Fanghao HUANG, Xiao YANG, Xuanlin CHEN, Deqing MEI, Zheng CHEN, 2025. A digital simulation platform with human-interactive immersive design for navigation, motion, and teleoperated manipulation of work-class remotely operated vehicle. *Frontiers of Information Technology & Electronic Engineering,* 26(8):1394-1410. https://doi.org/10.1631/FITEE.2400486

A digital simulation platform with human-interactive immersive design for navigation, motion, and teleoperated manipulation of work-class remotely operated vehicle

Key words: Underwater teleoperation; Telepresence; Navigation and motion control; Virtual reality; Visual and force assistance

Fanghao HUANG
E-mail: huangfanghao@zju.edu.cn
ORCID: https://orcid.org/0000-0003-3710-114X

Zheng CHEN
E-mail: zheng_chen@zju.edu.cn
ORCID: https://orcid.org/0000-0003-0961-8758

Motivation & main idea

- Underwater testing is difficult, expensive, and time-consuming, making algorithm development and operator training challenging.
- A simulation platform provides an economically feasible way for algorithm pretesting and operator training prior to the actual underwater tasks.
- Human-interactive design with visual and force feedback creates telepresence for more effective operation.

Method

□ Overall design

To obtain telepresence during the teleoperation process, a human-interactive digital simulation platform is developed, and two mechanisms are designed:

- virtual training with recorded in-situ data for operator skill development
- real-time visual and force feedback during the actual underwater tasks

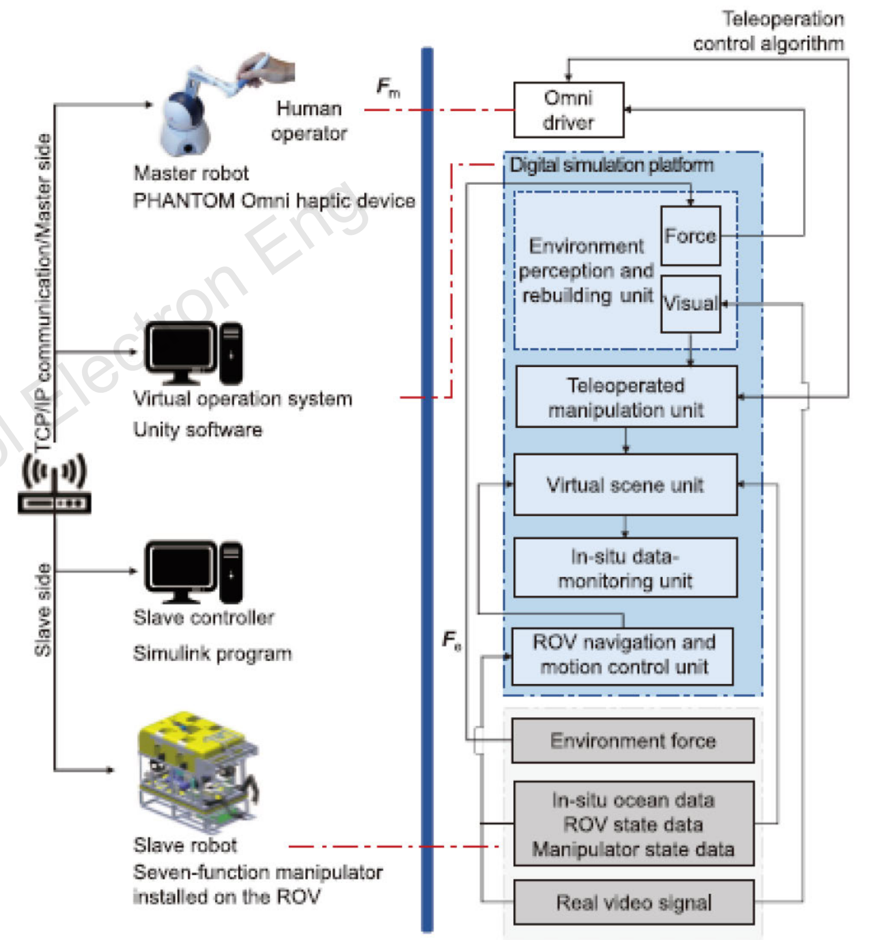


Fig. 1 Framework of the digital simulation platform

Method

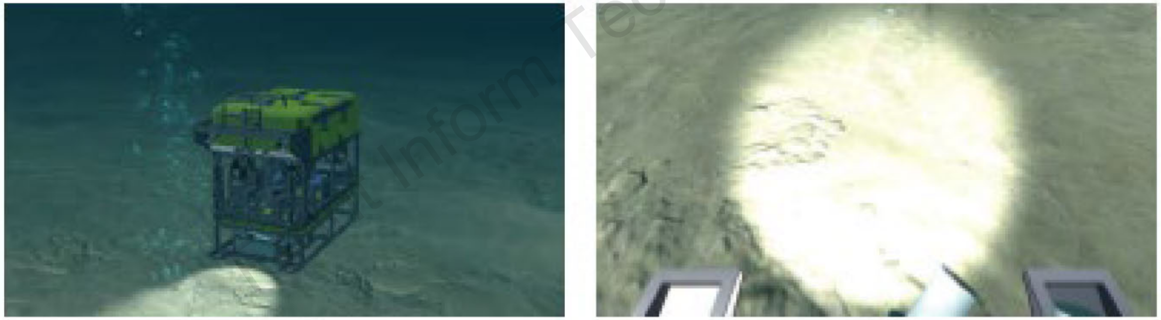
☐ Key component design

- Virtual scene unit: creating accurate underwater environments with terrain, hydrodynamics, and collision detection
- Navigation and motion control unit: dynamic windows approach (DWA)-based local navigation algorithm and sliding mode control (SMC) controller for remotely operated vehicle (ROV) movement
- Teleoperated manipulation: wave-variable architecture and radial basis function neural network (RBFNN)-based slave controller for precise manipulation

Method

☐ Key component design

- Environment perception and rebuilding unit: providing perspective visual feedback and haptic feedback for human operators



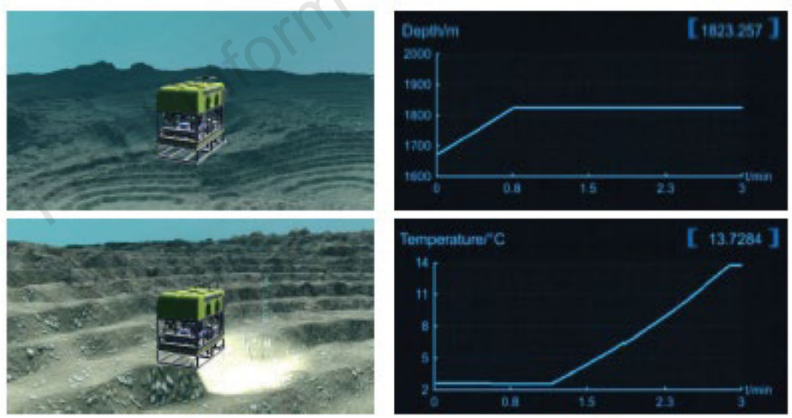
(a) (b)

Fig. 4 Multiple perspectives of a virtual scene: (a) third-person perspective; (b) first-person perspective

Method

☐ Key component design

- The in-situ data-monitoring unit displays:
    - a) environmental data (temperature, salinity, and depth),
    - b) ROV state data, and
    - c) manipulator state data.



(a) (b)

Fig. 5 ROV motion near a hydrothermal vent: (a) ROV motion simulation; (b) in-situ data monitoring

Major results

- ☐ The platform accurately simulates the full operation process:
  - ROV navigation to the sampling point
  - posture adjustment and preparation
  - teleoperated manipulation for sampling
  - retraction and return to the initial position

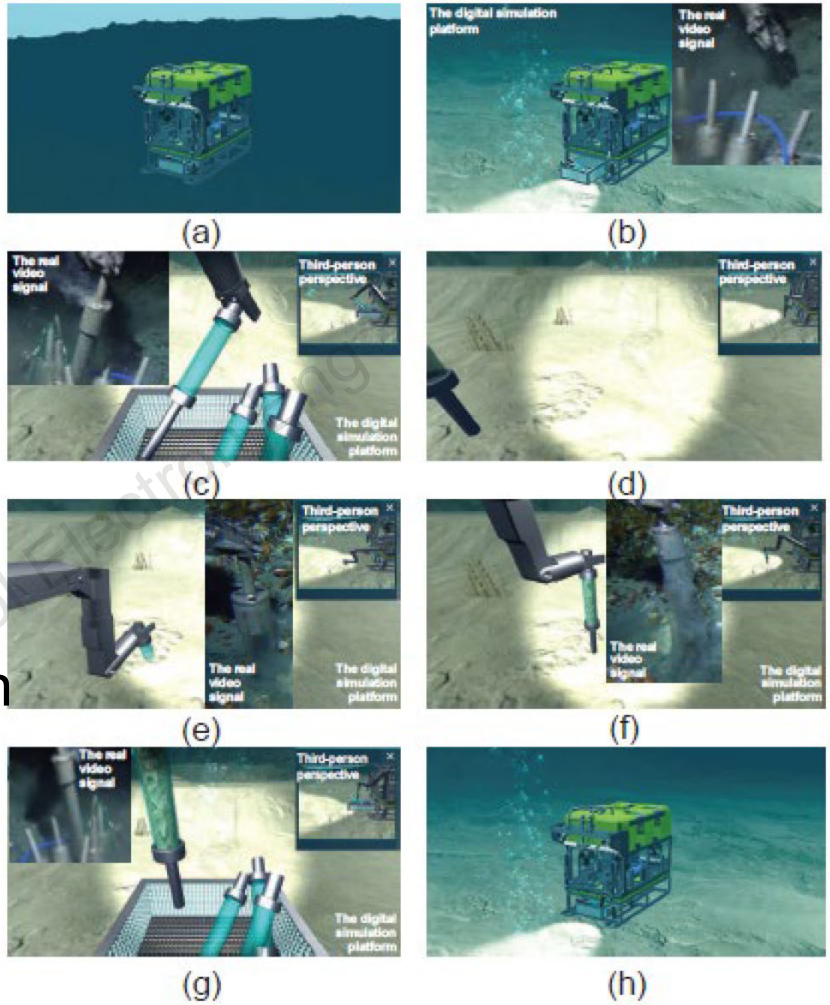
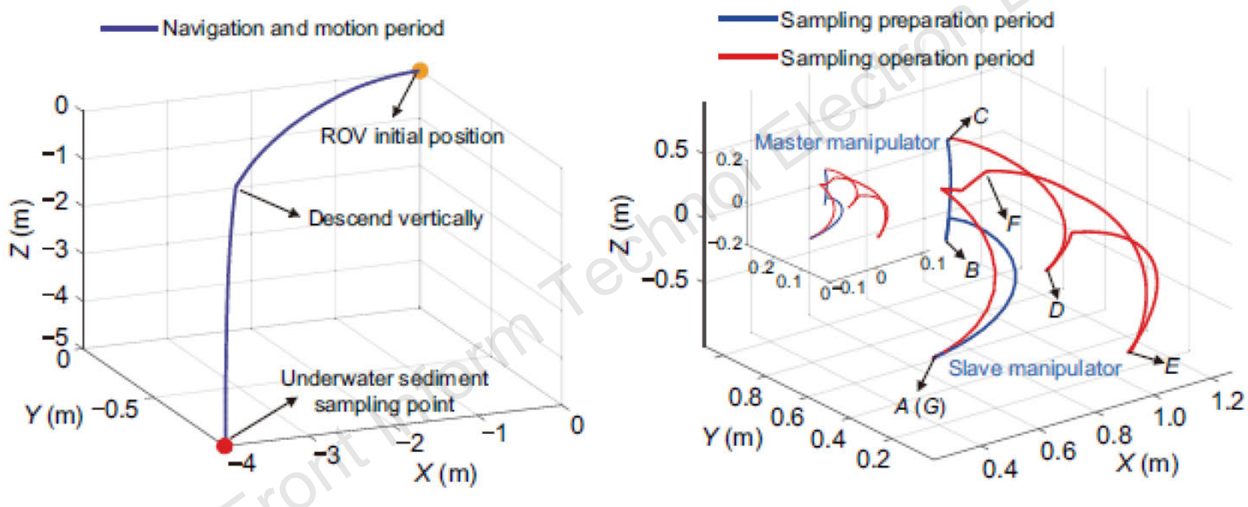


Fig. 8 The underwater sediment sampling process of ROV in the virtual scene: (a) ROV navigation and motion process; (b) ROV posture adjustment; (c) mud picker grasp; (d) ready to sample; (e) sediment sampling; (f) end of sampling; (g) retraction of the mud picker; (h) manipulator returns to the initial position

Major results

◻ Navigation & manipulation results



(a) (b)

Fig. 9 The motion during the full operation process of the work-class ROV and its manipulator for the underwater sediment sampling task: (a) the planned practical trajectory of the work-class ROV; (b) the end effector's displacement of the teleoperated master and slave manipulators

Major results

- User study results

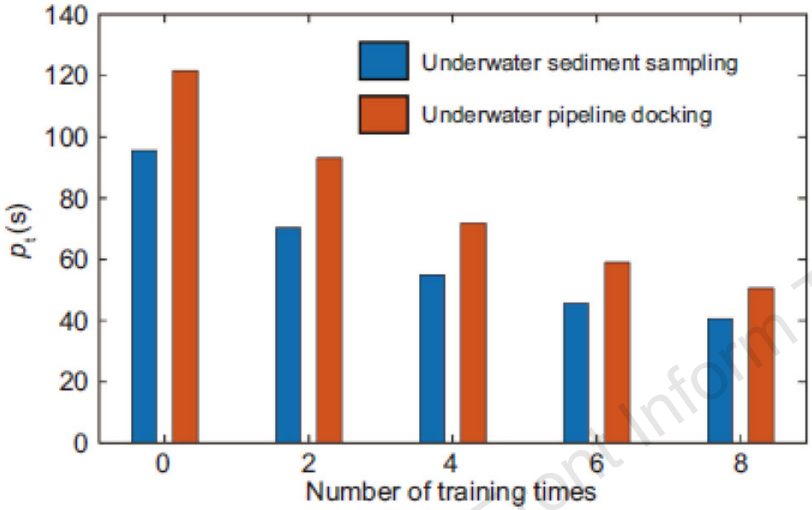


Fig. 11 Results of the user study Set 1

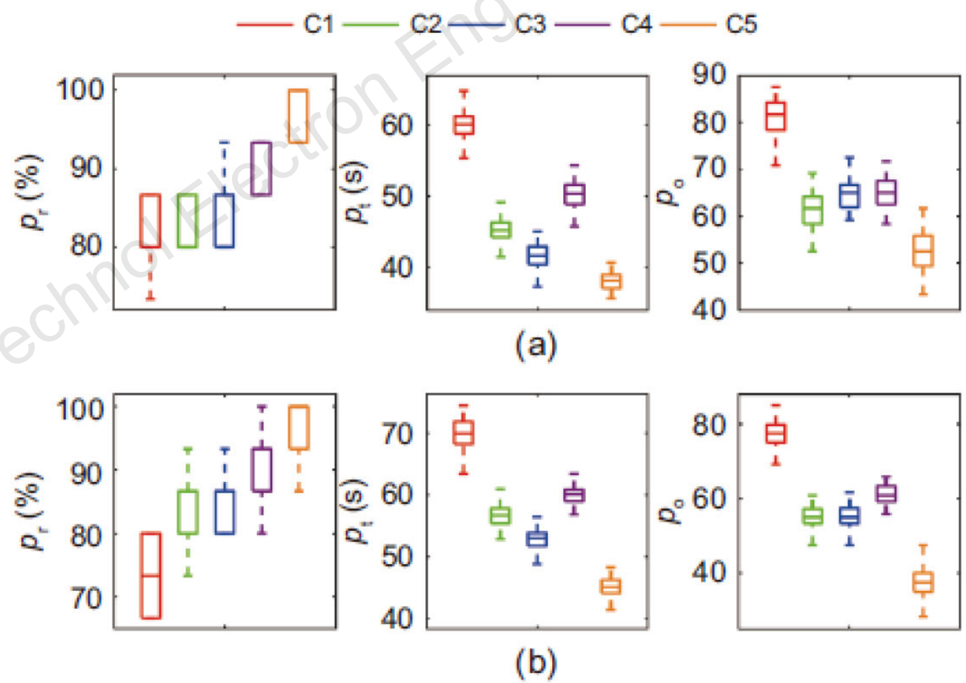


Fig. 12 Results of the user study Set 2: (a) underwater sediment sampling; (b) underwater pipeline docking

Conclusions

1. Effective training: the platform provides low-cost, immersive training with quality-improved telepresence using recorded in-situ data.
2. Algorithm testing: open data interfaces allow researchers to test and improve navigation and control algorithms before real deployment.
3. Improved performance: user studies confirm significant improvements in task completion time, success rate, and reduced operator workload.

Fanghao HUANG received the B.E. degree in mechanical engineering from Nanchang University, China, in 2017, and the Ph.D. degree in mechanical engineering from Zhejiang University, China, in 2022. Since 2022, he has been a postdoctoral researcher in the Ocean College, Zhejiang University. His research interests focus mainly on the advanced control of robotic and mechatronic systems (e.g., motion control, hybrid motion/force control, visual servo control, manipulation, tele-robotics, unmanned surface vehicles, and augmented reality).

Zheng CHEN received the B.E. and Ph.D. degrees in mechatronic control engineering from Zhejiang University, China, in 2007 and 2012, respectively. From 2013 to 2015, he was a postdoctoral researcher in the Department of Mechanical Engineering, Dalhousie University, Halifax, NS, Canada. Since 2015, he has been in the Ocean College, Zhejiang University, where he was promoted to the rank of professor in 2020. His research interests include advanced control of robotic and mechatronic systems (e.g., nonlinear adaptive robust control, motion control, trajectory planning, tele-robotics, hydraulic system, precision mechatronic system, soft actuator and robot, mobile manipulator, underwater robot, and exoskeleton).