IoT-Based Indoor Robot Simulation Experimental Teaching System

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Abstract. With the continuous development of IoT technology, IoT technology has an increasingly important role in experimental teaching. In response to the problem that traditional robotics experiments are usually restricted by space and experimental funding, resulting in unsatisfactory experimental teaching results, an IoT-based indoor robotics simulation experimental teaching system is designed. The traditional robot simulation system is based on client-side implementation, which is relatively inefficient. This paper explores the robot operating system ROS, makes corresponding application innovations, and uses a new B/S architecture robot simulation system design scheme to achieve remote control based on WebSocket and topic mechanism, considering the advantageous features of C/S architecture, which is extremely operable and makes the experiment easier.

Keywords: Internet of Things · Simulated Robots · Web · ROS · Simulation Experiments

1 Introduction

In the process of building a new engineering discipline, to cultivate innovative and practice-oriented talents, it is necessary to establish a diversified education model, as well as to offer leading, practical, forward-looking and cross-cutting courses [1]. Experimental sessions play an irreplaceable role in the teaching of science and technology subjects and are very important for students to understand the content of classroom teaching and to enhance their hands-on skills [2]. Robotics itself encompasses a multidisciplinary range of mechanical, electronic and computer knowledge [3]. In the industrial context of "Made in China 2025", robotics experimental teaching plays an important role in the teaching process of mechanical majors. However, traditional robotics experiments are often not as successful as they could be due to the school's own characteristics and the lack of investment in experimental funding and space, which makes it difficult for students to develop their skills [4]. With the development of computer and network

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technology, through the unremitting efforts and active construction of universities, at present, the Ministry of Education has identified and announced more than one hundred national virtual simulation experimental teaching projects, and the construction work of virtual simulation experimental teaching projects is gradually and orderly promoted.

In 2017, South China University of Technology combined system simulation and 3D virtual prototype modelling to achieve mechatronic-hydraulic integration and designed an integrated digital virtual simulation platform for forging robots [5]. In 2020, Tianjin University designed a virtual simulation experiment for deep-sea bionic robot control, applying virtual simulation technology to build a multi-joint release robot in a complex operating environment in the deep sea [6]. In the same year, South China University of Technology developed a robotics kinematics teaching system with virtual reality, remote control and a live laboratory [7]. In 2022, the University of Science and Technology of China (USTC) developed an experimental system for robot grasping simulation based on the results of robot grasping research with deep learning [8]. In response to the current situation of robot simulation experiments and combined with Internet technology, we developed an indoor robot simulation experimental teaching system based on the Internet of Things.

2 Robotics Web Experimental Teaching System

The IoT-based indoor robot simulation experimental teaching system designed in this paper is based on robotics-related courses for mechanical majors and combines ROS technology to form a virtual-real course teaching model.

After starting the simulation environment, the simulation scene is first built, and then OBS (Open Broadcaster Software, an open-source video recording and video real-time streaming software) is launched to achieve simultaneous recording of Gazebo. The simulation scenario, robot model and related parameters are then set up and imported into Gazebo. Finally, the server is started and a web-based login is used to access the simulation system to implement the experiments. During the experiment, students simply enter the corresponding URL into their browser, register and log in to the system to start the experiment. The system also allows students to build their own simulation environment and modify the operating code to achieve different experimental effects. This enriches the experimental content and helps to increase students' interest in independent exploration.

2.1 System Framework Design

The ROS-based robotics web-based experimental teaching control system focuses on remote control of robots via web pages. The entire system architecture is shown in Fig. 1 and is divided into three main modules.

(1) Front-end web pages: web pages are created using HTML5, JavaScript, CSS and other technologies. The front end is primarily for user manipulation.

(2) Servers: web server based on flask, proxy server based on NGINX, streaming server based on UDP protocol, TCP message server based on TCP/IP protocol. Servers mainly for the management and message forwarding of user and robot data.

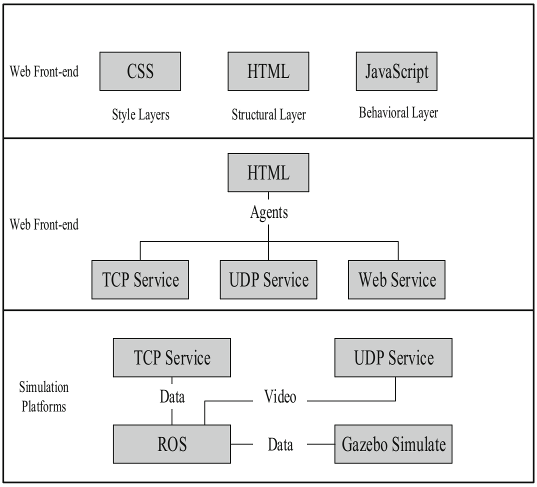

Fig. 1. System architecture diagram

(3) Simulation platform: Using the ROS system and the gazebo simulation platform, combined with the TurtleBot robot to simulate the operation and feedback of a real ROS robot.

2.2 System Simulation Environment Construction

The virtual simulation environment built in this system consists of Gazebo and TurtleBot2, a robot simulation software that provides some basic 3D objects - spheres, cylinders and cubes. Using these objects or variations of them, many interesting simulations can be designed. Gazebo also provides interfaces to various 2D and 3D design software such as CAD, Blender, etc., through which you can build models and then import the files into Gazebo to make the simulation environment look more realistic. TurtleBot is an open-source hardware platform and mobile base station. The Intel NUC-BOXNUC6CAYH mini-PC is used as the central control, equipped with Intel Real 3D camera, Orbbec Astra Cam depth camera, accelerometer, gyroscope, compass, and other sensors.

In this system, the user is assisted by live video and maps. The live video is done in real time with camera capture and transmission, while the live maps require the user to place the robot in the environment of use in advance and operate the robot to scan the environment to build the map. As this system uses a virtual simulation environment, it is necessary to instantiate the virtual environment, as shown in Fig. 2.

Once the map model has been created, the next step is to import the model you have just created into the TurtleBot robot and start it up. You can then move the robot via the keyboard and see the map information drawn in RVIZ and operate the robot to see the map shown in Fig. 3 after walking the model created. Finally, the map is saved so that when the robot is used again the map can be imported directly, avoiding the need to scan it again.

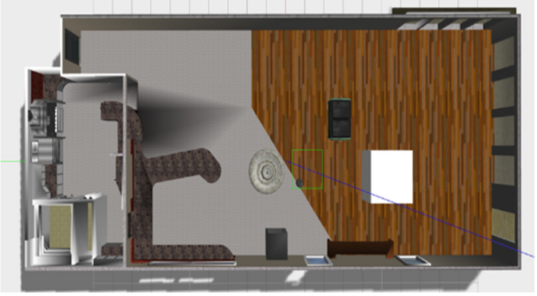

Fig. 2. 3D Virtual Map

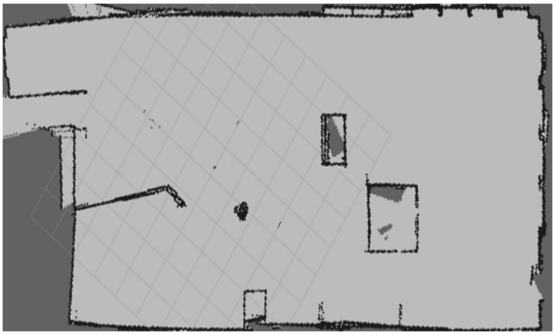

Fig. 3. Map in RVIZ

2.3 Cloud Server Design and Simulation Lab Operations

Flask is a lightweight web framework written in python, which is lighter, safer, more flexible, and easier to use than other frameworks of the same type, and has many extensions that make it flexible to import different packages according to the project's needs, making the developed application more compact. The Flask framework requires the creation of a virtual workspace (as shown in Fig. 4), where the Python version and libraries are limited to the application in the workspace during the project run.

2.4 Video Communication Solution Analysis and Design

The ROS robot operating system is not an operating system in the traditional sense of being responsible for process management and scheduling on a computer, such as Windows, Ubuntu, etc., but rather a sub-operating system that is essentially a collection of software tools running on operating systems such as Windows, Linux, etc. Its core function is to enable developers to be able to very flexibly and the core function of ROS is to provide a software peer-to-peer communication mechanism to enable developers to organise their robots' software systems in a very flexible and efficient way. The basic concepts of ROS are node, master, message, topic and server.

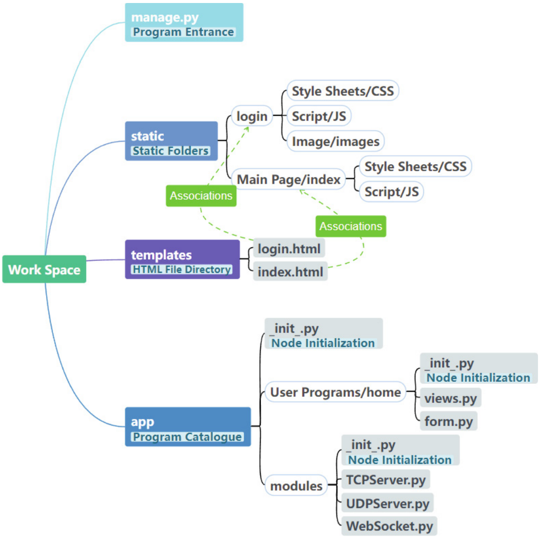

Fig. 4. Flask workspace structure

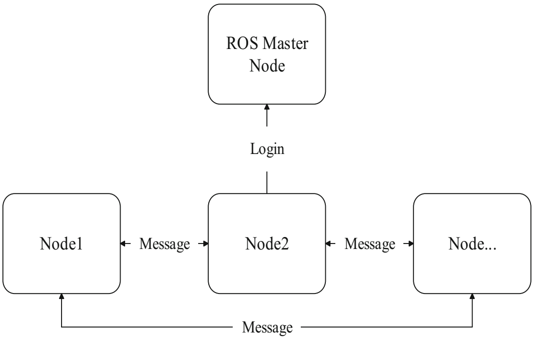

Fig. 5. ROS communication mechanism

When a node publishes a topic, the master node keeps a record of the topics published by the node. If another node subscribes to the topic, the two nodes can communicate, i.e., the publisher outputs a message that the subscriber receives.

The robot in this system does not yet have autonomous navigation capabilities, so if the robot is operated remotely based on map information alone, the actual environment may differ from the map, resulting in collisions and mis-operation. Therefore, the map can only be used as an aid, and the operator must be able to view the robot's surroundings in real time.

In the UDP protocol, the maximum data length of each packet is 65535 bytes, and by removing the 8-byte packet header, only 65527 bytes are available for carrying data. And in the actual use of the process, in order to ensure the stability of data transmission, the length of a single packet sent is generally smaller than this value, but in the video

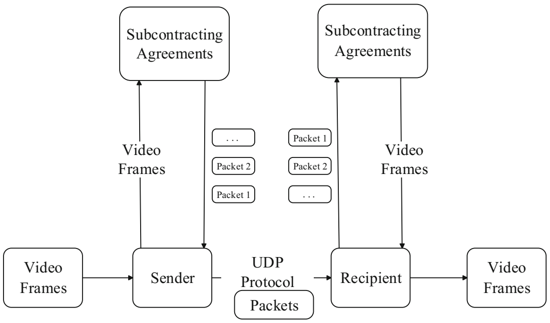

Fig. 6. Diagram of the UDP video data packetization process

transmission, the length of each frame of data is about 90,000 bytes, so it is not possible to send a whole frame of data at once, you need to use multiple packets sent separately. Here the concept of packetization is introduced, as a single packet cannot carry all the data required to be sent, the data is cut and chunked by the sender according to the packetization protocol, and then the corresponding identification data is spliced in the data block and encapsulated into a packet, so that a large packet is split into several small packets, and finally the packets are sent in order to the receiver, who reorganises the packet in reverse according to this protocol. The receiver reassembles the packets into frames of data in the reverse direction according to this protocol. This satisfies the packet size requirements of the UDP protocol, while successfully sending the data that exceeds this packet size requirement to the receiver. The whole process is shown in Fig. 5 (Fig. 6).

2.5 Simulation of Experimental Operations

First start Gazebo, then launch OBS (Open Broadcaster Software, the open-source video recording and video streaming software) to enable simultaneous recording of Gazebo. Then set up the simulation scenario, the robot model and the parameters for the operation and import them into Gazebo. Finally, the server is started, and a web-based login is used to access the simulation system to realize the experimental content.

(1) Real-time video window: This is used to show the images captured by the robot's camera in real time to assist the operator and can also act as a remote monitor to give the operator a real-time view of the room.
(2) Dynamic map window: The map data from the robot is an image, so the img tag is used here to receive and display the data, and the image address is generated dynamically based on the robot information bound to the user. The map window should not only display the map information, but also the robot's position and orientation. The img tag can only display the image but no other operations, so the same size canvas element needs to be superimposed on the img tag at the same location, and then the robot is drawn onto the canvas based on the robot's position and orientation data sent from the backend in real time.

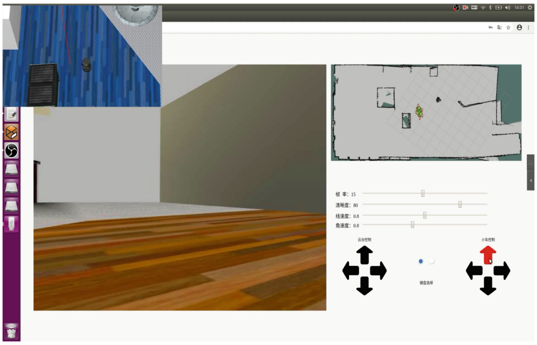
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Fig. 7. Operation interface

(3) The control buttons area: this area is for configuring the robot's parameters and controlling its movements. The parameters configured are frame rate and sharpness, and the operator sets the frame rate and sharpness to suit their network and operating scenario. The gimbal control button controls the rotation and tilt of the gimbal, allowing for a full view of the robot without moving it, while the robot control button controls the robot's forward and backward movement, left and right rotation. The robot can be controlled at different speeds to suit different scenarios (Fig. 7).

3 Advantages Of Robotics-Based Simulation Experimental Teaching Systems

Comparing the ROS-based robot simulation experimental teaching model with the traditional robotics experimental teaching model, several advantages of the experimental teaching model can be summarized.

(1) Safer experiments. Simulation teaching experiments based on this system are operated remotely via the Internet, avoiding direct contact between students and real robots while having a realistic robot operating experience.

(2) Reduced construction costs for the laboratory. The simulation experiment does not require the direct involvement of a physical robot, while the experiment is more flexible. It is not limited by time and space, and the simulation scenarios required for the experiment can be built artificially or imported directly into the system for experimentation.

(3) The experiments are more scalable. In the experiments, students can modify different experimental parameters to perform different robot operation experiences. Students can also customize their experiments and modify the control program to achieve different experimental effects.

4 Conclusions

In response to the problems of limited experimental space and underutilization of experimental resources in traditional robotics teaching experiments, a robot simulation experimental teaching system based on ROS was completed by combining Internet remote control technology with ROS. In the experimental teaching system, students are interested in the remote-control technology and the scalability of the system, which helps them to understand and explore different ways of operating the robot. At the same time, the simulation system avoids misuse of the robot by students, reduces damage to experimental equipment and improves the safety of the experiment. With the rapid development of Internet technology, the role of remotely operated experimental teaching methods in experimental teaching courses is becoming more and more obvious, which not only enriches the diversity of teaching experimental courses, but also provides a new way to solve the problems that exist in traditional experimental teaching courses.

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