

# Underwater Remotely Operated Vehicle Manufacturing Assembly and Training Using X3D/Virtual Reality Modeling Language

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## Abstract

There is a notable lack of available educational programs and training opportunities for enabling engineering and technology (ET) students to understand the wealth of underwater industry and equip them with the related knowledge, skills, and abilities needed to work in them. To this end, remotely operated vehicle (ROV) serves as a valuable tool in assisting students in engineering, technology, and science to understand the manufacturing assembly design process. The purpose of this paper is to investigate the challenges and obstacles of the manufacturing assembly design of the ROV and to create new opportunities for improvement through X3D/virtual reality modeling language (VRML). In doing so, the paper aims to enhance students' understanding of the underwater ROV manufacturing assembly process. Another goal of this paper is to assist students to participate and compete in the upcoming Marine Advanced Technology Education (MATE) annual competition. The paper will test the impact of these experiments to the knowledge base about engineering manufacturing courses for the College of Engineering at University of Hail. The virtual reality (VR) world generated in this study can be used for static observations as well as dynamic interactive purposes. VR scenes enable interactive exploration and navigation of the 3-D scene objects, which is a very valuable skill that can be incorporated into any training exercise.

## **Introduction**

ROV is an underwater robot tethered to the offshore industry. ROV is operated by a person aboard a vessel, which minimizes the risk of the human life and facilitates flexibility and maneuvering underwater. It is one of the best solutions to improve sea floor environmental monitoring and research. ROVs are generally accessorized with lights and a camera for video recording, and other extra paraphernalia can be added to enhance functional requirements. Such additions may consist of water sampling equipment, water clarity measuring equipment, SONAR (sound navigation and ranging), magnetometers, etc. Working in the underwater environment has become more common, from searching for and recovery of downed ships and vehicles to the extraction of gas and oil in depths of thousands of feet. The enhancement of measurement and audio/video technologies to overcome the obstacles of the underwater environment requires more and more skilled and talented individuals to support this research [1]. Many engineering students are unable to make the connection between their everyday lives, the wealth of underwater industries, and the knowledge, skills, and abilities needed to work in them [2]. This lack of awareness translates into a lack of available educational programs and training opportunities. Particularly, shortage is in educational programs that focus on the engineering and technology that support underwater activities, especially at the junior and senior levels, where students are preparing to think about their career paths [3]. The Marine Advanced Technology Education (MATE) Center has developed an adaptive model for gathering information on the marine work force and providing educators and students with that information, along with educational experiences that help prepare students for ocean-related careers[5, 6]. A good example of this model in action focuses on ROVs. The MATE Center has developed a knowledge and skill framework for ROV engineers and technician and has used the framework competencies to guide the development of its underwater technology curricula, which includes the text and accompanying instructor's handbook, *Introduction to Underwater Technology & Vehicle Design* [4]. The MATE model ties together the work that the center has done to assess marine workforce needs, develop curriculum, offer professional development to faculty, and provide students with information and experiences that will help them develop skills as well as increase their employability in the marine workplace [5].

## **Research Questions**

1. What is underwater ROV technology?
2. How does VRML help improve ROV assembly and structure?
3. How does underwater ROV technology help engineering and technology students in their academic programs?

## **Literature Review**

Robotics is estimated to be a critical area in future technological innovation following the personal computer and Internet [8]. This burgeoning interest is being exploited by several universities around the world to enrich students' learning experiences through laboratory assignments and other means [9]. In their work related to this, Bohm et al. [10] provide the basic,

introductory knowledge pertaining to this field. ROVs are one of the best practical and safest ways to perform underwater exploration. Exploring the sea and underwater areas for treasures and for salvaging sunken cargo, seafood, etc. [5-7] has been an activity for quite a long time.

## **Methodology**

### ***ROV Assembly Training Methodology***

At first, students are given an opportunity to practice and enhance their understanding of ROV functionalities. Subsequently, laboratory-based practice exercises are used by the instructor to instruct underwater ROV technologies. The students are divided into groups, and each group is allowed to select a specific aspect of underwater ROV technology. The student groups study their chosen underwater research area in much detail. Example topics include PVC structure, underwater maneuvering, ROV localization, and propulsion. At the end of this phase, each group is required to submit a report with findings, value-added activities, reasonable recommendations with pros and cons, assuming that their ROV assembly will be used in a real-life commercial ROV design. They also need to share their experience and the knowledge gained from the overall experience with other student groups in the class. They then use the information obtained in earlier steps to plan and assemble a model using the VRML/X3D (virtual reality modeling language/extensible 3-D) software. In this project, they need to use this software to demonstrate their design before fabrication. In Figure 1, a 3-D VRML rendering and a fabricated ROV model are illustrated for comparison and contrast purposes.

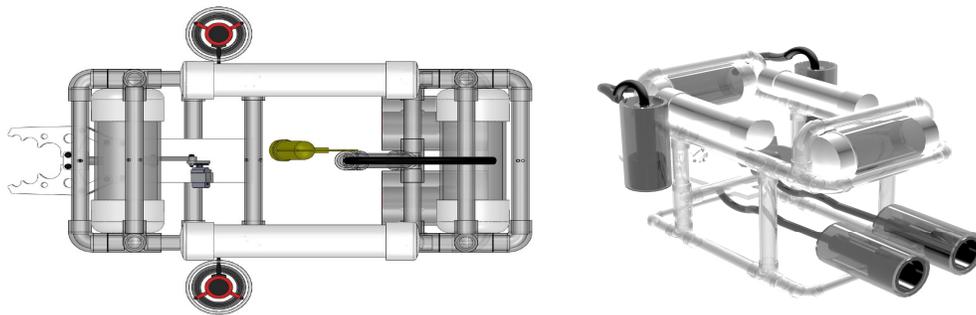


Figure 1. Blueprint of a fabricated ROV and VRML rendering

### ***VRML Procedures***

The study utilized VRML to introduce students to underwater ROVs. SolidWorks models have been used to develop ROV PVC structure, manipulator, buoyancy, thrusters, and audio/video parts. Students learned VRML to design tool to output a drawing other than the traditional 2- and 3-D drawings they were used to. Next, they brainstormed a number of PVC structure ideas and made a VRML drawing of their final idea.

## *VRML/X3D Based Visualization*

VRML is a specification to define static or dynamic, interactive 3-D scenes, which can be used on the internet. X3D, the latest version of VRML is capable of encoding this 3-D scene using XML syntax. A VRML/X3D scene is generated by building 3-D objects and assembling or structuring these smaller objects to constitute the whole scene.

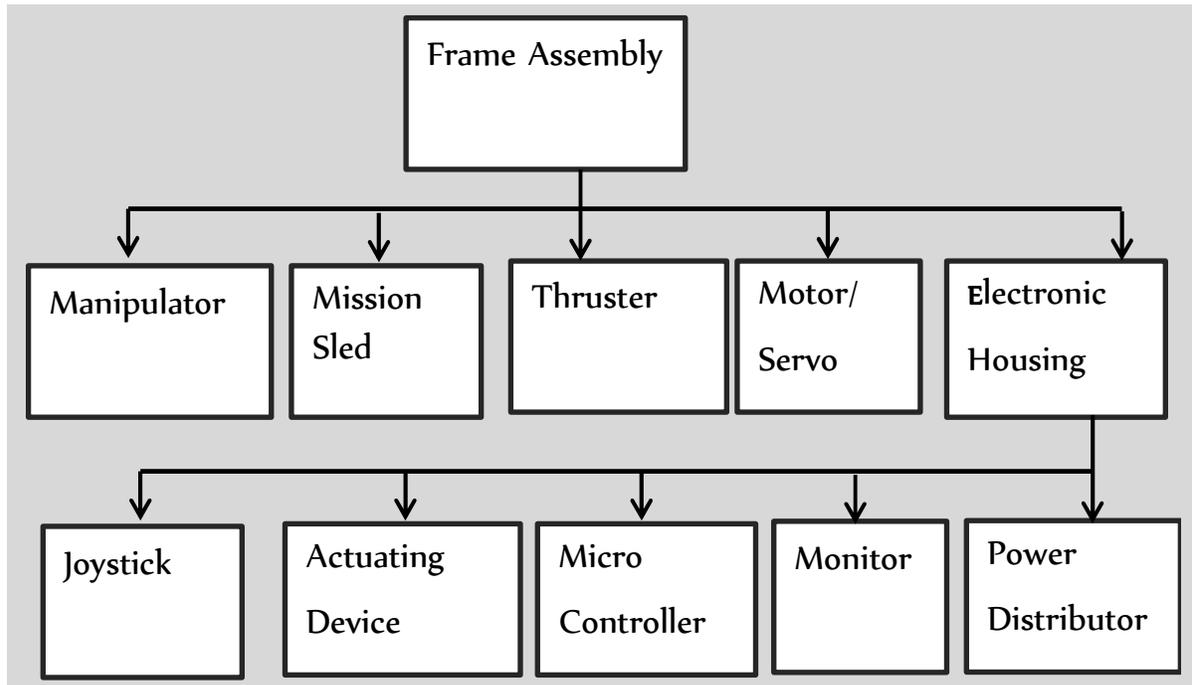


Figure 2, Hierarchical scene representation for virtual worlds

The 3-D virtual scene is built using nodes, the fundamental building blocks that are used to define the parameters (properties) of the scene objects. The scene objects created thus using nodes can be reused as and when needed using a feature called “inline.” Also, customizable objects can be built using a functionality called PROTO nodes, and these can be reused again later by calling the EXTERNPROTO node [11]. This ability to build once and be able to reuse the objects is an extremely time-saving and efficient way to construct scenes with 3-D objects. Figure 2 illustrates the components of the ROV represented hierarchically, corresponding to their VR scene tree representation. Every virtual scene object is defined using parameters (attributes) governing the appearance characteristics and geometric characteristics. While modeling a larger component for the virtual-world scene visualization scene, the actual construction is made by assembling smaller objects. Consider the sample scene, as in Figure 3 below. If further broken down into smaller fragments, the elements that result will also include much smaller mechanical and/or electrical components, which are a particular material, color, and dimension. All these are the attributes of the various

components. Thus, a scene is actually made up of a set of elements or objects, each of which has its own properties or attributes. As shown in Figure 2, the hierarchical representation objects are grouped using a “parent-child” relationship. A parent object can include any number of children, which can be grouped or assembled to function as a single entity. One of the primary advantages of this sort of grouping within a 3-D scene manifests itself in the ability to perform transformations.

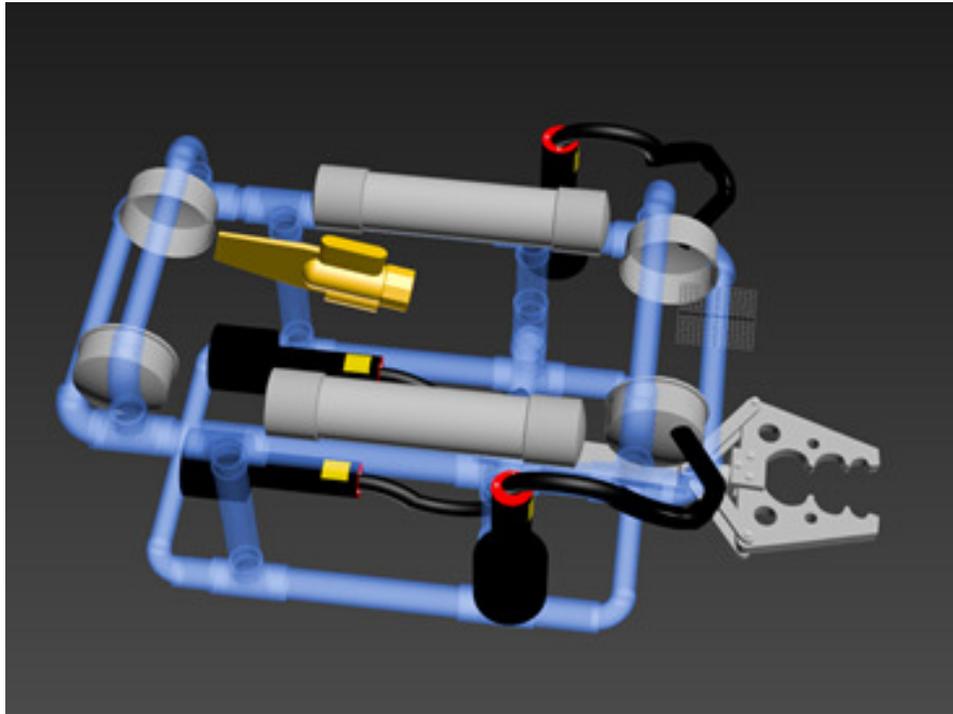


Figure 3. A stage in the development of the 3-D ROV model

### ***ROV Visualization***

From the earlier discussion, it can be seen that one parent object contains several children. As the user may desire or as may be required, the parent node can include any number of child nodes. Employing such object-oriented notion makes devising virtual worlds easier. The elements in a scene can be grouped in the form of a hierarchical structure in the form of parent-child relationships. For instance, “the wall” object can be grouped as a child of “the room” object. This sort of hierarchical approach is particularly useful in animation of a scene when it is required to animate different objects differently. In the simplest form, members of a hierarchy are ordered one below the other. This sort of arrangement helps in the step-by-step design of the object and also in understanding the framework at any later stage. A scene-tree construction is used in virtual scene renderings. The root or the parent object consists of the whole scene grouped together and all the other components are grouped under this parent object using parent-child relationships. Individual scene elements corresponding to each floor

type such as library, convention area, residential, commercial, recreational, and public utilities, were created from scratch and positioned according to their corresponding positions as per the Pareto plan obtained in the previous step. For complex objects including multiple parts, various object parts are grouped to form parent objects, leading to complete objects that are once again combined and positioned properly to form bigger objects, resulting in the final 3-D scene. Another advanced way of customizing the virtual objects is by using carefully defined and organized nodes, which the following section addresses.

### ***Virtual Objects Generation Using Customizable Nodes***

Virtual world objects are described as shapes with geometry and appearance. All features such as buildings, rooms, artifacts, etc. can be modeled as shapes that can be grouped together and transformed (translated or rotated) within the coordinate system in which they are built [13]. Generally, in VRML/X3D objects are created from the basic shape node that uses information pertaining to geometry and appearance. The geometry field is used to describe the geometric properties of the object, and the appearance field is used to describe how the object looks. Realistic scenes can be built by careful usage of textures, scaling them to precisely equal the real-world faces. The appearance node in VRML includes a texture element that denotes to the URL (link) comprising an image to be superimposed or overlaid on a particular face of the VRML object [14]. IndexedFaceSets are an important type of geometry node characterized by a list of x, y, z coordinate points, containing the details of the order of connectivity of these coordinates to build a face. Several studies have successfully used virtual worlds for diverse applications involving instruction and training [15-17].

### ***User Interface for Multi-Perspective and Multi-Scenario Visualization***

This kind of virtual representation is intended to be used by a diverse audience, some of whom may or may not be comfortable with the immersion and navigation functionalities offered by a virtual reality environment. To remedy this, an interface with object linking and embedding (OLE) is utilized. An OLE file is a document that brings together different file formats on a single common palette. Each scenario depicts a different configuration of, for example, the same rail station, which can be a simple re-organization of the elements in the previous scenario or a total rearrangement of the station components. Figure 4 illustrates a VB-powered GUI (graphical user interface) that facilitates navigation through the step-by-step training process.

Even though users can navigate within the VR world and explore the ROV themselves, the OLE interface ensures that beginners or trainees go through the steps in proper sequence to understand the ROV assembly process. Such virtual environments can be employed to generate even more advanced models for more complex needs. A model with a very high LOD (level of detail) can be designed and implemented using these features. Also, it must be noted that within real-world constraints or limitations, it is practically impossible to get to the level of the individual components when it is required to visualize any modifications that need to be changes made. Using VRML highly detailed models capable of dynamic behavior can be generated and more

importantly these models are scalable. More importantly, the training can be incorporated even when the model is being designed.

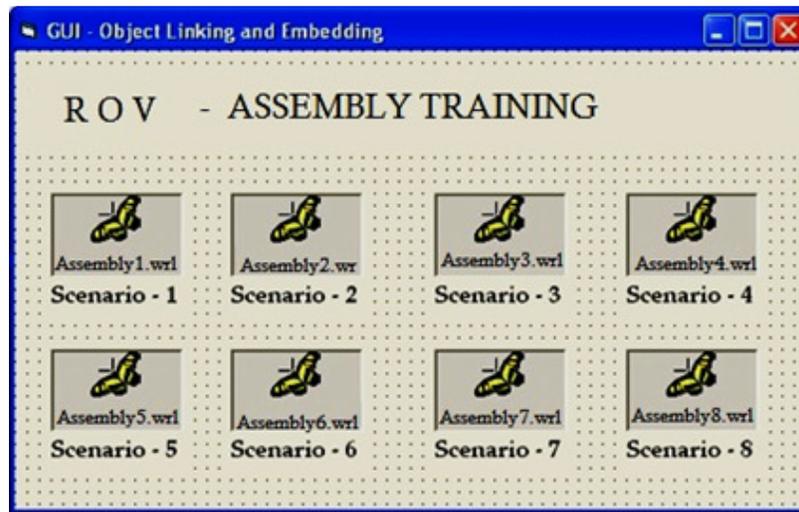


Figure 4. GUI with OLE functionality for step-by-step ROV assembly training

### **Manufacturing Assembly Process Exercise Overview**

Students used this brief foundation to build their own underwater ROV frame out of PVC. Instructors should group students into teams of 2-4, depending on class size and ROV kit availability. Students will discuss their ideas and designs and settle on a design they want to build together. They were reminded to think about balance between buoyancy and weight as well as balance along the various axes of the ROV. This exercise demonstrates the power of constructing the Saudi ROV through VRML. Students work in teams to plan, build, evaluate, and remodel an ROV assembly to satisfy the MATE quality requirements.

### **Objectives**

In the process of completing this exercise, students will accomplish the following goals:

1. Design an ROV PVC assembly as quickly as possible as per MATE quality
2. Design, manufacture, and install manipulator, thruster, cameras, tether the for ROV
3. Apply basic mathematical and science skills to plan and build the ROV
4. Compare differences between SolidWorks and hands-on product assembly

### ***Anticipated Outcomes***

Towards the end of this active learning exercise students would have:

1. Assembled a project by hand that meets the MATE quality criteria
2. Designed an assembly line process to assemble a product as quickly and efficiently as possible meeting the MATE quality criteria
3. Tested and redesigned the assembly line process
4. Compared the differences between assembling a product VRML versus hands-on

### ***ROV Design Process***

Role of the instructor:

1. Describe the basic concepts and fundamental components of underwater ROV
2. Demonstrate hands-on exercises and self-learning activities
3. Demonstrate the generation of material information
4. Corroborate exercises with supplemental notes on mass and material density
5. Review the design steps involved in the engineering process
6. Remind students to manuscript their scheme with pictorial representations (photo/video)
7. Reveal or explain the PVC pipe cutting using hacksaw and drilling vent holes in
8. Introduce additional required concepts including motors, electronic motherboard, switching, and thrusters

Student Role:

1. Perform mind-mapping and brainstorm ROV design ideas
2. Submit primary proposals and sketch diagrams
3. Initiate the ROV design process in 3-D (VRML) using part files/assembly
4. Estimate ROV weight using physics enabled 3-D modeling software
5. Compute ballast for small bobber and sinkers
6. Check design controls and calculate/record actual weights requirements
7. Construct the ROV frame
8. Submit design for approval and bill of materials
9. Assemble control systems and test controls

### **Results and Discussion**

The final ROV model generated is illustrated in Figure 5. The advantage with using a 3-D VRML model is that these can be both static and dynamic representations. The individual components (objects) have their own characteristics (properties) and behavior (actions or methods).



Figure 5. Partial view of the ROV model 3-D rendering

Dynamic models capable of user-interaction are generated for this study using the event-driven paradigm. Although a standalone VR application may not be able to achieve a complex animation or a greater level of interaction, scripting can be employed to accomplish these additional functionalities. Through the use of SCRIPT nodes, additional functionalities are embedded for dynamic interaction using JavaScript. This is especially useful to demonstrate the step-by-step ROV assembly training. In this research, the authors have integrated programming logic within VR worlds to accomplish dynamic interactive simulations that can be used for training purposes.

#### ***Analysis of Stress: Jaw Manipulator***

The following highlights the significant advantages of using an object-by-object construction of 3-D scene representations. This is illustrated using the stress analysis for the jaw manipulator. The 3-D jaw manipulator's correlation to factors such as safety can be tested using simulations applied in the 3-D models. Figure 6 shows the chart for the stress analysis and the 3-D rendering of the jaw manipulator (image on right). The 3-D model can be used to simulate reactions of the jaw manipulator under various conditions.

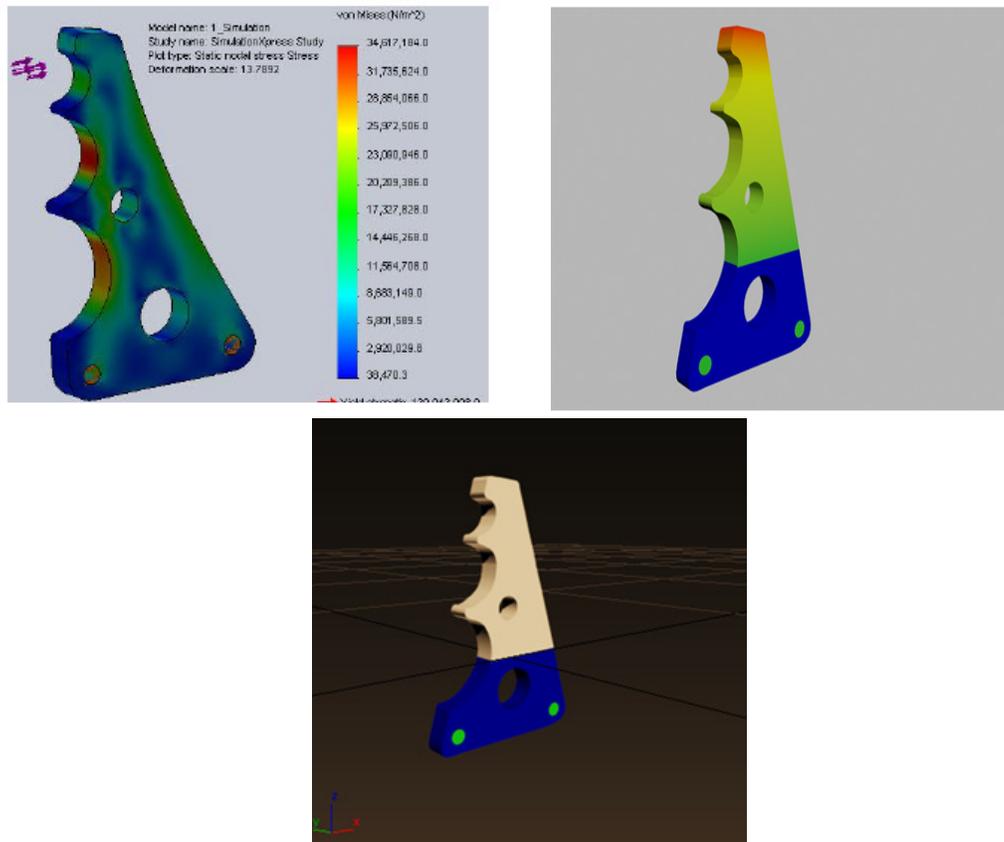


Figure 6. Stress analysis chart & 3-D model of jaw manipulator with controllable parameters jaw manipulator model generation

### ***Programming the Final Graphic Interface for User Interaction***

One of the primary reasons for implementing the graphic library using a VR-based interface is the ability to program the objects hence created. This event model facilitates controlling behavior and hence paves the way for creating complex objects and dynamic scenes. The key attributes of a graphics scene include geometry and appearance. There are numerous exposed fields that cumulatively control the shape and appearance of objects. While these can be achieved using commercial software, there are numerous restrictions to what can be done within such IDEs. However, these programmed objects offer innumerable possibilities whereby their behavior and attributes can be controlled. By creating scenes using carefully designed and hierarchically organized nodes, the behavior of the scene and constituent objects can be controlled very precisely to generate desired actions. The final OLE interface that can be used for multi-perspective multi-scenario visualization is shown below (Figure 7).

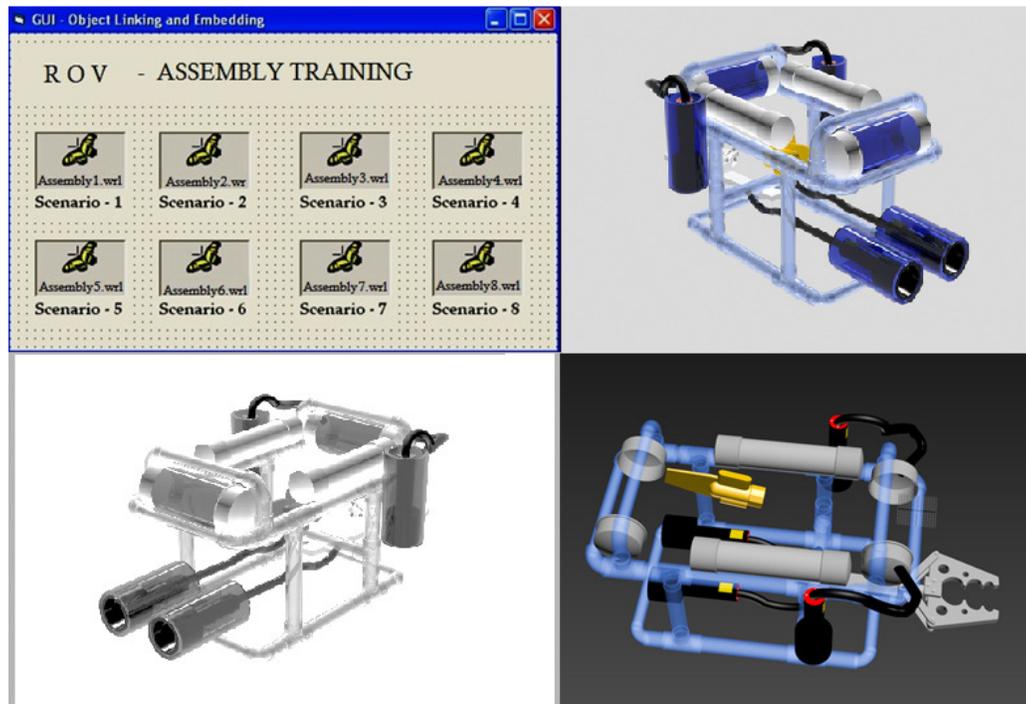


Figure 7. OLE interface for multi-perspective, multi-scenario visualization

## Conclusion

In this research, the authors have integrated programming logic within the VR worlds to accomplish dynamic interactive simulations to use for training. The goal of this paper was to teach students to investigate the challenges and obstacles of the manufacturing assembly design of a ROV and to create new opportunities for improvement through X3D/VRML. The paper studied the impact of these experimentations and contributed finding to the knowledge base about engineering manufacturing courses for the College of Engineering at University of Hail. The VR world generated in this study can be used for static observations purposes as well as dynamic interactive purposes. VR scenes enable interactive exploration and navigation of the 3-D scene objects, and this is a very valuable ability that can be incorporated into any training exercise.

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## Biographies

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