Supervisory Control Based Virtual Reality for Underwater Tele-operation Systems

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ABSTRACT

Recently, lots of experiences in the synergy between the fields of Robotics and Virtual Reality have been working. Those researches have shown that the symbiosis of robot techniques with VR techniques can break new grounds in the field of robotics. In this paper, we built a system with virtual reality man-machine interface for underwater robot tele-operation. One of our purposes is to best setup a virtual reality man-machine interactive control for tele-present by proposed method: VSCM (Virtual Supervisor Control Method). Based on VSCM, using technology of fusing information coming form both real sensors and virtual sensors the effectiveness and precision of underwater robot are improved.

Keywords: Virtual Reality, virtual supervisory, tele-operation, underwater robot

1. INTRODUCTION

Ocean oil and gas productions are moving to the water depth beyond the reach of human divers. Thus underwater robot is gradually replacing divers for tasks such as the sub-sea inspection, maintenance, and repair task associated with offshore oil installations. An underwater robot usually consist of a vehicle and manipulators, the vehicle generally called remotely operated vehicle (ROV) which has its own propulsion system and operated by a human pilot on board of a support vessel or on a fixed structure. Manipulators were settled on ROV. After ROV enter a workspace the manipulators execute operation tasks by manually or automatically. For a manipulator to do these sub-sea tasks effectively, a good tele-operation system is essential.

In the last ten years, lots of experiences in the synergy between the fields of Robotics and Virtual Reality (VR) have been working. Those researches have shown that the symbiosis of robot techniques with VR techniques can break new grounds in the field of robotics. An integrated robotic manipulator system using virtual reality concept has been studied by Mohan M. Trivedi and ChuXin Chen (1), utilizing real-time simulation and visualization technology they created a flexible and intelligent advanced user interface and discussed the possibility of development of an environment where experimentation with both real and virtual world system. Bradley J.Nelson and Pradeep K.Khosla (2) described and experimentally verified a framework of telerobotic manipulation with virtual environments using disparate sensing modalities. Within this framework, the real world was represented by dynamically updated 3D geometric models of objects in the environment. Kazuhiro Kosuge and his colleagues (3) proposed a control algorithm for a scaled tele-manipulation system based on a task-oriented semi-autonomous virtual tool and designed a controller for the scaled tele-manipulation. Tsuneo Yoshikawa and Hitoshi Ueda (4) described a method of construction of the virtual world by combing the dynamics modules. Dan O. Popa and Sunil K.Singh (5) developed a virtual environment for lumbar puncture; they simulated the involving in order to create a realistic simulation involving force feedback when the trainee inserted a specialized joystick needle in a virtual spine “feel”. Qingping Lin and his colleagues (6) introduced a virtual tele-presence operation approach based on ROVs (Remotely Operated Vehicles). They used virtual reality technology to generate 3D synthetic images of the worksite based on CAD model of site. The virtual interface provided the pilots with a full perception of its spatial location and flexible options of viewpoints and functions of tele-operation of underwater robots. Y.Tusumski and Miuchiyma proposed a predictive display technique (7) and its robustness against modeling error (8) based on the concepts of optional approach velocity and virtual reality. Eckhard Freund and Juergen Rossmann (9) gave some research results that have been carried out in the field of teleoperation in the recent years. They present concept of “projective virtual reality” . Crigore C. Burdea (10) reviewed the areas where the integration of the robotic and virtual reality could be beneficial. He told the synergy between the fields of robotics and virtual reality will be expected to grow in years to come.

In this paper, we proposed a virtual supervisory control method (VSCM) which combined VR technology and supervisory control. With our method, integrate virtual and real sensors information to build the interactive information between virtual environment and real world. A purpose is project virtual events to real world.

2. VR AND VIRTUAL SUPERVISOR
VR is a relatively new research area; it is a three-dimensional simulated environment generated by computers, which is rendered in real-time according to the behaviors of the user. The main feature of VR is immersion, interaction and imagination. In that world, a human can perceive the objects and events existing, he can also interact with the objects, and participate in the events as if it were real. Applications to robotics research based on VR have been found on various aspects such as creating advanced human-machine interface, simulation and visualization, sensory information processing and presentation, planning and control.

The remote environment can be synthetically generated based on its CAD model with VR technology. 3D synthetic images of the work-site, which is visibility-independent, can be displayed in the virtual tele-presence interface. An operator can observe robot's site by adjusting the viewpoint and image size.

The supervisory control strategy has been applied in many intelligent tele-operation systems. One of important characteristic of this strategy is that the human operators are a part of the system, they supervising autonomy operation process of the system, making decisions in high level and, if need be, in low level, even direct operating tele-robot move. Based on the VR technology, the operator can provide symbolic commands to pilot the object move in a 3D space and show structure relationship which update according the real-time feedback information from sensors. The real world is projected to virtual world by virtual graphics. Simultaneously, the virtual events are projected to the real world or real robot. This kind of supervisory operation should be prefixed with “virtual “, i.e. virtual supervisory, since the operations are represented to the real world by virtual actions from virtual environment.

3. VIRTUAL SUPERVISORY CONTROL FOR UNDERWATER ROBOT

3.1 Problems associated with virtual Supervisory in practical operation of underwater robot

When the underwater robot do an operation for a fixed object in water, based on manipulator’s workspace the position and orientation in where ROV should be tied are calculated and the manipulator could be got the largest free space. If robot position and its orientation in the virtual image is updated by a real sensors system, virtual supervisory sound perfect in principle. However, because the errors are existed in the virtual model and sensors system, virtual supervisory sound perfect in principle. However, because the errors are existed in the virtual model and sensors system, the project errors from virtual to real world are caused. A novel system with VSCM will be discussed following.

3.2 virtual supervisory control method (VSCM)

For a given operation task, let \( T_d \) be the desired task, \( T_v \) be the virtual event corresponding to \( T_d \) which generated by the virtual manipulator in the 3D virtual environment, and the virtual sensors information is included in \( T_v \). Comparing \( T_v \) with \( T_d \), we can modify the virtual environment model, a process projecting from real to virtual. The real event \( T_R \) directing the desired task is a projection of the pattern of the virtual event \( T_v \) to the real world and the information of real sensors being included in \( T_R \). At the \( N+1 \) time, real events are decided by the desired task and modified error during calculation \( T_R \), we setup a critical region around the environment object in order to avoid collision between virtual manipulator and virtual objects. On the 3D simulation interface, the distance from each arm or its joints to critical region is checked by virtual distance sensors, if the distance is less than a given constant, manipulator might trend to collide with object, we should re-plan this task. The size of crucial region refers to errors of the ROV location and the manipulator position, orientation. This means that if each error is limited within the range of its own boundary, robot arm will not collide with objects when it moves outside crucial region. The virtual events are projected to real world, the crucial regions are projected too, and thus crucial regions ensure that a robot arm will not collide with an underwater structure in real world if the arm is not inside the regions in virtual supervisory interface. We call the state the arm coming into the critical region critical state.

3.3 features and configuration of the VSCM interface

For supervisory control, man-machine interface is significant to improve efficiency and precision of the operation. With VR technology, a better interactive, higher effective and visionable interface can be designed. Main features of the VSCM interface which are different from traditional tele-presence supervisory are as following.

Visualization of operation information: It transforms numerical information of ROV initialization position and orientation, manipulator joint values into 3D graphics and gives on the graphics the robot arm positions and orientation.
This enables a better visualization of robot information.

**Simulate operation:** Based on the desired task, a simulation supervisory operation can be done on the interface as if it were be done by robot. On the VSCM interface the operators can see the path of arm motion, get each joint value in order to judge joint limitation. Applying this function, we can choose robot structure parameters, estimate arm path planned, and find better location where ROV will be settled.

**Represent simulation result:** When a perfect simulation result was obtained on virtual interface, it can be projected to real sub-sea workspace by outputting data from virtual interface to real robot. During representing operating processes of the underwater robot are shown on the interface and human operators can also modify or interrupt the robot motion.

**Control Viewpoint and image size:** An operator can chose the viewpoint and change graphics size, he will facilitate to view the manipulator’s positions and orientation when arm work at different space, also he can enlarges a part of 3D graphics when an accurate operation will be done. This gives the operator a full perception of robot so that he can operate arm efficiently in a complex task.

**Display of robot status data:** The position and orientation of arm end-point and the supervisory control command given by an operator can be all displayed in the form of output data. If a joint value trends to go beyond its limited, it will be displayed with different color on 3D graphics interface.

**Operator training function:** The supervisor interface provide a facility for robot operator training. A novice robot operator can be trained to learn the basic process of the operation when the robot mathematical modal of robot is available. And either experienced or novice operator can also be trained to get familiar with a new or complex environment in the robot working. This is very important when a very vital part of an subsea installation needs to inspection. In that case, the mission can be practiced before execution. The collision detection capacity of the interface can assist the assessment of the process in practice.

The configuration of the virtual supervisory system interface is shown in Fig.1. It consists of supervisory control command and data input block, virtual supervisory interface data processing unit, robot arm position and orientation data processing block, and real-time checking distance to crucial region processing unit, CAD models of sub-sea installation structure and arm, as well as a interface display unit.

![Fig. 1 Configuration of the virtual supervisory](image)

**3.4 software design of the interface**

VR software OpenGL for windows has been chosen for this VSCM interface. The outstanding advantage of using this software is that it is standard interface between graphic software and hardware. Our VR software is programmed by OpenGL based on VC++ platform. The OpenGL graphic library provides rendering of 3D images, and VC provides window management mechanism. This enable the user to directly program and thereby control the details of the virtual environment and sensor input, which means more flexibility in real application. The features of OpenGL can be compared beauty with primary workstation when it is run in advanced PC, The OpenGL program can be replanted easily between PCs and workstations.

There are four main modules involves in this virtual supervisory interface: real-time checking crucial state, robot arm path planning module, operator training module and, virtual supervisory interface data processing and 3D graphics display module.

(1) **Checking crucial state module** In the virtual interface, virtual distance sensors calculated real-time if joints enter crucial region and send out corresponding state.

(2) **Path planning module** Robot arm track path is planned according to initialized ROV location, manipulator...
configuration and velocity given by the robot operator. From the start point, robot arm moves along the trajectory and keep out the crucial region.

(3) Operator training module When the interface is switched from normal tele-operation or supervisory operation to training mode, the training module will imitate the process of operation except that the motion of the robot arm is calculated based on mathematical modules of the robot kinematics and dynamics. All the functions available in the virtual supervisory can be simulated in the training module. This will help the operator not only to learn the basic process of the robot operation and get familiar with intended robot working environment, but also to learn how to make the best use of the functions of the interface.

(4) Virtual supervisory data processing and 3D display module This module is the primary of the VSCM interface. It process all data which come from robot sensors system, robot crucial state processing unit, arm path planning module and CAD module, sub-sea installation structure and robot structure, and operator's operation or supervisory command and so on. This process includes necessary coordinate transformation and data conversion that result all data into the format used by VR software. A virtual supervisory 3D image of the robot and surrounded environment is generated based on the processed data.

4. EXPERIMENT

The virtual supervisory control system has been tested in a simulation environment of underwater derrick model to inspect the imperfection in their welding lines. An underwater robot taken hold of a probe at its end checked the welding line between two pipes. Because the welding line is a space curve, the checking work is hardly completely by handily operation depend on teleoperation only. Applying VSCM system, by means of the virtual interface and virtual supervisory, the operation process can be simulation previously, and then the operator supervises the robot working and if necessary intervenes in the work process directly. The collision was effectively avoided due to crucial state. A satisfied simulation result was projected to an underwater robot and its environment in the real world. The probe moved along the real welding line with a tolerable error. The test results of underwater operation demonstrated the practical application potential of the VSCM and virtual interface.

REFERENCE