, production and maintenance of aerospace propulsion subsystems and components. A smaller part of the company business is also dedicated to the naval sector for which produces turbine modules and automation systems to support the integrated control of the platform. A central activity is related to FREMM (Fregata Europea Multi-Missione), a military ship designed by Fincantieri and DCN to operate in anti-submarine, anti-air, and anti-ship settings. In such activity, the company looks for improving assembly feasibility and optimization of the (transducer plate of the) fuel system, with the aim to minimize overall assembly time and costs while enhancing compliance and operators' safety.

4 A DMU APPLICATION

Teamcenter Visualization Mockup (from now on VisMockUp) is a real-time digital prototyping solution that includes interactive 3D viewing and robust advanced analysis of large product assemblies.

Three-dimensional solid models of the components of the FREMM fuel system transducer plate were created in UGS NX 2.0. However, VisMockUp cannot access directly the solid model data saved in the NX file format. For this reason, the solid models were exported in JT file format using the translator provided by NX. We made modifications on the configuration of the NX translator (called PVTRANS) in order to increase reliability in assembly and clearance simulation. We have used a PER_PART structure option to obtain a JT file for the assembly and a directory containing the JT parts.

JT file format is capable of storing an arbitrary number of faceted representations with varying levels of detail (LODs) We have defined two LODs and set the chordalOption to the ABSOLUTE value in order to obtain a constant chordal value in the two LODs defined. In this way, the maximum absolute distance that a line segment may deviate from the smooth curve is approximately constant for each part and independent from the part size. This distance is expressed in the same unit of measure as the part. For the two LOD defined we have set a chordal value of 0.2 and 0.5 millimetres. Furthermore the second LOD defined has forty percent less or fewer polygons respect the first (because its Simplify option has been set to 0.4). Finally we have used a lossless compression for the first LOD and a lossy compression in the second LOD.

VisMockUp alternate hierarchies are generally used to reorganize product assembly models according to the specific design needs. We used alternate hierarchies in order to represent the assembly steps. In particular, each component of this alternate hierarchy corresponds to an assembly step. An assembly step contains the component to be mounted at this step, the fasteners used and a reference to the previous assembly step. In Fig. 3, it is showed a representation of an assembly step in which the transducer is being installed upon the plate. The elements highlighted outside the plate are the transducer to be mounted and the fasteners used (four screws are visible). This approach was chosen to take into consideration both the current element to be mounted and the target assembly on which the element is mounted. Each step defined is re-mapped in the VisMockUp animation environment that is used to implement the path defined by the DFA procedure.

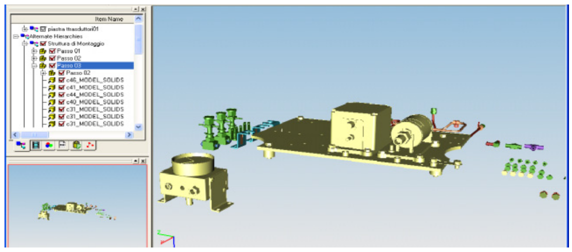

Figure 1: An assembly step.

The animation system within VisMockUp is organized by events which are generally organized in a sequence, unless there are changes in the interdependencies among the events. Each event contains a set of actions which are executed in a concurrent or sequential way according to what has been specified in the event timeline. In particular, VisMockUp supports different types of actions which can be visualized to make an animation. For instance, the *liner path action* is used to define a path that translates and/or rotates the selected parts along a path that is created in the 3D view. The *camera action* is used to rotate, pan, and zoom the view of the model whereas the *snapshot action* is used to rotate, pan, and zoom the view and also to set the visibility and transformation of parts. Finally, the *text action* is used to add text mark-up to the view, either anchored to a part or unanchored.

In our application, the assembly simulation at each event coincides with an assembly step as defined in the assembly hierarchy. Each event should thus contain at least linear path actions which implement a real assembly path and a snapshot action to establish the initial layout of the assembly step. In this way, it is possible to execute each assembly step separately from others. It is important to remark that the layout of a given step is obtained from the end of the execution of the previous step. As an option, an event can contain text and camera actions to ease up the understanding and visualization of the assembly simulation.

Another important action for motion simulation is the action addressed to execute VFM files. These are files containing a set of discrete positions of the part to be moved, without interpolation among the points representing the position of the part. There are several ways to obtain a VFM file, for instance by applying transformation on the part and capturing its position or by using an automated functionality provided by VisMockUp (called "path planning"). This functionality identifies extraction paths for parts or assemblies that need to be removed from models for maintenance reasons. In particular, this functionality generates a collision-free extraction path in the form of a VFM file by specifying the parts to be extracted and the parts to be avoided, and a set of "key positions" of extracted parts. The key positions must be at least two: a "start" position and an "end" position. Intermediate positions can also be defined to constrain the path direction. However, there are several limitations in the use of VFM files. In particular, they cannot be edited once defined and it's not possible to simplify them through interpolation. We have also used the "path planning" functionality to discover if a de-assembly path exists for a particular component and then to establish manually the related assembly path though the use of the linear path action.

Once the initial layout of an assembly step has been defined (snapshot action), it is possible to define the assembly paths through the use of a *linear path action*. A path consists of a series of control points (nodes) connected by segments. There are several ways to add a control point to a path: a) by picking points directly on the 3D model (a feature called *pick mode*); b) by using a dedicated node creation panel; or c) by selecting the component to be moved along the path and applying directly on transformations.

The control of one point's coordinates is obtained through the use of a manipulator or transformation window (figure 4) in which it is possible to precisely characterize the current manipulator's position and orientation. Since the manipulator and the part coincide, this also determines the part's position (x, y, z) and its spin angles (θ_x, θ_y, θ_z) which refer to a reference coordinates' system defined in the NX CAD environment. VisMockUp doesn't allow to estimate the path duration time, which has been therefore deducted based on the results of the DFA analysis.

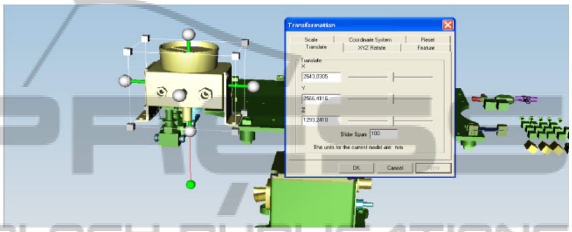

Figure 2: Manipulator and transformation window.

Once an assembly path for the components is established, they undergo a test for clearance analysis. Clearance analysis identifies points of contact and/or penetration among parts or groups of parts. We can define clearance as the distance between a pair of items in which there is no physical interference. VisMockUp allows to specify a clearance distance. All the items below this distance (including contacts and penetrating items) are identified and signalled to the user. VisMockUp allows both static and dynamic clearance detection. By setting the dynamic clearance analysis option, when components are selected and the path associated with them is executed, all the parts that are within a predefined range from active parts are analyzed. For the clearance analysis, we have imposed to the calculator to use NURBS for the calculation of the points of contact in order to obtain a better approximation respect to the JT tessellated data.

If a collision occurs, the colliding path has to be modified in order to make it collision-free. There are some collisions which are acceptable and that the engineers should be capable to identify (e.g. a screw that collides with its screwed hole).

To make the assembly simulation more reliable, we also developed the tools used in the assembly process. In particular, the tools have been modelled in NX CAD environment, according to the Italian UNI standard and using NX parts families. For each type of tool, a part family was developed to allow the user to obtain the necessary tool by varying some typical parameters. Naturally, parameters are selected by the user in a way to obtain tools available on the market. Figure 5 shows the sketch of part families realized in NX and which represents single open end wrench. The process of importing from NX to VisMockUp has been described in paragraph 3.1.

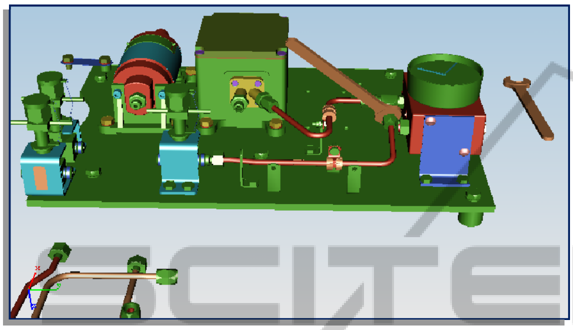

Figure 3: Single open end wrench used in assembly simulation.

Once an assembly step has been verified, it is possible to add the assembly instructions that the operator must follow in order to execute that step. We keep separated assembly path verification from assembly text instruction. In fact, assembly instructions are contained in a separated event executed in parallel with its associated assembly event. An assembly instruction contains the part number of components to be mounted, the fasteners' part number, and the assembly tool to be used. It is also possible to specify the tightening torque for fasteners such as a nuts or bolts and any other technical information. The complete assembly simulation, along with assembly instructions, can be exported in a standard video file format (e.g. avi, mpeg, etc.) and used for company training purposes.

4.1 Technological Limitations

There are some limitations in the version of VisMockUp used for the application in AVIO. For example, in the linear path creation it is not possible to obtain a feature-based alignment for the path nodes definition and it is not possible to realize a simple screw hole alignment using a linear path pick mode option. Indeed, it's not possible to select the hole and the screw centres as inferred points. A possible workaround is to include in CAD models some datum points in correspondence of the inferred points of interest, so that they are present and selectable in the relative JT files. Datum points insertion, however, would involve extra work time for designers who own CAD models. Another limitation is the fact that flexible components are not supported since all the components are treated as rigid bodies. To address this problem, it could be supposed that if a path exists for a flexible component treated as a rigid body then it also exists the path for the flexible component itself. However, this is not always true and in particular for complex wiring systems that need different assembly procedures respect to rigid components. For those limits the activity of DMU development has been frozen. However, Avio actually uses the DMU application knowing its limits. The limits above described can be overcome by the subsequent versions of the DMU tool that should provide improved and ease of use functionalities. Furthermore, immersive virtual reality technology integration can be an interesting evolution of this research that could be thus channelled towards the integration, within the DMU environment. .

DMU allows the user to make some geometric verification on product or its sub-system. Therefore, purpose of a Digital Mock-up is all kind of simulations concerning the geometric shape, kinematics or design studies. Instead simulations regarding product intrinsic functionalities (e.g. performances) not related to geometric envelopes or product components spatial position are excluded form the DMU verifications. In this case other simulation tools are needed.

5 CONCLUSIONS

Starting from the relevance of design for new product development, the paper highlights the importance of the Digital Mock-Up to provide assembly simulation to improve the result of the design phase of a new product.

The paper is a technical one and describes the development of a Digital Mock-Up application in a naval company. Limits of the application are related to the technology used.

Future research will apply process based performance measurement methods to assess how the new technology impacted assembly processes.

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