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Virtual Reality Integration in Maritime Engineering Education: Bilingual Simulation Models for Naval Electromechanical Systems

Florin POSTOLACHE[1], Octavian Narcis VOLINTIRU[1], Radu MANU[2]

[1]"Mircea cel Bătrân" Naval Academy, Marine Engineering Faculty, Electro-mechanical Department, florin.postolache@anmb.ro, octavian.volintiru@anmb.ro
[2]"Mircea cel Bătrân" Naval Academy, Interdisciplinary Research Center in the Maritime Field, radu.manu@anmb.ro
***florin.postolache@anmb.ro**

Abstract. The paper presents the integration of Virtual Reality (VR) technologies into maritime engineering education within "Mircea cel Bătrân" Naval Academy. Focusing on Hydraulic Machines and Drives, Hydraulic and Pneumatic Systems, Hydraulic Actuation, and Naval Mechanical and Hydropneumatic Installations, the project develops a bilingual (Romanian-English) VR repository of 3D simulation models. Using SolidWorks Premium, SolidWorks Flow, Siemens NX and 3D Xperience, the project addresses traditional practical training limitations by providing realistic, risk-free operational environments. Key phases include 3D modeling, didactic integration and full VR deployment, aiming to enhance technical proficiency, bilingual competence and alignment with European educational standards. The initial results demonstrate significant improvements in operational training and student engagement, setting new benchmarks for immersive learning in naval engineering education.
Keywords: Virtual Reality (VR), Augmented Reality (AR), 3D Modeling, Naval Training Simulation.

Introduction

In an era where maritime operations demand increasing automation, technical proficiency and rapid adaptation to global challenges, innovative educational methods are essential. Virtual Reality (VR) has emerged as a transformative tool within the academic field, offering immersive, interactive learning environments that dramatically enhance students' engagement, retention and application of knowledge. Particularly in technical education, VR allows for the safe simulation of complex scenarios that would otherwise be costly, hazardous, or logistically difficult to reproduce in traditional settings.

The application of VR in the field of electromechanical naval engineering represents a major step forward in modernizing maritime education. Naval electromechanical systems, comprising intricate hydraulic, pneumatic and mechanical operations, require not only theoretical understanding but also intensive practical training. VR technology bridges this gap, enabling students to experience real-world system behavior, troubleshoot issues and engage in procedural training without the risks associated with physical equipment.

This research investigates the integration of VR technologies into the learning processes of technical disciplines at the "Mircea cel Bătrân" Naval Academy, focusing on Hydraulic Machines and Drives, Hydraulic and Pneumatic Systems, Hydraulic Actuation and Naval Mechanical and Hydropneumatic Installations. Delivered bilingually in Romanian and English, the initiative aims to enhance the quality, accessibility and practical relevance of training for future naval engineers and officers.

For students, the main aims include:

- acquiring in-depth knowledge and hands-on experience with electromechanical systems in a virtual environment.
- developing critical technical vocabulary in both Romanian and English.
- enhancing operational decision-making skills and response to crisis situations.
- building confidence and proficiency in handling real-world naval systems.

For teachers, the main aims are:

- facilitating a more dynamic and interactive teaching process.
- providing realistic, risk-free training scenarios.
- supporting bilingual education and technical terminology acquisition.
- enabling continuous innovation in didactic strategies by leveraging VR tools.

Context and Relevance of the Research

The increasing complexity of naval electromechanical systems demands a rethinking of traditional educational models. Classic maritime engineering education often relies on theoretical lectures supplemented by limited practical exposure to real-world equipment, constrained by costs, safety risks and logistical challenges. Consequently, students may graduate with substantial theoretical knowledge but insufficient practical competence in operating, diagnosing and maintaining critical naval systems.

Virtual Reality (VR) provides a solution to these challenges by creating fully immersive, safe and repeatable training environments. In the context of maritime education, VR technologies allow students to explore complex hydraulic, mechanical and pneumatic systems virtually—experiencing operational behavior, troubleshooting common malfunctions and engaging in maintenance procedures without the physical and financial constraints of working with real vessels and equipment.

The integration of VR into the electromechanical naval field is particularly crucial as maritime operations increasingly require proficiency in automated and hybrid systems. It offers a scalable way to familiarize cadets and engineering students with the machinery they will encounter aboard modern naval and commercial vessels. Additionally, bilingual VR content enhances language competencies crucial for careers in international maritime sectors.

By addressing both technical and linguistic skill development in an integrated and interactive manner, this project not only modernizes the educational process at the “Mircea cel Bătrân” Naval Academy but also aligns the institution with European and global trends in digital education and maritime operational training.

Research Objectives

The overarching goal of the project is to overcome the practical limitations traditionally associated with onboard technical training by creating a comprehensive, bilingual (Romanian-English) VR-based repository of 3D models replicating critical naval electromechanical systems. Recognizing the logistical challenges, safety concerns and high operational costs linked to physical access to maritime equipment, this project leverages Virtual Reality to deliver an interactive, risk-free learning experience.

The project unfolds through four major phases:

1. **Digitalization:** Systematic collection and analysis of technical documentation to identify essential hydraulic, mechanical and pneumatic components requiring simulation.
2. **3D Modeling:** Development of high-fidelity, animated 3D models capable of reproducing real-world behavior, system interactivity and operational dynamics.
3. **Didactic Integration:** Embedding the VR simulations into structured, bilingual teaching modules to support academic curricula and skill-based training.
4. **VR Deployment:** Full-scale implementation of immersive VR learning environments to enable students and instructors to engage with complex systems virtually, mirroring real-world operational conditions.

Specific objectives include:

- Realistic simulation of hydraulic, mechanical and pneumatic operations typically inaccessible during standard academic training.
- Enabling safe, cost-effective practical exercises simulating critical operational procedures and emergency scenarios.
- Development of both technical and linguistic competencies by providing immersive training in Romanian and English.
- Alignment of educational outcomes with international standards and expectations for modern naval engineering professionals.

Through these objectives, the project seeks to modernize naval technical education, ensuring that graduates possess both theoretical understanding and operational competence essential for success in an evolving maritime industry.

Methodology

The research employs an integrated and multidisciplinary design combining both quantitative and qualitative approaches. Recognizing the need for high-fidelity simulations that replicate real-world electromechanical behaviour, the methodology focuses on developing detailed 3D models and integrating them into immersive Virtual Reality environments.

The main software tools employed in the project for 3D modelling and VR simulation are:

- **SolidWorks Premium** for precision mechanical modelling.
- **SolidWorks Flow** for simulating fluid dynamics within hydraulic and pneumatic systems.
- **3D Xperience** platform for collaborative model management and real-time updates.
- **Siemens NX** for advanced electromechanical component modelling and validation.

These tools were chosen for their robustness, compatibility with VR deployment environments and their capacity to render complex dynamic behaviours crucial for naval training applications.

The methodology involves the following key steps:

- Systematic digitalization and technical documentation analysis.
- Generation of animated 3D models that reflect the real-world functionality of pumps, valves, hydraulic cylinders, compressors and other critical shipboard systems.
- Testing and iterative refinement of the 3D models within VR environments to ensure operational realism and educational value.
- Structuring the simulations to support bilingual (Romanian-English) training modules, facilitating simultaneous technical and linguistic competency development.

Hardware investments include VR headsets, high-performance graphic stations and 4K monitors, ensuring a smooth, immersive and high-quality simulation experience for all users. These technological solutions collectively enhance the interactivity, accessibility and realism of maritime engineering education.

Implementation and Results

The project implementation was structured to ensure progressive achievement of educational and technical goals, addressing both practical and strategic dimensions.

Phase 1: Digitalization and 3D Modeling

- Component Selection: Identification and prioritization of hydraulic, mechanical and pneumatic systems essential for naval training, such as centrifugal pumps, piston pumps, hydraulic cylinders, compressors and valve systems.
- Model Development: High-fidelity 3D models of these components were created, capturing structural details, operational behaviors and maintenance functionalities.
- VR Environment Integration: The models were embedded into immersive VR applications, allowing interactive manipulation and simulation of real-world scenarios.

- Testing and Feedback: Initial user testing sessions with students and instructors provided critical feedback on usability, functionality and educational value, leading to iterative refinements of the models and environments.

Achievements:

- Creation of a foundational archive of bilingual VR models accessible for academic and professional training.
- Successful demonstration of VR simulations at the workshop "The Future of Immersive Technologies in Romania" held in May 2024.
- Initial integration of VR sessions into selected academic modules, enhancing student engagement and comprehension.

The early implementation results confirm that Virtual Reality significantly enhances the learning experience by offering practical, risk-free exposure to complex electromechanical systems. Students reported improved understanding of component functions and better preparation for real-world operational challenges.

Detailed 3D Modelling and Simulation Outputs

Throughout Phase I, several critical electromechanical components were successfully modelled, simulated and validated within VR environments:

- Centrifugal Pump: A complete 3D model illustrating the rotor, stator, collector chamber and dynamic fluid flow. The simulation visualized energy transformation mechanisms and fluid motion under operational conditions (see Figure 1).

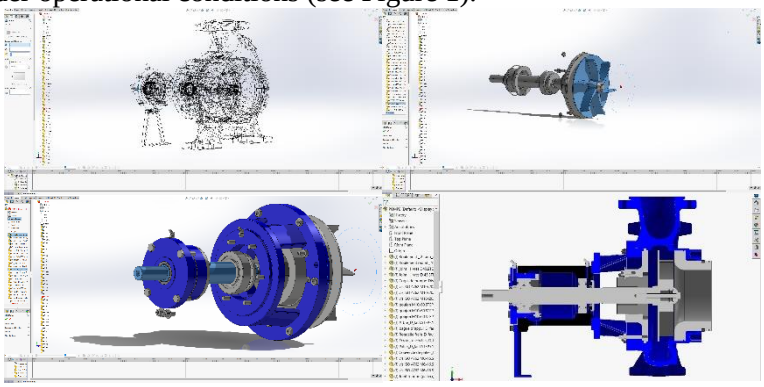

Figure 1. Centrifugal Pump

- Hydraulic Cylinder: Interactive 3D model of a linear hydraulic actuator, visualizing extension and retraction phases for force application (see Figure 2).

Figure 2. Piston Pump

- Gear Pump: Accurate modelling of gear rotation dynamics, illustrating the suction and pressure delivery processes as the gear teeth engage and release (see Figure 3).

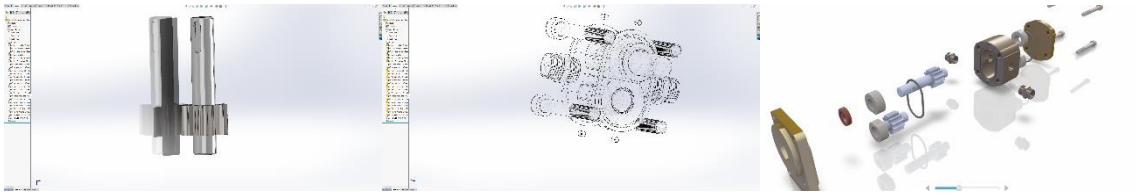

Figure 3. Gear Pump

- Compressor: Realistic simulation of gas compression processes, emphasizing volume reduction and internal energy increases during operation (see Figure 4).

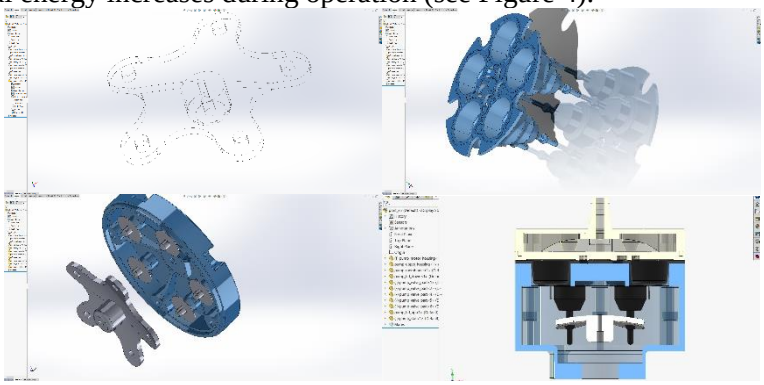

Figure 4. Air Compressor

- Ball Valve and Butterfly Valve: 3D operational models demonstrating fluid control and regulation mechanisms, with rotational movements of the ball or disc within pipelines (see Figure 5).

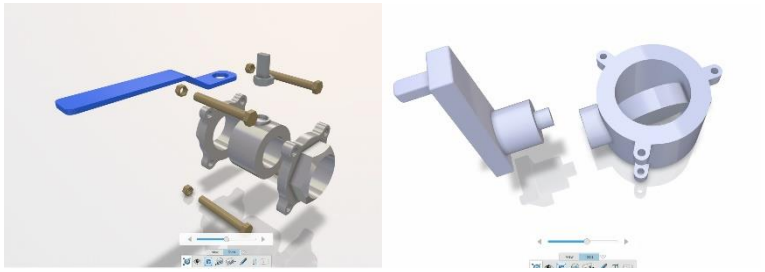

Figure 5. Valves

These 3D simulations allow users to interact dynamically with component functions, observing behaviour under various load, pressure and fault conditions. Animations were tested within VR scenarios, ensuring that users could manipulate views, inspect internal mechanisms and simulate operational cycles.

The models were designed to be bilingual (Romanian-English) and have been integrated into the Academy's VR educational platform to support didactic scenarios, including normal operations and emergency procedures

Impact and Innovation

The integration of Virtual Reality into maritime engineering education introduces transformative opportunities for both students and instructors. The project demonstrates that immersive simulation can overcome practical training limitations by offering:

- Enhanced accessibility to complex electromechanical systems.
- Risk-free environments for practicing critical operational and maintenance procedures.
- Significant cost savings compared to physical resource-based training.
- Development of bilingual technical skills necessary for global maritime careers.

Virtual Reality significantly augments students' operational understanding, emergency response skills and technical vocabulary in both Romanian and English. By merging theoretical instruction with dynamic, hands-on VR experiences, this project sets a new educational standard for naval engineering.

Phases in Progress:
Through these next phases, the project aims to refine and expand the repository of VR simulations, ensuring that training remains relevant, accurate and closely aligned with contemporary naval operational standards

Phase II: Virtual 3D Modelling
- Generating high-fidelity 3D models.
- Testing and validating the 3D models.
- Utilizing the models in VR applications simulating the functionality of onboard components and installations.
- Dissemination of results through academic and professional channels.

Phase III: Optimization and Adaptation for Didactic Use
- Analysing the created 3D models for their application in diverse VR scenarios and operational simulations.
- Preparing performance studies to optimize the educational impact of each 3D model.
- Testing the transposition of models into realistic VR training environments.
- Disseminating the optimized results to enhance broader educational integration.

Conclusions

The "Virtual Reality Integration in Maritime Engineering Education" project clearly demonstrates that innovative, immersive technologies are pivotal in reshaping the educational landscape for naval engineering. By providing access to realistic, interactive and risk-free environments, the project overcomes traditional training limitations, addressing critical needs for practical experience, technical competence and bilingual proficiency.

The early phases have already achieved significant milestones: detailed 3D modeling of critical shipboard components, integration into VR applications and positive feedback from academic users. Students and instructors alike have experienced substantial improvements in comprehension, operational readiness and engagement.

Moving forward, the continued development phases will ensure that the VR simulations become increasingly sophisticated, reflecting diverse operational scenarios and maintenance requirements. The optimization of educational materials and testing in real academic contexts will further strengthen the practical relevance of the models.

Moreover, this initiative supports the "Mircea cel Bătrân" Naval Academy's mission to align with European and international standards, preparing a new generation of engineers and naval officers who are equipped with the technical, operational and linguistic skills necessary for the maritime industry of tomorrow. Through continued innovation and commitment, VR-based education will firmly establish itself as a cornerstone of maritime training excellence.

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