International Journal of e-Navigation and Maritime Economy 10 (2018) 014–021

Available online at http://www.e-navigation.kr/
e-Navigation Journal

Original article

Development of a Virtual Teaching Platform for Remotely Operated Vehicles ☆

Yingfei Zan[a], Haitao Zhu[b*], Lei Song[c], Lihao Yuan[d]

[a] College of Shipbuilding Engineering, Harbin Engineering University, Harbin, China, zanyingfei@hrbeu.edu.cn

[b*] College of Shipbuilding Engineering, Harbin Engineering University, Harbin, China, zhuhaitao@hrbeu.edu.cn, Corresponding Author

[c] Naval Architecture & Marine Engineering College, Shandong Jiaotong University, Weihai, China, songlei2962@163.com

[d] College of Shipbuilding Engineering, Harbin Engineering University, China, Harbin, yuanlihao82@163.com

Abstract

Courses on the motion and operation of remotely operated vehicles (ROV) tend to feature abstract theoretical concepts, numerous formulas, combinations of mathematical and physical concepts and teaching that is disconnected from practice. As with the development of computer technology, the dynamic connection between the combination of the highly-realistic visual effects of simulation and theoretical classroom teaching has the aesthetic characteristics of a physical science. In this study, a virtual teaching platform for ROVs was developed on the basis of current virtual simulation technologies, as well as the needs of courses focused on ROV motion and operation. Based on detailed analyses of the functional and performance requirements of a virtual teaching platform for ROVs, the system was subdivided into six subsystems: remote-control simulation, dynamic and kinematic mathematical modeling, underwater operation tools simulation, visual scene display, teacher control and network administration, using an object-oriented design method featuring modularization and standardization. The subsystems facilitate modular development, integration and function extension, and support the openness, inheritance and reusability of the system. The platform is used to intuitively acquaint students with ROVs' kinetic characteristics and operating methods by means of intuitive 3D models, precise motion calculation, and real operating scenes. Based on teaching practice in colleges and universities, a typical work-task-oriented practical teaching system was developed, along with the application of course design and scenario design for the ROV virtual teaching platform. Through interactive operation, students can dynamically and intuitively observe the motion of ROVs during navigation, helping them to learn about hydrodynamic performance. With simulated ROV operation, students learn about the principles of dynamic mechanical tools as well as the relationships between the interaction forces of ROVs. This contributes to disciplinary progress in naval architecture and ocean engineering, as well as the development of students' practical engineering competence.

Keywords: Remotely operated vehicle; Mathematical model; Virtual teaching platform; Engineering practice; Platform development

---

1. Introduction

Courses on the motion and operation of remotely operated vehicles (ROVs) tend to feature abstract theoretical concepts, numerous formulas, combinations of mathematical and physical concepts and teaching that is disconnected from practice. As computer technology develops, the visual effects of simulation and the theory of teaching can be highly integrated (Conradi, 2009). The appropriate application of such modern teaching approaches to mechanics courses that feature theory and abstract concepts could be highly beneficial (Liu, 2017; Guasch, 2010). Several researchers have studied this issue from various perspectives, including teaching means and methods, teaching conditions, and scientific research and application and obtained significant results for teaching and related fields—see, for example, Parra (2017), Häfner (2009) and Jarmon (2009).

In this study, a virtual teaching platform for ROVs was developed on the basis of current virtual simulation technologies as well as the needs of courses focused on ROV motion and operation. The proposed virtual teaching platform is a complex platform that integrates instructional theory with 3D visual modelling techniques, network technology, control technology, virtual reality, real-time calculation and data processing. A kinematic mathematical model was established to reflect the vehicle's motion features, the rules of motional variations and the interactive relationships between the vehicle and the other entities. The mathematical model was not only key to the successful development of the proposed platform but also a core index measuring the platform's fidelity. Through interactive operation, students can dynamically and intuitively observe the motion of ROVs during navigation, helping them to learn about hydrodynamic performance. With simulated ROV operation, students learn about the principles of dynamic mechanical tools (e.g., manipulators) as well as the relationships between the interaction forces of ROVs.

2. Principles for Developing a Virtual Teaching Platform for ROVs

The virtual underwater environment, virtual operating tools, manipulation devices and teaching courses were designed based on the requirements of theoretical and experimental teaching. The teaching resources platform can be designed according to the teaching platform and subject attributes and expanded for different professional courses. To support the teaching effect, it was determined that a virtual teaching platform for ROVs should be designed in accord with the following principles (Jarmon, 2009):

(a) Normativity. First, a virtual teaching platform for ROVs should be designed strictly following the syllabi for undergraduate courses and the content of major courses, based on which practical engineering operations should be fully taken into account to expand and deepen knowledge (i.e., the combination of theory and practice).

(b) Applicability. To support students' career development, course design should pay attention to the development of new technologies and techniques in the field. Thus, to improve students' comprehensive knowledge and capacities, a virtual teaching platform for ROVs should satisfy engineering requirements by building working scenes based on theoretical knowledge.

(c) Accuracy. In combining theory and practice, all basic materials used to design the platform must be accurate; otherwise, students could be misled. To enable a virtual teaching platform derived from practice, an accurate kinematic ROV model should be built following the principles of ship dynamics. This should be based on a full investigation of ROVs' operating rules and of the underwater operating environment, using techniques such as underwater photography, among others.

(d) Extensibility. The design of a virtual teaching platform for ROVs should be modular and standardized with an open architecture to enable openness, inheritance and reusability, and to facilitate the integration and expansion of new functional modules. Resource sharing and the compatibility and expandability of hardware and software were also considered to supplement new models when the platform is updated in the future. Teachers should be able to use the control module to expand the teaching platform according to actual teaching circumstances.

3. Designing a Virtual Teaching Platform for ROVs

Based on detailed analyses of the functional and performance requirements of a virtual teaching platform for ROVs, the system was subdivided into six subsystems using an object-oriented design method featuring modularization and standardization. The subsystems facilitate modular development, integration and function extension, and support the openness, inheritance and reusability of the system.

3.1 ROV Remote-Control Simulation Subsystem

To simulate the manipulation environment, the layout, devices, instruments and signal display devices of an ROV remote-control console, as well as their operations and indications, should be consistent with those of a real ROV. When the operator manipulates various devices (e.g. remote operating lever, throttle, switches), not only should the instruments and signal lights work normally, but the sounds of different devices and the external environment should also be heard (to simulate underwater sounds).

As shown in Figure 1, the ROV remote-control console consists of hardware and software. The former consists of a 1:1 synthetic virtual remote-control console (including the manipulating devices and instruments), a seat and a computer for simulating signals from generators such as sonars, videos and operating handles.

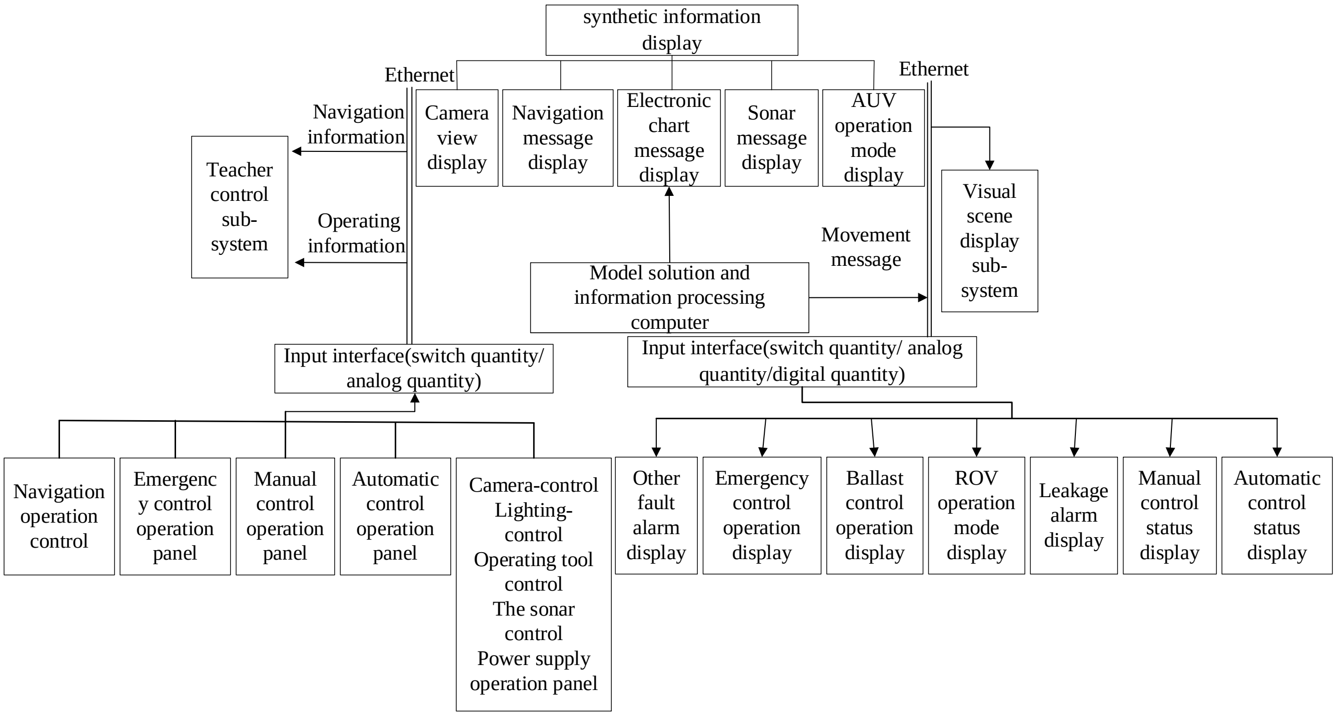

Figure 1: Block Diagram of the ROV Remote-Control Console

3.2 Dynamic and Kinematic Mathematical Modeling Subsystem

The proposed virtual teaching platform aims to present correct descriptions of ROV motion. For this, it was necessary to build a kinematic mathematical model that could reflect the vehicle's motion features, the rules of motional variations and the interactive relationships between the vehicle and the other entities. There were two key issues regarding the dynamic and kinematic mathematical models: model accuracy and the instantaneity of model calculation, both of which were rather difficult. A false motion model gives students incorrect information and a misunderstanding of ship theories, which can have adverse results (Mai, 2017). Therefore, the mathematical model was not only key to the successful development of the proposed platform but also a core index measuring the platform's fidelity.

As shown in Figure 2, the dynamic and kinematic mathematical modeling subsystem receives commands from the environment and from courses set by the teacher control system. It provides the remote-control devices, instruments and visual scene system with the real-time simulation results of mathematical models concerning multiple environments (e.g. the vehicle's state of self-propulsion and operating modes); thus simulating remote control, pipeline laying assistance, and other underwater operations.

3.3 Underwater Operation Tools Simulation Subsystem

Different tools are used during ROV operation (e.g. manipulator, cleaning device, hydraulic shear, cameras) (Matsebe, 2009). To give students an accurate representation of the tools' mechanical dynamic features, as well as the counterforce of the tools acting upon the vehicle, the following kinematic and dynamic models had to be built for the operating tools:

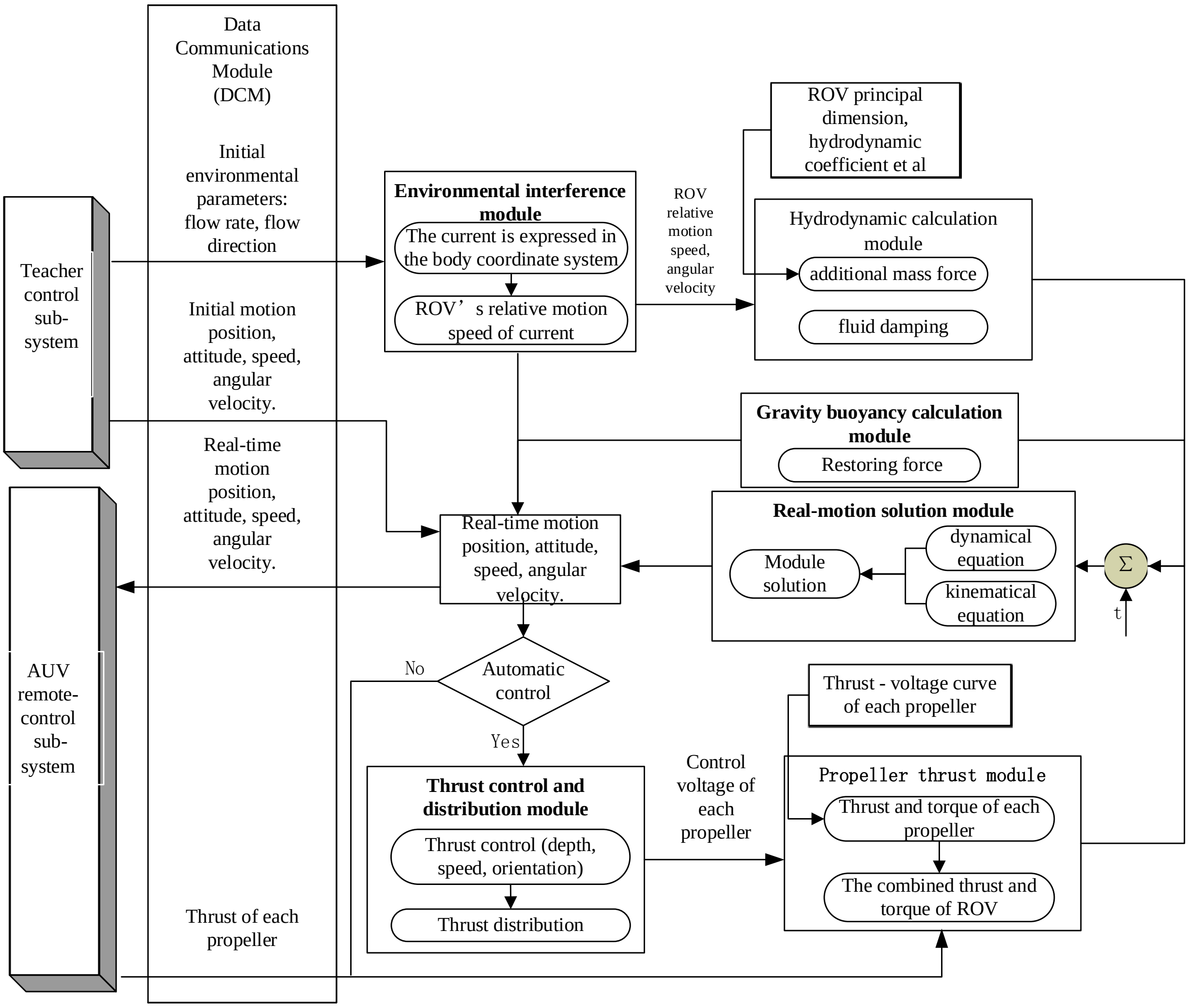

Figure 2: Computation of System Dynamics Model and Kinematic Mathematical Model

(a) Kinematic and dynamic models of the mechanical arm

(b) Kinematic and dynamic models of hydraulic shear

(c) Kinematical simulation of the other operating tools

(d) Simulation of underwater imaging, to build a model simulating imaging at a low illumination level

(e) Simulation of acoustic tracking and measuring devices, to simulate tracking, measuring, scanning, side scanning, sub-bottom profile, sounding and pipeline tracking

(f) Simulation of the CP probe, to simulate submarine structures or the potential processes of sacrificial anodes on the ship.

(g) Simulation of the nondestructive testing (NDT) sensor, to simulate the potential meter, ultrasonic thickness meter and component water leakage detection system

3.4 Visual Scene Display Subsystem

The visual scene display subsystem was developed to simulate the training scenes of the ROV (e.g., remote manipulation; pipeline laying assistance; observation, detection and interposition operations), providing students with scenes of underwater operation (e.g., the vehicle's navigation status, motion of the mechanical arm, interposition operation). With this system, multichannel visual scenes generated by a computer are displayed on an LCD display to form complete visuals. With such 3D visual information, students are immersed in the simulated real environment of underwater vehicle operation (Zhang, 2017; Kwasnitschka, 2007). Components of the visual scene display subsystem are shown in Figure 3.

3.4.1 Establishing a 3D Model Database

Based on the ROV visual simulation system's requirements for 3D models, to achieve hierarchical management, an OpenFlight format 3D model database was built that accommodates the simulation requirements. Models can be simply classified according to the 3D visual scene as follows:

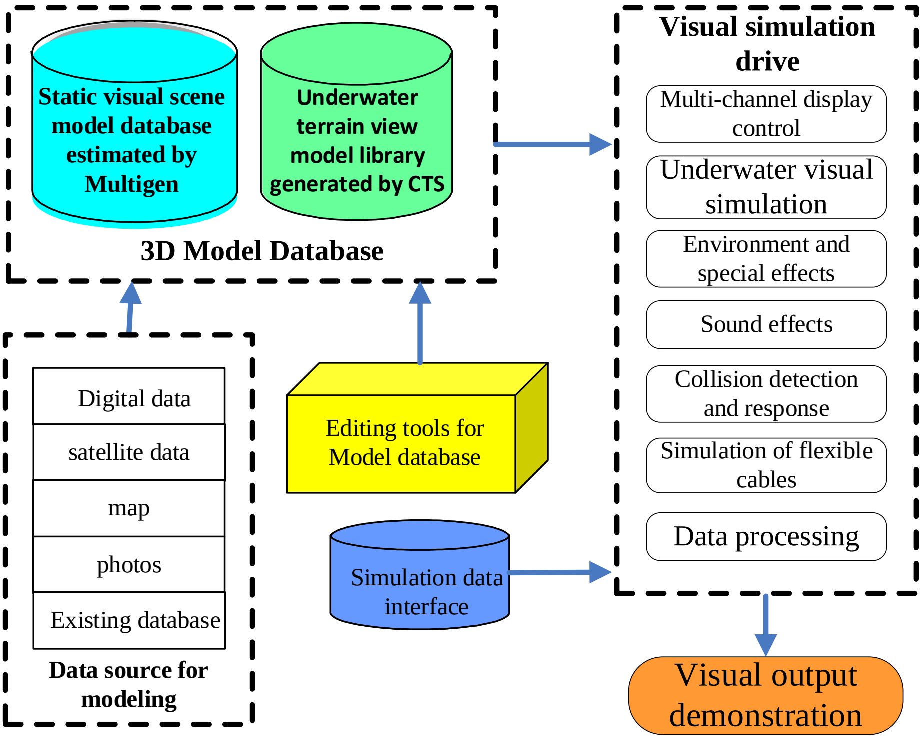

Figure 3: Composition of the Visual Display Subsystem

(a) Static visual scene model database: includes 3D models of the typical ROV, the mother vessel, the target ship, navigation aids, lifting devices, underwater operation tools, operating platforms and pipeline laying equipment.

(b) Visual database of large-scene topography: includes the ocean, seabed, islands and undersea creatures.

3.4.2 Visual Simulation Drive

The visual simulation drive was intended to perform the following functions:

(a) Multichannel display control: controls the output, update and synchronization of multichannel images.

(b) Sea wave simulation: simulates the dynamic effects of the ocean.

(c) Underwater visual simulation: simulates visual scenes of the vehicle operating underwater.

(d) Environment and special effects: simulates visual scene variations in plankton, rain, snow, visibility, brightness, fog, bow spray, wake, etc.

(e) Sound effects: simulates the sounds of the main engine of the mother vessel, collision, sirens, wind and waves and the vehicle's operation underwater.

(f) Collision detection and response: detects whether the underwater vehicle and the mother vessel collided with the training scene and the object, sends corresponding information to the kinematic mathematical model for calculation, and adjusts the attitude of the motion model.

(g) Virtual instruments: instrument development software was used to generate a user-friendly synthetic information display interface for the real-time display of the main ROV engine parameters, including the rotational speed of the main engine and the propeller's azimuth; it could also display water depth, ship speed, bearing, rudder angle, submergence depth, track, etc.

3.5 Teacher Control Subsystem

The teacher control subsystem consists of the console and interface. The former is equipped with a series of control buttons and indicating devices used to control various subsystems of the virtual teaching system, as well as fault detection and protection, to ease the burden on teachers. Mounted on the control panel, these buttons and devices enable teachers to perform easy operations and settings, allowing them to acquire an ROV's status more quickly when a student manipulates it. Teachers also can operate the system conveniently and monitor the entire simulation system online and offline.

Teachers depend on the control interface to teach; it plays a critical role in determining the learning effect. When launching training using the simulation system, teachers must assign tasks to trainees (e.g. remote-control navigation and underwater operation), set environmental parameters (e.g. visibility, wind, waves, current, weather), and observe how students manipulate the ROV simulation system using the remote monitoring console to perform timely analysis and give instructions.

3.6 Network Administration Subsystem

As a complex system comprising computer groups, the ROV virtual teaching platform features enormous information interactions between its subsystems. To facilitate information sharing, online data management and system instantaneity, a network administration subsystem was developed to connect the various subsystems in the network and reasonably arrange information exchange between them. The proposed network administration subsystem is composed of two-gigabit network switches, multiple-gigabit network interface cards, and a network data administration system.

4. Course Design

By summarizing the content of ROV operation, operating procedures and specifications based on the principle of ROV teaching platform construction, courses were designed and classified into single-course training and underwater operation training (Schjølberg, 2015).

4.1 Single-Course Training

(a) Training in remote-operated navigation: includes diving, depth-keeping cruise and floating after load rejection to acquaint students with an ROV's basic moving capabilities and underwater navigation environment.

(b) Training in the application of underwater operation tools: includes selection of underwater operation tools, mechanical arm operation, hydraulic shear operation, camera operation and detection device operation to familiarize students with those tools and their mechanical dynamic characteristics.

4.2 Underwater Operation Training

(a) Platform jacket installation: includes seabed survey, platform jacket launching operation and survey after the installation of the platform jacket.

(b) Petroleum pipeline installation: includes pipeline laying, releasing the initial cable buckle, releasing the expansion bend, installing the cement briquetting on the expansion bend, surveying after pipeline laying and detecting petroleum pipeline leaks.

(c) Cable laying: includes pre-survey, emergency fault handling, landing cables on the platform for operation, grounding site monitoring and post-survey (e.g. cable burial depth and locations of important cables).

(d) Detection of oil field structures: includes checking for structural deformations, depressions, loss of sacrificial anodes, internal cracks, and wall thickness after erosion.

(e) Replacing divers to perform underwater operations: includes loosening/tightening bolts and opening/closing underwater valves using the hydraulic box wrench, cutting members and cleaning and ditching to bury cables.

5. Application Example

The object of this paper's research is an ROV named Quantum, manufactured by Soil Machine Dynamics Limited.

Figure 4 shows students manipulating the ROV remote-control station. They received training in underwater navigation and installation based on a course set by the teacher control console (Figures 5 and 6). Based on teaching practice in colleges and universities, a typical work-task-oriented practical teaching system was developed, along with the application of course design and scenario design for the ROV virtual teaching platform. This platform can help to advance naval architecture and ocean engineering, in addition to developing students' abilities in engineering practice.

Figure 4: A Student Operating the ROV Remote-Control

Board

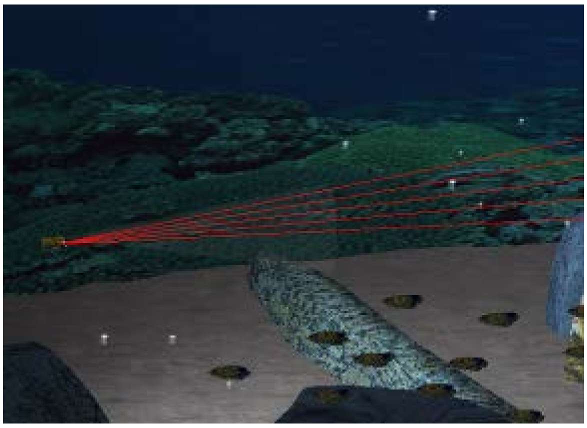

Figure 5: ROV Seafloor Navigation

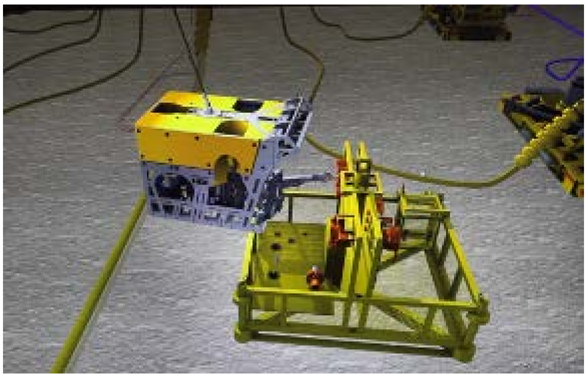

Figure 6: Simulation of ROV Installation Underwater

6. Conclusion

The ROV virtual teaching platform was developed for this study to verify and demonstrate the complex and abstract theories of various disciplines (e.g., hydrodynamics and mechanical dynamics) as well as experimental knowledge. The platform was subdivided into six subsystems: remote-control simulation, dynamic and kinematic mathematical modeling, underwater operation tools simulation, visual scene display and teacher control and network administration using an object-oriented design method featuring modularization and standardization. This can help to deepen students' understanding of complex theoretical knowledge, combine theory and practice, stimulate students' enthusiasm for learning and develop serious and pragmatic learning attitudes. A typical work-task-oriented practical teaching system was developed, along with the application of course design and scenario design for the ROV virtual teaching platform. This system can help promote the advancement of naval architecture and ocean engineering.

Submitted: November 06, 2018; Accepted: October 6, 2014

7. Acknowledgements

The first author would like to express his gratitude to the National Key R&D Program of China (Grant No. 2018YFC0309400), the National Natural Science Foundation of China (Grant No. 51809067) and the National Science and Technology Major Project of China (Grant No. 2016ZX05057020) for financial support for this study.

References

Conradi, E., Kavia, S., Burden, D., et al (2009), Virtual patients in a virtual world: Training paramedic students for practice, *Medical Teacher*, Vol. 31, No. 8, pp. 713-720.

Liu, X. and Wang, Y. (2017). Development of the Virtual Teaching Resource Database for Fluid Mechanics, *Higher Education*, No. 4, pp. 76-77.

Guasch, T., Alvarez, I. and Espasa, A. (2010). University teacher competencies in a virtual teaching/learning environment: Analysis of a teacher training experience, *Teaching and Teacher Education*, Vol. 26, No. 2, pp. 199-206.

Warburton, S. (2009). Second Life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching, *British journal of educational technology*, Vol. 40, No. 3, pp. 414-426.

Parra, C (2017). Virtual Teaching in Postgraduate Programmes: The Importance of Social Collaboration in Virtual Communities, *Procedia-Social and Behavioural Sciences*, Vol. 237, pp. 1430-1438.

Häfner, P., Häfner, V. and Ovtcharova, J. (2013). Teaching methodology for virtual reality practical course in engineering education, *Procedia Computer Science*, Vol. 25, pp. 251-260.

Jarmon, L., Traphagan, T., Mayrath, M., et al. (2009). Virtual world teaching, experiential learning, and assessment: An interdisciplinary communication course in Second Life, *Computers & Education*, Vol. 53, No. 1, pp. 169-182.

Mai, C., Pedersen, S., Hansen, L., et al (2017). Modelling and Control of Industrial ROV's for Semi-Autonomous Subsea Maintenance Services, *IFAC-Papers on Line*, Vol. 350, No. 1, pp. 13686-13691.

Matsebe, O., Kumile, C. M., Tlale, N. S. (2008). A Review of Virtual Simulators for Autonomous Underwater Vehicles (ROVs), *IFAC Proceedings Volumes*, Vol. 41, No. 1, pp. 31-37.

Zhang, J., Li, W., Yu, J., et al (2017). Study of manipulator operations maneuvered by a ROV in virtual environments, *Ocean Engineering*, Vol. 142, pp. 292-302.

Kwasnitschka, T., Hansteen, T. H., Devey, C. W., et al (2013). Doing fieldwork on the seafloor: Photogrammetric techniques to yield 3D visual models from ROV video. *Computers & Geosciences*, Vol. 52, pp. 218-226.

Schjølberg, I. and Utne I. B. (2015). Towards autonomy in ROV operations, *IFAC-Papers on Line*, Vol. 48 No. 2, pp. 183-188.