Ocean Engineering 37 (2010) 1036–1047

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Workspace control system of underwater tele-operated manipulators on an ROV

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ARTICLE INFO

Article history:
Received 17 July 2009
Accepted 31 March 2010
Available online 5 May 2010

Keywords:
Underwater manipulator
Tele-operation
Workspace-control
Inverse kinematics
Nonlinearity compensation

ABSTRACT

This paper presents a control technique for structured undersea tasks that require a high degree of precision. The overall efficiency of tele-operated underwater manipulation is improved by reducing the burden on the human operator. A new workspace-control system composed of a computer and input devices in workspace was developed to support the operator. The computer transforms the desired velocity of end-effector in workspaces to desired joint angles by solving the inverse kinematics of the slave manipulators. The desired joint angles are transferred to the slave controller through RS-485 serial communication, and be followed by the slave manipulator. The developed master system provides advantages in conducting structured tasks(coring, drilling, underwater connector mating, etc.) that require precise control of the end-effector's motion and attitude. The existing master system, however, is more useful for unstructured tasks than newly developed master system. By combining the two master systems, the work efficiency of the underwater tele-operated manipulator system was improved. This paper presents the development of the workspace-control system and a working strategy to alleviate operator's burden in underwater works. Experimental results are presented to evaluate the effectiveness of the proposed method using underwater manipulators mounted on the KORDI deep-sea ROV Hemire.

1. Introduction

The underwater manipulator has become an essential tool of underwater vehicles for performing underwater works such as drilling, cutting in coordinated tasks, and sampling, coring, and connector-mating in the fields of scientific research and ocean engineering. Autonomous manipulation, which is a major part of studies on manipulators mounted on underwater vehicles, has been the main research issue in the field of underwater vehicle-manipulator system (UVMS) (Antonelli et al., 2000; Kim et al., 2002; Marani et al., 2006, 2007, 2009). However, tele-operated manipulators mounted on remotely operated vehicles (ROVs) and manned submersibles are still important tools for underwater manipulation, because of the highly unstructured properties of underwater work. Due to the increase in demand for more dexterous and precise underwater manipulation, many researches involving for the kinematic and dynamic analysis of the underwater manipulator have been performed. These studies include the dynamic model and efficient dynamic simulation of an underwater vehicle with a robotic manipulator (Tarn et al., 1996; McMillan et al., 1995), the reduction of the dynamic coupling between manipulator and underwater vehicle (Dunnigan et al., 1998), and the manipulability analysis of underwater robotic arms on ROV (Jun et al., 2004). These researches, however, were limited to their simulation results that were achieved without field experiments using underwater manipulators. In addition to these researches, there have been many studies on manipulator control for enhancing the efficiency of underwater manipulation, such as the force feedback control of underwater manipulators mounted on ROV (Ryu et al., 2001), motion planning, and control of autonomous underwater vehicle manipulator systems (Sarkar et al., 2001), an uninstrumented manipulator control by visual servoing (Marchand et al., 2002), and the computer-based control and real-time motion compensation of deep-sea manipulators (Hildebrandt et al., 2008, 2009). Despite these researches, most underwater works conducted in field still depend on operator's skill. The operator's burden is higher in special underwater works requiring precise linear motion control with constant orientation, such as pushing and pulling of a long core into and from a storing cylinder, drilling of a deep hole. Therefore, a computer-based control system is proposed in this study for easy and precise control of underwater manipulator on ROV.

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doi:10.1016/j.oceaneng.2010.03.017

Fig. 1. Hemire ROV with two manipulators.

The Korea Ocean Research and Development Institute (KORDI) developed a 6000 m-class scientific ROV Hemire in 2006 (Lee et al., 2006, 2007) which is shown in Fig. 1. The Hemire is equipped with two ORION manipulators that are typical master-slave-typed tele-operated manipulators (Schilling, 2007). Since the tele-operator can perceive the only motion of the manipulator detected by several video cameras mounted on near the slave arm site, he has to control all the slave joints, while considering the joint limitation as well as the relative position and orientation of the end-effector. Due to the fact, the manipulator's control is not easy even if the operator is an expert. Moreover the burden of the operator is dramatically increased, if the works require linear directional motion with fixed orientation of the end-effector, such as coring and drilling. To handle this problem, we developed a new master system which one can control the slave manipulator in workspace by. The developed master system(workspace-control system) is composed of a computer and a joystick (Jun et al., 2004). The computer solves the forward and inverse kinematics of slave manipulator in order to get the desired joint angles from the desired velocity of the end-effector. The joystick is used, instead of master manipulator, as a velocity input device of end-effector in Cartesian space (workspace). In addition, the workspace-control system provides a simulator with virtual reality (VR) of slave manipulator to operators. The simulator as the assistant training tool enhances operator's skill by enough exercise prior to field manipulation, such as many simulators (Agba et al., 1995; Meng et al., 1996; Radetzky et al., 2000; Sobh et al., 2001; Her et al., 2002). Also, the simulator reduces operator's burden by providing VR, when one performs an underwater work relying on only camera.

The purposes of workspace-control system as summarized as follows: (1) alleviation of operator's burden; (2) enhancement of the working accuracy and speed; and (3) safety improvement to reduce the operator's mistakes. To achieve the purposes, the workspace-control system was designed to have the following functions: (1) graphic visualization of the slave arms; (2) workspace operation in Cartesian or tool coordinates; (3) preprogram mode operation; and (4) joint space operation which is the same function of the original master system. The paper presents the development of a new workspace-control system with the above functions and the effectiveness of the system was validated in experiments.

In Section 2, the desired joint angles are derived from workspace velocity command of end-effector by solving the forward and inverse kinematics of the slave manipulator. The nonlinearity compensation between the joint angles and the linear actuators is described in Section 3. Section 4 presents the hardware and software structures of the proposed workspace-control system. Using the developed system, the working strategy is proposed to improve the work efficiency of the underwater tele-operated manipulator system in Section 5. In Section 6, experimental results are presented to investigate the effectiveness of the proposed method using the implemented manipulator system embedded in the KORDI ROV Hemire.

2. Kinematics

2.1. Forward kinematics of the manipulator

The mathematical model of the slave manipulators, which is required to solve the kinematics, is derived in this section. The Hemire ROV has two ORION manipulators; a standard reach

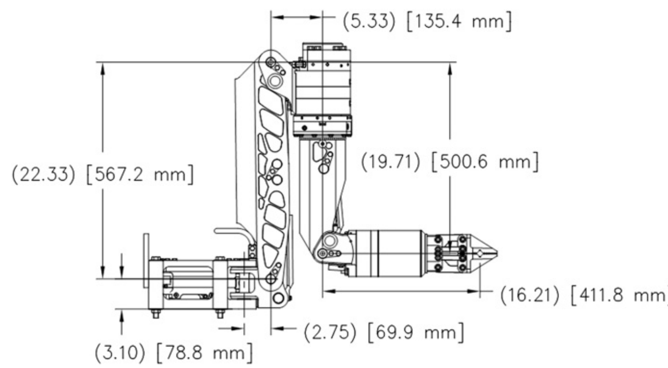

Fig. 2. Physical dimension of the standard reach ORION manipulator.

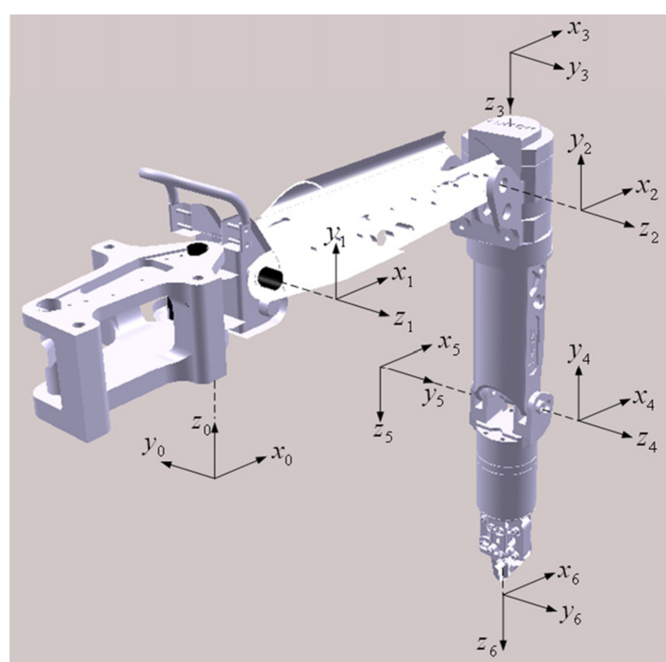

Fig. 3. Establishing link coordinate systems of the manipulator.