UERSim: An Integrated Modular Simulation Platform for Underwater Ecological Monitoring and Robot Learning

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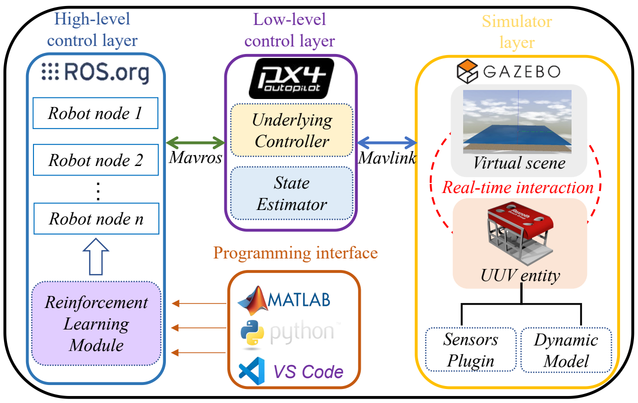

Fig. 1: Illustration of the integrated modular simulation platform for underwater ecological monitoring and robot learning.

I. Introduction

In the current global context, underwater ecological monitoring is imperative for preserving marine biodiversity, preventing environmental pollution, and promoting the sustainable development of the aquaculture industry [1]. With rapid advancements in technology, simulation platforms have become indispensable tools in underwater ecological monitoring. These advanced simulation technologies enable researchers to replicate complex underwater environments, train underwater robots for precise operations, and ultimately achieve a seamless transition from simulation to reality (sim2real) [2]. However, this field has seen limited prior work, and existing simulation platforms lack accuracy, user-friendliness, intelligence, and the intergration of ecological monitoring.

In this paper, we develop an intelligent simulation platform "UERSim" based on the robot operating system (ROS) and Gazebo. UERSim integrates basic modules such as high-precision simulation scenarios, dynamic models, sensors and controllers, while reserving programming interfaces. In addition, UERSim provides reinforcement learning (RL) environment for underwater robot intelligent learning and YOLOv8 for ecological monitoring, supplemented with multi-agent RL, offline RL techniques to realize efficiently training for complex tasks, multi-robot coordination, and sim2real deployment.

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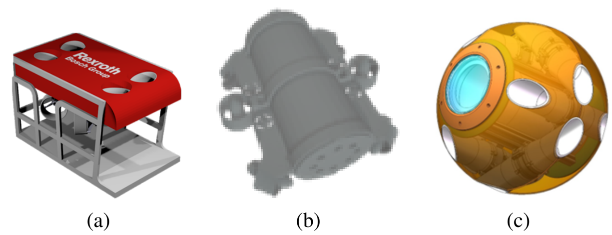

Fig. 2: Three underwater robot models equipped in our integrated modular simulation platform. (a) The work-class underwater vehicle, which is suitable for underwater operations. (b) The six-propeller robot enables full range motion. (c) The spherical robot for exploration in narrow spaces.

II. Design and Development of UERSim

A. Overall Framework of UERSim

The overall framework of UERSim is shown in Fig. 1, which is mainly divided into simulator layer, low-level control layer, high-level control layer and reserved programming interface. The Gazebo-based simulator layer is mainly responsible for creating simulation entity and virtual scenario, while UUV entity contains dynamic models and sensor plugins of underwater robots. Besides, the low-level control layer based on PX4 software in the loop (SITL) mainly contains core functions such as state estimation and underlying controller. The high-level control layer is connected to the programming interface and supports multi-agent tasks. These three layers communicate via MAVROS and MAVLink to subscribe information and issue commands. In addition, we develop RL environment and virtual ecosystem in our platform by combining Blender with Gazebo and ROS. It mainly includes Gazebo-environment class (GazeboEnv), Robot-environment class (RobotEnv) and Task-Environment class (TaskEnv). GazeboEnv is connected to Gazebo and can reset, pause, and resume simulations. The RobotEnv, inherited from GazeboEnv, handles the robot's information and controls it. TaskEnv, inherited from RobotEnv, contains the main elements needed for RL to determine the task structure the robots need to learn.

B. Robot Models and Sensors

The model of UUV entity can be produced by software such as solidworks or directly use existing open source robot

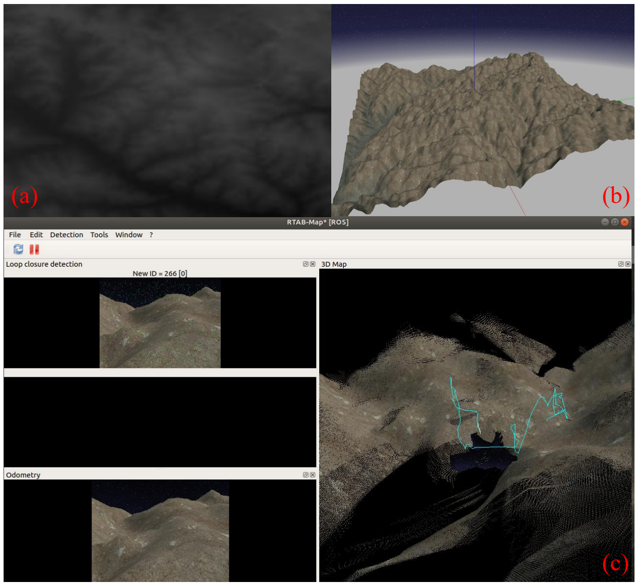

Fig. 3: Seabed construction process and 3D mapping. (a) Height map. (b) Visualization in Gazebo. (c) Real-time image of the environment.

models. To meet different mission requirements, our platform is equipped with three robot models as shown in Fig. 2.

C. Construction of High-Precision Underwater Scenario

The challenge of constructing a high-precision underwater scenario is to accurately model the seabed and underwater ecosystem according to real terrain and marine ecological data.

1) Seabed Modeling Process: The Anaconda ogr2ogr library is firstly utilized to view the hierarchical information of the S-57 chart and perform non-visual processing operations, including format conversion. Then the vector data is converted to raster data by QGIS or Arcmap software and the terrain file (.tif file) is obtained. This is then converted into a height map (.png file) using Global Mapper software. In addition, the resolution of the pixel is modified to improve the precision of the generated terrain. Finally, the terrain generator tool is used in ROS to convert the height graph into the .world file, which is finally displayed in the Gazebo simulation environment, and the visualization process is shown in Fig. (3a)-(3b). Further, integrated testing of modules in UERSim is carried out with an example of three-dimensional mapping of the seabed. The robot is controlled to continuously scan the terrain via sonar, obtain the three-dimensional point cloud data of the terrain and visualize it, which is shown in Fig. (3c).

2) Ecosystem Modeling Process: Fisrt, we introduce flora and fauna specific to the underwater ecosystem, and use particle systems for distributing plant life like seaweed and corals. For mobile fauna, such as fish and other marine animals, model these creatures and utilize ChatGPT, ROS and Gazebo to enable them to behave as they would in the real ecosystem. Finally, apply realistic materials and textures to all elements, while utilizing shaders that mimic the iridescent surfaces of fish or the rough textures of rocks via Blender.

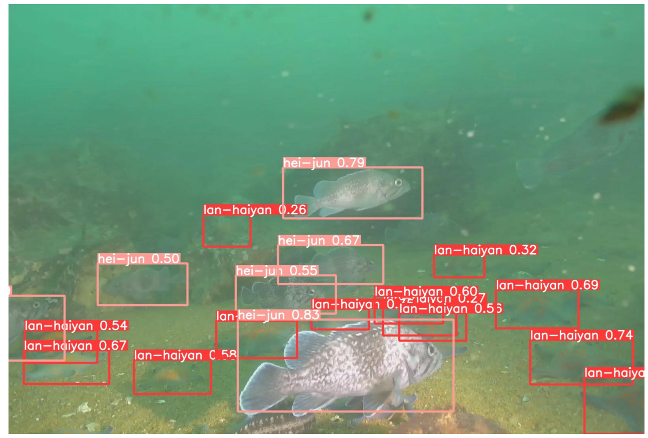

Fig. 4: Ecological monitoring in the South China Sea.

III. From Simulation to Reality

A. Underwater Ecological Monitoring Pre-training

Our goal is utilizing multi-agent RL algorithms to train multiple underwater robots equipped with YOLOv8 to distribute them across various locations in the virtual scenario for collaboratively identifying various fish species, quantifying their frequency and density in that region, and conducting regular tracking of rare fish species to document their movement patterns and behavioral characteristics. With the increase of training episodes, the robot's policy gradually improves to the expert level, and network model parameters (.pth file) is saved.

B. Sim2Real Transition and Online Fine-tuning

The .pth file is migrated to the underwater robot to conduct the real experiment in the South China Sea. Given the gap between simulation and reality, we allow the robot to interact with the environment in order to assess its performance while also enabling it to fine-tune its policy online. Experiment results are shown in Fig. 4, which prove the effectiveness and practicability of the integrated modular simulation platform.

IV. Conclusion

In this paper, an integrated modular simulation platform for underwater ecological monitoring and robot learning named UERSim is developed. Firstly, the framework of UERSim is introduced. Then the robot models and sensors, and the construction process of high-precision underwater scenario are detailed. Finally, we introduce the entire working process of UERSim and sim2real. The experiment results demonstrate the effectiveness and practicability of UERSim.

References

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