# *Virtual Platform of a Remotely Operated Vehicle*

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***Abstract*—A remotely operated vehicle (ROV) carrying an underwater manipulator plays an important role in underwater operations. In this paper, we develop a virtual platform of a ROV to animate operation tasks under the sea. The ROV model refers to the structure of a typical ROV which performs operation tasks below the ocean's surface 1000 meters and the manipulator model refers to a master-slave servo hydraulic manipulator with seven functions developed by Shenyang Institute of Automation (SIA), Chinese Academy of Sciences. The virtual platform is used for training an operator to teleoperate the ROV under the sea by coordinating a pan-tilt camera, the ROV main body, and the underwater manipulator. In order to demonstrate the feasibility and effectiveness of the virtual platform, we present two typical underwater operation tasks: maintaining a subsea platform and clearing a tethered mine.**

***Keywords—Virtual Platform; ROV; Underwater Manipulator with Seven Functions; Underwater Operations***

## I. INTRODUCTION

The ROV, which is a major tool for underwater operations, mainly consists of submersible, umbilical cable, and surface console. The cable provides power to the submersible and establishes communication between the submersible and console. Because the ROV can run in deep and dangerous underwater environments for a long time to complete operations with high intensity and large quantity, it has been widely used for observing ocean environments, exploiting marine resources, inspecting and maintaining underwater platforms, laying or clearing marine mines, etc. [1-4]. An operating system, including the manipulator and operation tools, is the important part of the ROV [5]. The ROV usually carries one or two manipulators with degrees of freedom (DOF) from three to seven according to task specifications. The underwater manipulator has to use some special tools to complete complex and diverse underwater operation tasks, such as cleaning brush, shearing machine, etc., based on live videos about surrounding information sent back the surface console.

In order to simulate the underwater operation processes of the underwater manipulator mounted on the ROV, we develop the virtual platform using the Webots simulator [6]. The ROV model refers to the structure of a typical ROV which can operate below the ocean's surface 1000 meters and the manipulator model refers to the structure a master-slave servo hydraulic manipulator with seven functions, which is able to perform operations below the ocean's surface 7000 meters. The developed virtual platform has the following advantages. 1) The virtual platform is a low-cost, safe, and feasible tool, so that the operator can use it to conveniently set training environments to practice how to coordinate a pan-tilt camera, the ROV main body and the underwater manipulator for accomplishing operation tasks. 2) The virtual platform can serve as an effective tool to investigate and evaluate motion control methods for both the ROV and manipulator. 3) The virtual platform can be used as an auxiliary control system to display the motion state and trajectory of the real ROV main body and the underwater manipulator in the deep sea [7]. In order to demonstrate the feasibility and effectiveness of the virtual platform, we present two typical underwater operation tasks: maintaining a subsea platform and clearing a tethered mine.

## II. PROBLEM STATEMENTS

An operator needs to go through comprehensive training processes before pratically operating both the ROV and manipulator. However, trainning the operator by using a real ROV carrying on a manipulator is not only exeperive, but also dangerous, so it is necessary to develop a virtual platform to simulate underwater operation processes realistically. GRI Simulations Inc. developed a ROV virtual platform, carrying a virtual manipulator referring to the structure of TITAN 4, using the VROV simulator as a training platform for an operator [8]. GRI as a commercial company charges a high fee for using its virtual platform. It is not convenient to use the virtual platform in some cases, because customers need to configure the virtual platform for different training purposes, such as to modify the manipulator with different mechanical structures and kinematic parameters. Therefore, in this paper we develop our virtual platform, which is cheap and can be easily reconfigured. The work in [9] constructed a ROV virtual perform using the Webots, but its structure too simple to incorparate with a manipulator to carry out complex and diverse underwater operations. The ROV visual simulator [10] developed by Multigen Creator3.5, Vega Prime3.0, OpenGL and VC++ provided a user with three training scenarios: remote operation, observation, and detection, but it did not incorparate with any manipulator to carry out underwater operations. Currently, there migh be no good way to evaluate motion control methods for both the ROV and manipulator due to the limitation of experimental conditions. In order to test the physical ROV and manipulator smoothly in the real experimental conditions, we

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need a preliminary validation based on the virtual platforms [11, 12]. In this paper, we develop the ROV virtual platform carrying on an underwater manipulator using the 3D robot simulation software package — Webots to provide an operator with the low-cost, safe, and conveniently configurable training platform.

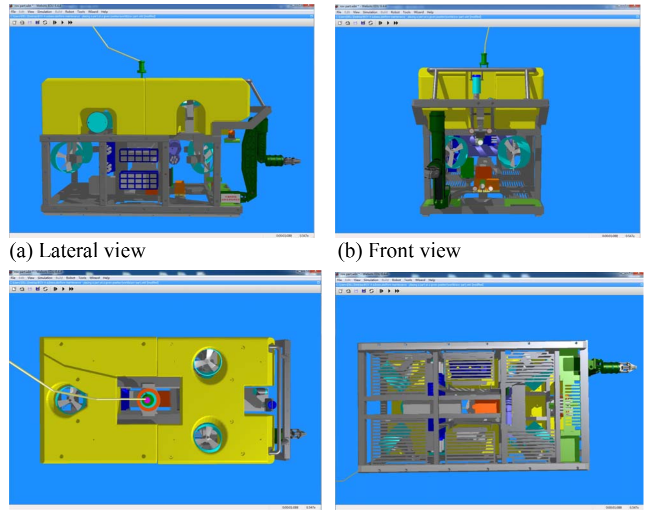
## III. VIRTUAL PLATFORM

Webots is a professional mobile robot simulation software package, developed by Ceberbotics Ltd [6], for fast prototyping and realistically simulating mobile robots. It allows a user to create 3D virtual worlds with physics properties such as shape, color, texture, mass, friction coefficients, etc. These robots may be equipped with a number of sensor and actuator devices, such as distance sensors, cameras, servos, touch sensors, etc. The user can design mobile robots with passive or active features and program each robot individually to exhibit the desired behavior. In this paper, we use Webots to develop the virtual platform.

### *A. ROV Model*

The ROV virtual model used for developing the platform refers to the structure of a typical ROV, which can operate below the ocean's surface 1000 meters. It implements movements with six degrees of freedom in three demensions (3D), including three translational motions (surge, heave and sway) and three rotation motions (roll, pitch and yaw). Fig. 1 shows the lateral view of the ROV, the front view of the ROV, the top view of the ROV, and the bottom view of the ROV. The ROV model is composed of the seven main components: buoyancy blocks, bearing frame, propulsion module, underwater manipulator with seven functions, sealed cabin, umbilical cable and auxiliary fittings. The buoyancy blocks, including front and behind buoyancy materials, are located on the top of the ROV to produce sufficient buoyancy. The bearing frame is the main load-bearing body for launching and retrieving the ROV and the base for mouning ROV system equipment, such as the buoyancy blocks, the sealed cabin, operation tools, etc. The propulsion module is composed of seven propellers to ensure the agility of the ROV in 3D, including four horizontal direction propellers and three vertical direction propellers. The underwater manipulator with seven functions is located in the lower-front of the ROV, which is an indispensable tool for underwater operations. The sealed cabin is located at the upper-back of the ROV, which is used to protect the internal electronic components and detection equipment. The umbilical cable is located on the top of the ROV and connected to the bearing frame, which is used to provide power for the submersible and to establish communication between the submersible and the console. The auxiliary fittings distributed over the bearing frame mainly include motor pumps, valve boxes, junction boxes, branch boxes, compensators, headlamps, pan-tilt and camera, sensor holders, etc.

A scene tree graphically represents a simulated world, including robots and environment. A list of nodes is organized in hierarchical structures. Each node contains fields, and the fields contain other nodes. We implement the ROV virtual model by adding a Robot node and expanding all the components of ROV as its children.



(a) Lateral view (b) Front view

(c) Top view (d) Bottom view

Fig. 1. ROV virtual model

The geometry and appearance of each component are defined by its Shape node. We add a Geometry node as the geometry field of each created Shape node. The sealed cabin, umbilical cable and any parts of the auxiliary accessories are constructed by geometrical primitive nodes: Box node, Capsule node, Cylinder node, etc., due to their simple structures. But for the components with complex structures, such buoyancy material, scaffold, propellers, etc., we use the following two ways to construct them: 1) using the IndexedFaceSet node, which represents a 3D shape formed by polygons with a list of vertices; 2) using the SolidWorks software to model them as VRML97 format and to import them into the Webots environments. We add an Appearance node as the appearance field of each created Shape node, and then add a Material node to the material field of each created Appearance node. The visual attributes (like color, brightness, texture, etc.) of all the components are specified by their Material nodes. We make the buoyancy material to yellow by setting its Material node as follows: ambientIntensity field to 1; diffuseColor field to (0.28, 0.28, 0.0); emissiveColor field to (0.04, 0.04, 0.04); shininess field to 0.4; specularColor field to (0.5 0.5, 0); transparency field to 0; texture field to NULL. Similarly, we modify the visual attributes of other components. The position and orientation of each component (and of its children) are determined by the translation and rotation fields in a Solid node. A Transform node changes the relative position and orientation of each component. Other attributes, such as physical properties, physical bound, can be moved or not, etc., can be used to represent each component by modifying corresponding fields in Solid nodes.

A Servo node to a joint forms a degree of freedom (DOF) for a mechanical simulation. The joint placed between the parent and children nodes move the children objects with respect to their parent. The type field is a string specifying the Servo type and can be either "rotational" (default) or "linear." A "rotational" Servo simulates rotating motion and a "linear" Servo simulates sliding motion. We apply three "rotational" Servos and three "linear" Servos to simulate ROV's rotations and translations along the x, y, and z axes, and two "rotational"

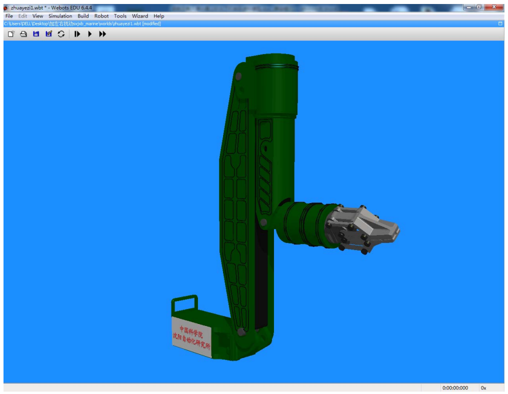


Fig. 3.Virtual model of the master-slave servo hydraulic manipulator with seven functions developed by SIA

Servos to the pan-tilt camera to implement its yaw and pitch motions, several "rotational" Servos to the umbilical cable to simulate its movement when the ROV is under operation. We apply a Camera node with color type to the pan-tilt camera to feedback information from the virtual world. The "youbot" controller program in C controls the ROV and the manipulator to simulate operation tasks when a simulation starts.

### *B. Underwater Manipulator Model*

An underwater manipulator is an indispensable tool for ROV underwater operations. Its capability determines the overall operational performance of the ROV system. Our virtual manipulator model refers to the master-slave servo hydraulic manipulator with seven functions developed by SIA, as shown in Fig. 2. In order to develop the virtual platform, we place the underwater manipulator at the lower-front of the ROV. The manipulator consists of six rotary joints and one parallel gripper with eight axes of rotation. The manipulator operations are performed by controlling the shoulder yaw, shoulder pitch, elbow pitch, forearm rotation, wrist yaw, wrist rotation, gripper releasing, gripper gripping, manipulator stop and manipulator reset. The wrist with three DOFs usually has the following four forms defined by the bent structure (B) and the rotational structure (R): BBR, BRR, RBR and RRR. The SIA manipulator adopts the RBR type, so the back three joints determine the pose of the end gripper and the front three joints determine the position of the wrist origin.

The virtual manipulator populates the child's list of the Robot node. Since the manipulator mechnical structure is complex, we construct the manipulator using the SolidWorks software, save it as VRML97 format, and import it into the Webots environments. We choose green color with image texture for the virtual manipulator.

In order to control the manipulator, we develop its kinematic model according to the D-H notation [13], which describes the spatial relationship between two adjacent links with a 4×4 homogeneous transformation matrix. We define the coordinate systems of connecting rods to the underwater manipulator with seven functions [14], as shown in Fig. 3. We deduce the corresponding homogeneous transformation matrix of the gripper coordinate system relative to the reference coordinate system. The parameters of each connecting rod to

TABLE I. PARAMETERS OF EACH CONNECTING ROD TO MANIPULATOR

| $i$ | $a_i$/(mm) | $\alpha_i$/(°) | $d_i$/(mm) | $\theta_i$/(°) | Range of each joint variable/(°) |
|---|---|---|---|---|---|
| 1 | 144 | -90 | 0 | $\theta_1$ | -60～60 |
| 2 | 940 | 0 | 0 | $\theta_2$ | -90～30 |
| 3 | 126 | -90 | 0 | $\theta_3$ | -30～90 |
| 4 | 0 | 90 | 479 | $\theta_4$ | -90～90 |
| 5 | 0 | -90 | 0 | $\theta_5$ | -90～30 |
| 6 | 0 | 0 | 396 | $\theta_6$ | 360 continuous rotation |

the manipulator are listed in TABLE I [15], where $i$ represents the number of the connecting rod, $\theta_i$ represents a rotation angle around the $z^{i-1}$ axis to align the $x^{i-1}$ and $x^i$ axes, $d_i$ represents a translation distance along the $z^{i-1}$ axis to bring the $x^{i-1}$ and $x^i$ axes into coincidence, $a_i$ represents a translation distance along $x^i$ axis to bring the two origins into coincidence, and $\alpha_i$ represents a rotation angle around the $x^i$ axis to make the two coordinate systems completely coincide. In order to implement the manipulator kinematics, we use the cascading structure, i.e., the second connection rod is a child of the first connection rod, the third connection rod is a child of the second connection rod, etc., and add a Servo node with the "rotational" type between every two adjacent rods, and set the rotational torque and the rotation range value of each Servo node. Eight Servo nodes with the "rotational" type in the gripper maintain the gripping parts in parallel status during operation.

We derive the homogeneous transformation matrix T of the gripper coordinate system relative to the reference coordinate system according to the method in [14],

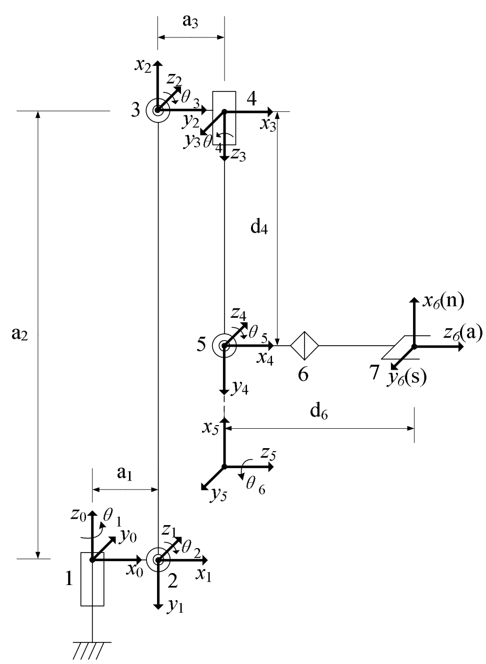



Fig. 2. Coordinate systems of the connecting rods to the underwater manipulator

$$T = \begin{bmatrix} {}^0x_6 & {}^0y_6 & {}^0z_6 & {}^0p_6 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} n_x & s_x & a_x & p_x \\ n_y & s_y & a_y & p_y \\ n_z & s_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

The 3×3 matrix $[{}^0x_6\ {}^0y_6\ {}^0z_6]$ in "(1)" represents the orientation of the sixth coordinate system relative to the zeroth coordinate system. The vector ${}^0p_6$ represents the origin of the sixth coordinate system relative to zeroth coordinate system. For conveniently expressing "(1)", we replace sine($\alpha_i$) and cos($\alpha_i$) with -1, 0 or 1, and define the following notations:

$$n_x = C_1[C_{23}(C_4C_5C_6 - S_4S_6) - S_{23}S_5C_6] + S_1(S_4C_5C_6 + C_4S_6) \quad (2)$$

$$n_y = S_1[C_{23}(C_4C_5C_6 - S_4S_6) - S_{23}S_5C_6] - C_1(S_4C_5C_6 + C_4S_6) \quad (3)$$

$$n_z = -S_{23}(C_4C_5C_6 - S_4S_6) - C_{23}S_5C_6 \quad (4)$$

$$s_x = C_1[-C_{23}(C_4C_5S_6 + S_4C_6) + S_{23}S_5S_6] + S_1(-S_4C_5S_6 + C_4C_6) \quad (5)$$

$$s_y = S_1[-C_{23}(C_4C_5S_6 + S_4C_6) + S_{23}S_5S_6] - C_1(-S_4C_5S_6 + C_4C_6) \quad (6)$$

$$s_z = S_{23}(C_4C_5S_6 + S_4C_6) + C_{23}S_5S_6 \quad (7)$$

$$a_x = -C_1(C_{23}C_4S_5 + S_{23}C_5) - S_1S_4S_5 \quad (8)$$

$$a_y = -S_1(C_{23}C_4S_5 + S_{23}C_5) + C_1S_4S_5 \quad (9)$$

$$a_z = S_{23}C_4S_5 - C_{23}C_5 \quad (10)$$

$$p_x = -C_1[d_6(C_{23}C_4S_5 + S_{23}C_5) + S_{23}d_4 - a_2C_2 - a_3C_{23} - a_1] - S_1S_4S_5d_6 \quad (11)$$

$$p_y = -S_1[d_6(C_{23}C_4S_5 + S_{23}C_5) + S_{23}d_4 - a_2C_2 - a_3C_{23} - a_1] + C_1S_4S_5d_6 \quad (12)$$

$$p_z = d_6(S_{23}C_4S_5 - C_{23}C_5) - C_{23}d_4 - a_2S_2 - a_3S_{23} \quad (13)$$

where $C_i \equiv \cos\theta_i$, $S_i \equiv \sin\theta_i$, $C_{ij} \equiv \cos(\theta_i + \theta_j)$, and $S_{ij} \equiv \sin(\theta_i + \theta_j)$.

## IV. VALIDATION AND EXPERIMENT

In order to test the virtual platform, we remotely control the ROV to carry out two typical operation tasks: 1) maintaining a subsea platform and 2) clearing a tethered mine. For current implementation, we use the buttons on the keyboard to operate the ROV main body, the underwater manipulator, and the pan-tilt camera. The buttons' allocations to the corresponding operations and are listed in TABLE II.

TABLE II. ALLOCATIONS OF BUTTONS ON KEYBOARDS TO CORRESPONDING OPERATIONS

| **ROV Body** | | **Underwater Manipulator** | | **Cradle Head** | |
|---|---|---|---|---|---|
| ***operations*** | ***buttons*** | ***operations*** | ***buttons*** | ***operations*** | ***buttons*** |
| hover | End | shoulder yaw | Q/W | yaw | U/I |
| surge | ↑ / ↓ | shoulder pitch | E/R | | |
| roll | Num 1/ 2 | elbow pitch | A/S | pitch | J/K |
| sway | →/← | forearm rotation | D/F | | |
| pitch | Num 4/ 6 | wrist yaw | Z/X | stop | N |
| heave | PgUp/PgDn | wrist rotation | C/V | | |
| yaw | Num 7/ 8 | gripper releasing /gripping | T/Y | reset | M |
| | | stop/ reset | G/H | | |

*1) Maintaining a subsea platform*

One of the essential operation tasks of the ROV is to inspect and to maintain subsea platforms, so the first simulation experiment presented herein is to how operate the ROV to maintain a subsea platform. We construct a virtual environment for this operation mission described as follows: picking-up a machine part form its initial state in a basket and placing it in the slot on an apparatus, as shown in Fig. 4(a). In doing it, we choose the settings of Webots world for this operation mission below: 1) setting the skyColor to blue; 2) defining a parallel light with its ambientIntensity to 2.0, castShadows to TRUE, and direction to {1.8, -2, -1.5}; 3) displaying the seafloor with an image texture; and 4) adding three cameras in the virtual environment to observe the operation process. The lower-left window of Fig. 4(b) displays images taken by the first camera to show motions of pan-tilt camera and headlamps. The upper-right window of Fig. 4(b) displays live videos taken by the second camera to show configurations of the underwater manipulator. The lower-right window of Fig. 4(b) displays live videos taken by the third camera to show gripper motions. The upper-left window of Fig. 4(b) displays live videos taken by the pan-tilt camera to provide surroundings' information. The process of the operation mission is described as follows. An operator manipulates the pan-tilt camera to search for the machine part in the basket, then sails the ROV to the basket and operate the manipulator to grasp the part, and then places it in the apparatus slot, as shown in Fig. 4(a) – 4(d).

*2) Cutting a tethered mine chain*

One of the important tasks for the ROV is to remove marine mines, so the second simulation experiment presented herein is to cut a chain of a tethered mine, which is a kind of marine mine fixed on a certain depth, supported on an anchor chain from an anchor resting on the bottom. We use a cutting tool gripped by the underwater manipulator to cut off the anchor chain when removing a tethered mine, and then explode the tethered mine after it emerges from the water. We construct

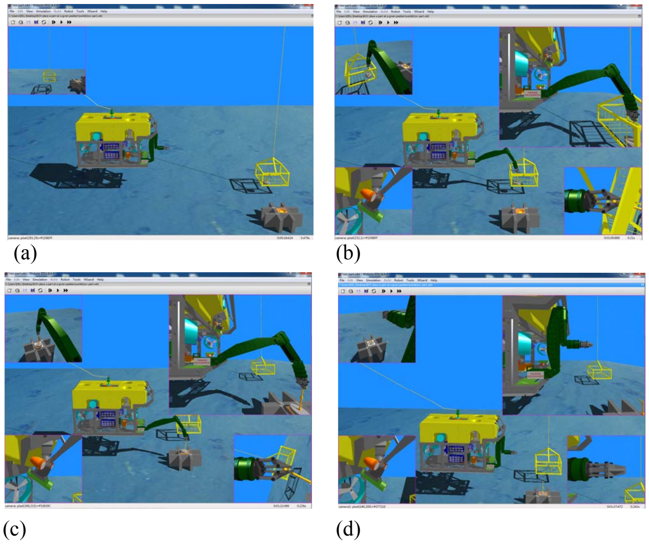


Fig. 4. Maintaining a subsea platform

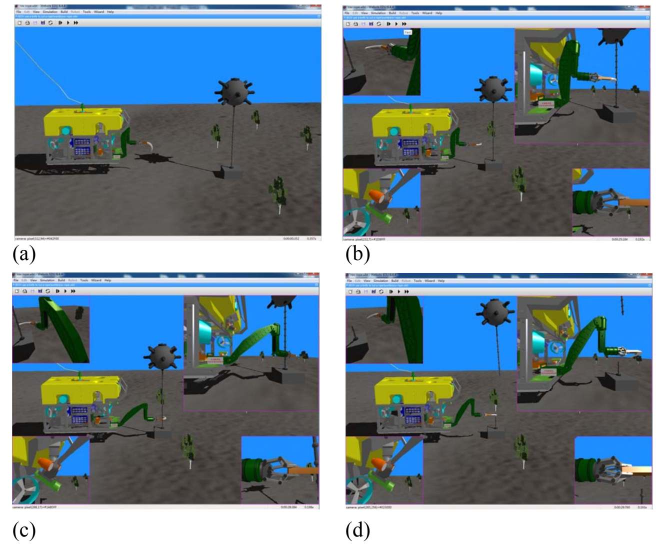


Fig. 5. Cutting a tethered mine chain

the simulated world with a tethered mine, four marine plants and a cutting tool used for cut off the anchor chain, as shown in Fig. 5(a). We choose the settings of the Webots world for this operation mission below: 1) setting the skyColor to blue; and 2) displaying the seafloor with a soil image texture; adding three cameras in the virtual environment to observe operation process, as shown in Fig. 5(b). The operation process is described as follows. An operator operates the pan-tilt camera to confirm the location of the tethered mine, then sails the ROV to it, and uses the cutting tool gripped by the manipulator to cut off the anchor chain, as shown in Fig. 5(a) – 5(d).

## V. CONCLUSION

In this paper, we develop a virtual platform of the ROV carrying the underwater manipulator. The simlaution results show that the virtual platform is a useful tool to train an operator to remotely conduct operation tasks under the sea. Our further research will implement the dynamics of the ROV and the manipulator.

## REFERENCES


[1] T. Salgado-Jimenez, J. L. Gonzalez-Lopez, L. F. Martinez-Soto, E. Olguin-Lopez, P. A. Resendiz-Gonzalez and M. Bandala-Sanchez, “Deep water ROV design for the Mexican oil industry,” OCEANS 2010 IEEE-Sydney, pp. 1-6, 2010.

[2] S. J. Park, T. K. Yeu, S. M. Yoon, S. Hong and K. Y. Sung, “A study of sweeping coverage path planning method for deep-sea manganese nodule mining robot,” OCEANS 2011. IEEE, pp. 1-5, 2011.

[3] H. R. Talkington, L. Jolla, “Tethered mine hunting system,” U.S. Patent 3,880,103. 1975-4-29.

[4] G. Posseme, C. Labiau, G. Kervern, G. L. Bihan, “Method and system for destroying submerged objects, in particular submerged mines,” U.S. Patent 5,844,159. 1998-12-1.

[5] Y. Yan, P. S. Ma, D. Y. Wang, X. G. Gao, “Development of Deep Sea ROV and Its Working System,” ROBOT, vol. 27, pp. 82-89, Jan. 2005.

[6] Webots. http://www.cyberbotics.com. Commercial Mobile Robot Simulation Software.

[7] X. Ge, W. Guo, “Design of Assisted Control System of ROV Based on Virtual Reality,” Machinery Design & Manufacture, vol. 11, pp. 91-93, 2012.

[8] GRI Simulations Inc., In Manipulator Trainer, http://www.grisim.com/products.html#ManipTrainer, 2014.

[9] Hamzah M, Salzahrin M, Zakaria M, et al, “3D Virtual Simulation Software for Underwater Application,” 2008.

[10] Y. Chi, “Research on Operation Scene Simulation Technology of ROV,” Harbin engineering university, 2013.

[11] H. Shim, B. H. Jun, P. M. Lee, et al, “Workspace control system of underwater tele-operated manipulators on an ROV,” Ocean Engineering, vol. 37, pp. 1036-1047, 2010.

[12] M. Hildebrandt, L. Christensen, J. Kerdels, J. Albiez, F. Kircher, “Realtime motion compensation for ROV-based tele-operated underwater manipulators,” OCEANS 2009-EUROPE. IEEE, pp. 1-6, 2009.

[13] R. S. Hartenberg and J. Denavit, “A kinematic notation for lower-pair mechanisms basedon matrices,” Journal of Applied Mechanics, vol. 22, pp. 215-221, 1955.

[14] J. S. Fu, “Robotics: Control, Sensing, Vision, and Intelligence,” China Science and Technology Press, Beijing, 1989.

[15] L. Q. Huo, “Research on independent operation method of underwater manipulator based on monocular vision,” Shenyang institute of automation Chinese academy of sciences, Shenyang, 2012.