iMoted
3D Virtual Reality Solution for Assembly, Integration and Test of the Space Segment

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ABSTRACT

The iMoted [1] solution aims to introduce Virtual Reality (VR) environments and new interactive control devices into several sectors, including Space. For the Space sector this framework allows engineers to evaluate, analyze, and plan the assembly of mechanical systems within the Assembly, Integration and Test (AIT) activities of the Space Segment. AIT activities are present in system's definition, with the development of the AIT plan, as in the verification phase with the development of the planned activities. The main purpose of this research is to contribute with innovative tools that can improve the performance on assembly of components in the Space sector. This paper describes the functionality and applications of iMoted.

1. INTRODUCTION

Assembly, Integration and Test (AIT) are System Engineering [2] activities that involve the assembling of all spacecraft parts, integration of mechanical and electrical equipments and the subsequent tests at different levels (Equipment, Subsystem, Element or Spacecraft System levels).
In this context, Virtual Assembly (VA) is a relevant content in the mechanical design where assembly tasks represent up to 60% of the whole development and production [3]. Much of the assembly problems in the Space sector derived from the design process of structures, equipment and vehicles. Therefore, the Virtual Assembly, Integration and Validation (VAIT) process (Fig. 1) should to evolve to solve problems such as: path-planning for extraction/assembly of units, assure correct order in assembly, assembly accessibility analysis, technical training simulation and improving the usability on handling virtual objects.

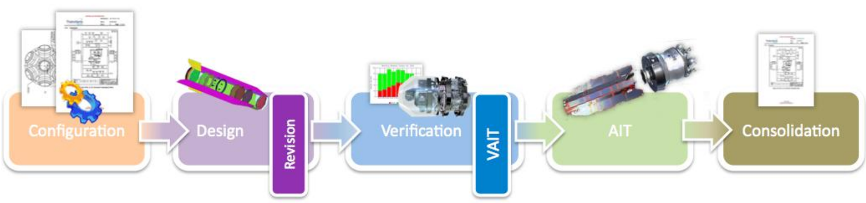

Fig. 1. Design process including VAIT

Nowadays, simulation and virtual interactions are essential aspects to support several engineering areas in order to obtain and predict results. The process of simulation and visualization of assembly is an important link to realize virtual assembly of product. Tasks such as, free handling of elements in a scenario and simulating assembly sequence of equipment concerning physical properties of elements, are continually being developed and improved in order to enhance virtual assembly. To meet the demands, VA makes full use of the Computer-Aided Design (CAD), Visualisation,

Simulating Technology, Decision theory Assembly and manufacture process research as well as virtual reality [4].
The rest of the paper is organized as follows: section 2 presents related work applied in VA, section 3 introduces the iMoted framework and section 4 describes our approach for the virtual assembly sequence for training and implemented features. Section 5 demonstrates preliminary results and, finally, section 6 closes this paper with the conclusions and future work.

2. RELATED WORK

The assembly of complex products, composed by many parts, can lead to several assembly sequences possibilities. These sequences make the assembly process diversified and its modification will significantly affect the assembly paths and assembly results [5,6]. VR training systems break real-world restrictions allowing new equipments, more training time and environments cutting down the development cycle of new products. The traditional automatic assembly planning study uses a disassembly process based on the assumption that "if you can disassemble a part, you can assemble it, and vice versa." [3,6]. Monitoring the activities of assembling and disassembling a set of components in the virtual environment enables the design of the assembly plans [7]. VA also analyzes the assembly performance and other related features, optimizes the assembly process and provides training and demonstration for engineers.
Recently, both theories and applications of virtual assembly have been subject of research in many countries. Yuichi Tamara [8], J. Cohen [9], S. Gottshcalk [10] and G. Zachmann [11] have proposed reliable solutions for collision detection in virtual assembly. Wan Huagen [12] studied a new intuitive and natural way to interact with objects using two virtual hands. Sankar [3,6] built a VADE (virtual assembly design environment) that allows engineers to evaluate, analyze, and plan the assembly of mechanical systems using an immersive virtual environment. Yao Lili [13] researched and implemented a training system for Virtual Assembly operations based on animation script control. Kuehne and Oliver [14] built a simple virtual assembly system that can generate all feasible assembly sequences of the product according to CAD models and assembly hierarchies. Jing Fan [15] analyzes main problems on existing assembly sequence plans and introduces a new Assembly Sequence Planning (ASP) algorithm. Heger and Richter [7,16] proposed an immersive assembly planning system that uses a 'snapping algorithm' to locate components accurately, additionally this system incorporates as well hands tools. Nong Ye [17] presented an experiment to investigate potential benefits of VR environments in supporting assembly planning. Liu Zhenyu [18] has also done some researches on VA and has developed a prototyping system named VDAS (virtual design and virtual assembly). Guimin Lin [4] designed a 3D interactive virtual assembly system using Java and EAI interface provided by VRML2.0. Finally, Yupeng Su [3] proposed VAP (virtual assembly platform), a new virtual assembly platform based on personal computers to provide virtual assembly technology on low-capacity computers.
The studies mentioned above are attempting to find solutions related to the assembly and are focused on the performance of activities. An open point left is how to integrate different assembly techniques in a single system.

3. IMOTED FRAMEWORK

This paper describes the iMoted framework[1], which integrates several assembly techniques and technologies such as a reliable 3D engine and external devices. Several mechanisms were implemented to assist and improve assembly tasks. This system allows the visualisation of complex geometries and simulates, with high precision, the physical behaviour of elements. Additionally this system can handle two virtual hands to be controlled by more accessible and affordable remote

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[1] iMoted website: http://www.evolve.pt/research-a-development/120

controllers (such as Wii Remotes®) and also able to manipulate human models for training assembly sequences. This solution contributes to:

- Early assessment and validation of AIT Plan;
- Accelerate and improve the design of equipment and its development process;
- Enhance integration of design data, analysis and verification.

The iMoted framework makes use of a set of different technologies and components (Fig. 2) to provide the necessary functionalities for the development of VAIT activities.

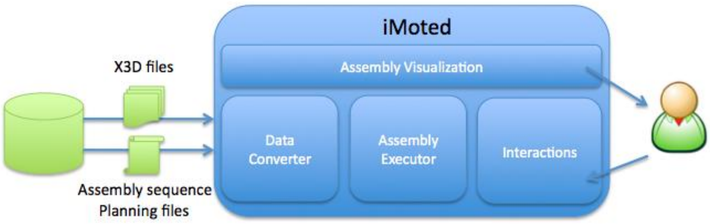

Fig. 2. iMoted framework overview

The iMoted framework is based on open-source solutions and takes advantage of OSGi plug-ins, Eclipse© Rich Client Platform (RCP) and Standard Widget Toolkit (SWT) to provide a user friendly and configurable Graphical User Interface (GUI). Making use of Open Source Software (OSS) is considered an added value for the dissemination and consequent collaboration among individuals or a set of entities on the development and maintenance of a software tool. iMoted framework has four main development drivers: Visualisation, Interactions, Data Exchange, and Assembly Execution. As core of this paper, Assembly Execution will be detailed in section 4.

Visualisation of realistic 3D

Virtual Reality (VR) creates a virtual world allowing a person to have different sense experiences. iMoted 3D engine enables a fast, attractive and intuitive graphical representation of geometries, allowing the user to manoeuvre 3D objects and solve usability problems that are characteristic of applications with complex user interaction. This platform offers a set of functionalities including: geometrical models, camera, lights, shadows, reflections, animations, physical engine, particles systems, and other effects. It also allows the user to manipulate humanoids in simulation environments for training purposes or for accessibility assessment in tiny compartments. Using iMoted, engineers can cross-compare different versions of 3D CAD Spacecraft models and also validate these confronting 2D design diagrams (e.g. SysML design diagrams from SVG files) during the system verification activities. This functionality also supports the execution of AIT procedures since the user can concurrently follow the AIT flow through the visualisation of activity diagrams.

Interactions with low-cost devices

This system also allows several devices to interact with the virtual environment through the use of generic controllers. The platform was developed in order to receive multiple controllers that may behave as multi-input tools. The iMoted provides the opportunity to experiment an immersion sense (the feeling of “being there”) with low-costs devices like Nintendo Wii Remote© or the Apple iPhone©. The 3D Space Navigator© device allows an easy and realistic manipulation of the 3D objects in a virtual environment.

Data exchange using standards

The iMoted is compliant with 3D graphics rendering standard, by implementing the specifications of Extensible 3D (X3D). This standard provides a clear advantage for exchanging 3D models between the different actors involved in the design and development of a Spacecraft. Nowadays, different tools used in this process to provide visualisation and user interaction with 3D models, make use of proprietary formats and have expensive licenses, encumbering the Concurrent Engineering tasks. X3D (VRML evolution) is a ISO standard XML-based file format and is also a scene modelling language used for establishing virtual reality of three-dimensional objects. Additionally, X3D specification defines a set of features such as elements position, kinematics, animations, physical behaviour, mannequin's skeleton and also offers external entry points using Scene Access Interface (SAI). Currently, X3D version 3.2 format it is used to exchange geometrical data and assembly information between external applications. This open format has been evolving continuously and many organizations are adapting this standard into their solutions. It enables possible injection of specific information about the geometrical elements, reference external files to extend the scene functionalities, and specify joint types between elements. Besides scene definitions, X3D language has the advantage of defining the structure of the skeleton of a humanoid.

4. VIRTUAL ASSEMBLY FOR TRAINING

In the Space domain, the training of mechanical assembling and the creation of assembly training sequences (Fig. 3) are very important, since they provide the study resources and controlling for engineers. Concerning theses points this paper presents a solution for training in a virtual assembly. Our solution uses a script to define the assembly process and control the playback of the animation. The script is described in XML (similarly as [19]) and parsed by a procedure, being in that way suitable and flexible. It is composed by a set of operations to handle several kinds of elements and is able to request user actions.

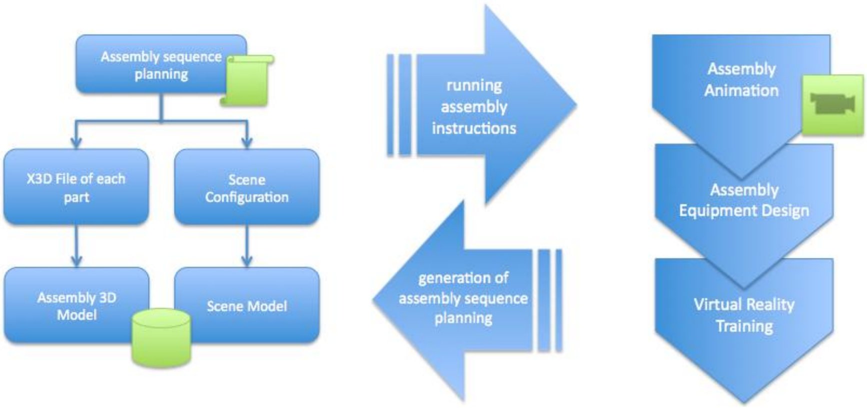

Fig. 3. Assembly sequence planning process

Each assembly sequence, so called *Assembly Sequence Plan*, takes into account the Scene, Model, and set of Operations and Resources. The script can be produced manually (editing the file) or using reverse engineering over the actions (i.e. automatic generation of instructions through 3D graphical controllers). The assembly sequence plan has reference to a Scene Configuration and to a set of X3D files for each part of the model. Each X3D file is parsed on iMoted framework that compiles the geometrical information and repositions each part in a different position on the scene, concerning its relative position. Running an assembly sequence plan produces assembly animations, on the other hand, the system can produce assembly instructions considering the free animation of elements, by recording the position and orientation concerning the execution time, or by key frames interpolation of each element. Engineers can replay and modify the assembly path and assembly sequence interactively in the virtual environment. Assembly path can be modified in discrete mode, namely, to change the discrete positions of assembly trajectory in which engineers can adjust them manually. Smoothing parametric curves paths is also considered (e.g. bezier and splines).
The typical assembly models include the relationship model, hierarchical tree model, mixture model and others, but generally the product structure is hierarchical and can be represented by X3D.

Usually, the products are made up by several sub-assemblies and thousands of basic parts, and the sub-assemblies can be divided into other components until they cannot be further divided [3]. To display the structure in different angles and details it is required to combine several parts according to the scene graph (Fig. 4).

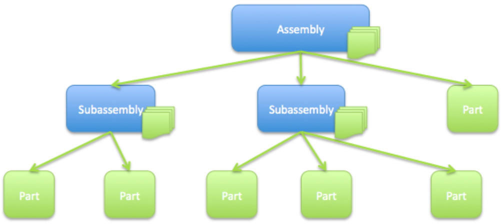

Fig. 4. Hierarchical tree structure

Concerning the task of joining different parts of a product, it is proposed a set of Virtual Assembly techniques and tools. VA is a digital method for geometric modelling of AIT facilities, spacecrafts and kinematics to reflect method and process. A simplified definition of VA is the connection of two nodes with physical properties. The employment of physics (e.g. objects with realistic collisions) and the use of animations in the Virtual Environment (VE) together with user interaction functionalities confer to iMoted the ability to allow the assembly of 3D Spacecraft elements. There are three different options that can be considered:

- Manually or automatically move the selected element to its target position and orientation;
- Free manipulation of 3D objects, visual detection of compatible interfaces and automatic snap of the elements;
- Record of extraction activities and playback sequence in rewind.

To achieve the goals of this research, knowledge and techniques derived from video games and professional tools were applied. In contemplation to explore user interactivity, solutions for assembly tasks were attempted. The use of movement restrictions, different types of joints and physics were considered. To improve accuracy on tasks, some techniques were implemented to assist the user: *Assembly by Proximity* and *Disassembly*. These two approaches have several differences, since the first technique is used to assist the user to join different parts, the second reverts the process of assembly. Both techniques produce a set of instructions into an *Assembly Sequence Plan*. To support the usability in assembly procedure, it was also implemented interactive tools to handle geometries in the virtual environment such as *Virtual Hands* and *Mannequins*.

Assembly by proximity technique

Assembly by proximity method offers an intuitive and realistic approach to assembly. A version of this method was already successfully tested with "Proximity Snapping" [8]. Unlike snapping by collision, this mechanism takes into account the final position to enable the connection. Our implementation represents the final position with an interface point, which changes its representation when a correct pair is detected nearby. Each interface pair is represented by a unique color. The position of interface points and the joint types are configured through X3D parameterization, taking into consideration the centre of mass and size of objects, anchor position, and directional axis. Proximity detection highlights and increases the volume on both interfaces (Fig. 5 - a), releasing the grabbed object starts the coupling procedure.

Disassembly technique

The Disassembly technique consists in the dismantlement of a product (Fig. 5 - b). The dismantlement sequence is recorded and a post-procedure reverts the sequence plan, instead mounting from an initial state. This method avoids a large number of possible assembly sequences that may exist in a complex assembly environment with numerous parts. It can reduce the assembly time and improve its efficiency compared to the traditional methods. Our implementation requires manual user interaction to manage the assembly in real time. In future work, automatic algorithm for assembly sequence plan may be considered as shown in [6,18]. Generally, before assembled to a complete product, components have usually been assembled integrally. So, first to ensure successful progressive assembly procedure of components, sometimes it is necessary to disassemble some parts from those assembled components [20]. During continuous destruction, the assembly events, the parts involved and assembly relations will be recorded automatically, producing the assembly sequence of the product and the assembly path as well.

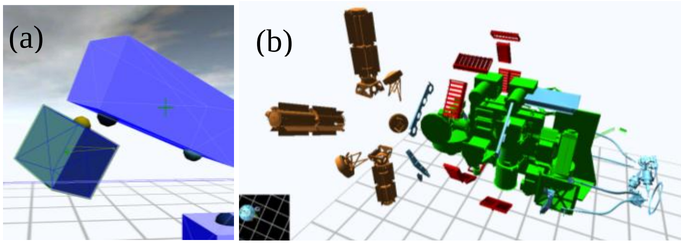

Fig. 5. Virtual Assembly techniques: *Assembly by proximity* (a) and *Disassembly* (b)

Virtual Hands tool

The iMoted solution introduces two virtual hands capable of grabbing, holding, moving and orienting any object in the scene, reproducing real human hand interactions, similarly to [12]. A hand can reproduces up to four postures: *Plain* , *Aim*, *Grab* and *Two Fingers*. Two Nintendo Wii Remotes (Fig. 6 - c) are used to move the virtual hands in the virtual space including in depth, and are capable to select postures by pressing buttons. Combining movement, orientation and posture of the hands allows the system to determine which action should be started such as: *drag*, *zoom*, *rotate* or *up*.

Virtual Mannequin tool

A virtual mannequin (Fig. 6 - d) contributes to the process of part assembly simulation. The human models are used to solve industrial real cases involving complex geometric issues and algorithmic path planning challenges such as assembly sequence, fine motion planning or narrow passage following [21]. In our approach, the mannequin is treated as an unbreakable tool that can be moved and articulated using kinematical joints. The physical engine used in iMoted supports inverse-kinematics, based on pseudo-inverse Jacobian transforms, that allow the automatic and efficient calculation of the angles and positions of all involved parts when a specific one moves to a desired position (e.g. movement of an arm with the reposition of the hand). The mannequin is made with several degrees of freedom to allow the engineers to freely manipulate parts. The skeleton articulation is used to animate characters. Our approach uses X3D to exchange the human models, between external applications, and recreates the skeleton into the engine. X3D specification is very detailed, defining small parts as knuckles or rotation of the eyes, being an excellent baseline to follow. H-Anim is a X3D tag that initiates the humanoid definition. After this tag a set of joints, segments and different levels of joints are considered. Each specific joint (e.g. hanim_r_shoulder) indentifies angular restrictions that should be assumed by these nodes in render time, recreating movement restrictions of humans.

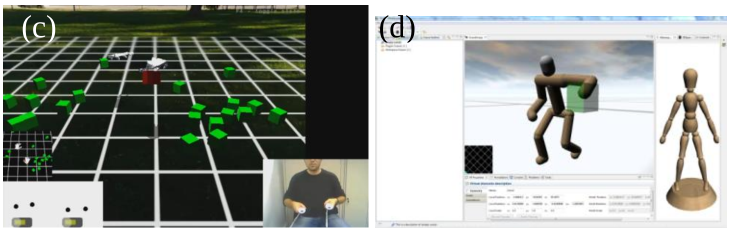

Fig. 6. Virtual Assembly tools: *Virtual Hands* (c) and *Mannequins* (d)

5. PRELIMINARY RESULTS

A series of operational tests for VA tasks were performed. Preliminary results demonstrate that the users prefer the reverse assembly approach, instead of assembly by proximity. Participants found Disassembly technique less complicated because they do not have to worry about the interfaces of the product. As a work tool, the virtual hands have been extremely useful, however our initial tests demonstrate that using the infrared from Wii Remote is not sufficiently reliable and proved to be problematic in truthfully replicating all 3D movements. These initial tests indicated the need to adjust the learning curve on the system. For compatibility tests, we compared iMoted with other programs[2] that are compliant with X3D specification, having the best results for *Rigid Body Physics* components. Performance tests demonstrate that iMoted is able to load complex products and render 1.348.782 vertices at 31fps and consuming below 154MB of memory.

6. CONCLUSIONS AND FUTURE WORK

iMoted integrates several assembly techniques and 3D technologies. Additionally, this paper has demonstrated the iMoted advantages in VAIT tasks presenting interactive virtual hands to freely manipulate 3D objects, and mannequins for accessibility analysis, while being compliant with the best standards for virtual data exchange. It has presented two possible strategies to assembly virtual parts of a complex product. The first one aims to solve the problem from scratch attempting to snap pieces together without any pre-established sequence order. The second one, records the disassembly sequence, taking into account collisions and possible paths. Both techniques require manual user operations, and also solve industrial real cases involving complex geometries. In future work the virtual mannequins will be detailed and the Assembly Executor module will be implemented completely.

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