Trends and Applications of Robotics Development in Virtual Environments

Joon Young Kim
School of AI Convergence
Sungshin Women's University
Seoul, South Korea
jkim@sungshin.ac.kr

Jeong Min Oh
School of AI Convergence
Sungshin Women's University
Seoul, South Korea
ojmin55@gmail.com

***Abstract*—In this paper, we investigated the current trends and applications of robotics development in virtual environments since robotics has become the main in the mobility service field. First, we identified the various components of robotic systems in which components can be used and developed in virtual spaces. After our analysis, we followed up on the current technical robot trends by running four simulators to verify development capabilities. In addition, we discussed the possible considerations and issues associated with robotics development in virtual settings.**

***Index Terms*—Robotics Development, Functionality, Simulator, Virtual Development Environment (VDE), Virtual Space**

I. Introduction

From engineering and technology perspectives, devices have always been developed in tangible and visible forms with exterior design, hardware, and software. Especially hardware-based products and devices, such as bicycles or vehicles, are designed, developed, and tested via prototyping genuine products. However, recent advancements in computing resources, including computing processing units (CPUs), graphic processing units (GPUs), and high-speed network systems, allow developers to develop devices into Virtual Development Environments (VDE). This virtual development setting can be extended from device exterior and interior design to software verification. Robotics development is one of the promising areas that VDE can offer since it has become significantly popular in the mobility service field. Robots also have much more reasonable size and operation approaches for development than vehicles or other heavy devices.

However, existing tools or software can only develop and test robots partially. Programming-based toolkits such as MATLAB or Python can do only particular simulations and verification in minimal settings, including robot arm movement or optimal body balancing. Also, existing simulation tools like Open Dynamic Engine, as shown in Fig 1, can only simulate and test the movement and partial operation of the body and legs of the robots. It is not capable of full external sensor integration and data generation whereas modern robotic developers need task-specific functionality like autonomous driving and object detection. We need to follow up on the current status and application of development solutions for robotics development. In this paper, we analyzed and investigated the current trends and applications of robotics development in virtual environments. We first detailed the basic structure and procedure of virtual robotics developments. We also provided the current robotics trend and VDEs used in the industry and academia.

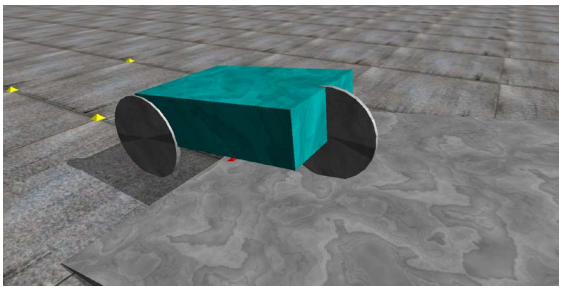

Fig. 1: Our Testing Example Scene of Open Dynamic Engine

This paper consists as follows. Section 2 details the basic structure of the virtual development environments for robotic systems consideration. Section 3 provides one of the main robot trends and virtual development environment applications. We also discuss the consideration for virtual development in section 4. After that, we concluded in Section 5.

II. Virtual Environments for Robotics Development

A. Basic Environment Model

For this paper, we need to specify a generalized structure of the VDE to describe its trends and applications in the intuitive senses. Based on our investigation and research, we identified the main components and structure of the environments and provided the basic structure shown in Fig 2. [1]–[5] In the structure, the main modules include robotics exterior and interior objects, locomotion, sensor components, robot systems, and a virtual development platform.

- **Exterior and Interior:** These objects contribute to testing and verifying robot quality and usability since they decide the robot's outlook. In the aspect of the quality assessment, the slight modification of these objects can impact robotics balancing and operation, which results in the degradation of overall robot qualities.

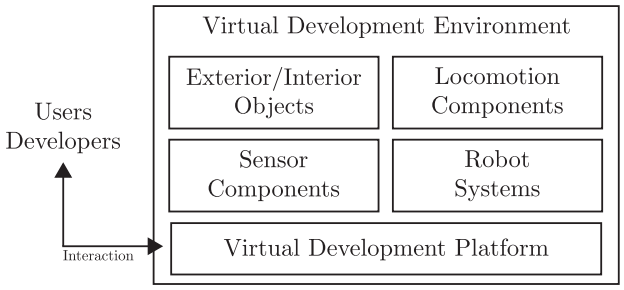

Fig. 2: Basic Structure of Virtual Robot Development

- **Locomotion:** It is another main factor for robotics development since the physical location movement from source to destination is one of the critical features for robots. For locomotion perspectives, the robot may attach legs or wheels. Depending on the size, shape, and mounted locations of the locomotion parts, the robot operation may be impacted in terms of operation performance.
- **Sensor Components:** Recent sensor enhancements contribute to the sensor placement in robots. In addition, autonomous driving has become a key feature and enables the sensors to become the main parts of robotic systems, such as mobile robots or automated ground vehicles (AGV). The scope of sensors includes microphones, Radar sensors, Lidar sensors, ultrasonic sensors, bumper sensors, and cameras. In VDEs, those sensors simulate the existing physical sensor functions and operations and adapt their same performances for testing.
- **Robot System:** This system is a comprehensive portion of the robotic systems that process all information, manage sustainable operations, and decide robot behaviors and integration. For the performance improvement of the robots, the system must contain advanced algorithms and logistics. In the VDE, the system structure and software algorithms are designed virtually and applied as simulated objects or modules.
- **Virtual Development Platform:** For the actual robotics development in the virtual space, the user has to access the VDEs with high computing performance and resources that can handle heavy 3D-rendering capabilities. Hence, the virtual platform is designed to adapt the interface for the users and developers. At the same time, VDEs are usually set up in a high-performed workstation, server, or cloud platform.

B. Procedure of Robotics Development

The basic lifecycle of robotic development in VDEs has three phases: Design, Development, and verification. Once the robotic technical specification is ready, the necessary robot components and objects are designed first. After the design, those components and objects are assembled and developed. In the development process, the fully functional virtual robot must operate in the virtual space for verification and identifying issues. After the verification and update, we prototyped robot systems physically.

III. Main Trends and Applications

Our investigation and research confirmed that one of the main robot trends is autonomous mobile robots, which perform in various fields, including manufacturing, delivery, and information service. Its market size also increased exponentially. According to [6], the estimated market size of the autonomous mobile robot will reach 3.36 billion dollars in 2023 and 6.94 billion dollars in 2028. With this promising forecast, the mobile robot needs to be designed and tested in a wide range of places where VDEs can be sufficient to test the robot's performance. With our own actual installation and operation, we listed four applications with detailed explanations: Virtual Robot Kits, Drake, SVL Simulator, and NVIDIA Isaac Sim.

A. Application 1: Virtual Robot Kits

Fig. 3: Example Development Scene of Virtual Robot Kits

Virtual Robot Kits is the simple robot builder in the virtual space for educational purposes. [1] Supported by LEGO, it aims to build and simulate the LEO-styled robot within VDEs so that the user can easily approach the design and operation of the LEGO robot in a simple setup. It can also allow users to upload and share their version of the robot with others so that they can interact and share ideas.

B. Application 2: Drake

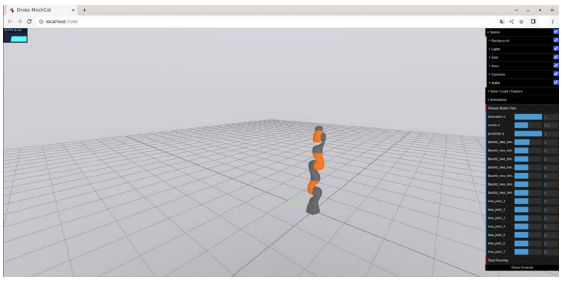

Fig. 4: Example Visualizer Scene of Drake

The primary purpose of Drake is to design the robot in the simulated setting so that it can imitate the challenging conditions for the robot design verification and evaluation. [2] It started with MIT and is currently led by Toyota Research Institute. The core of this toolkit consists of three components: multibody dynamics engine, systems framework, and optimization framework. While robots, in general, are the

target of this toolkit, the prominent simulation examples on the drake include gripping and cooking robots.

C. Application 3: SVL Simulator

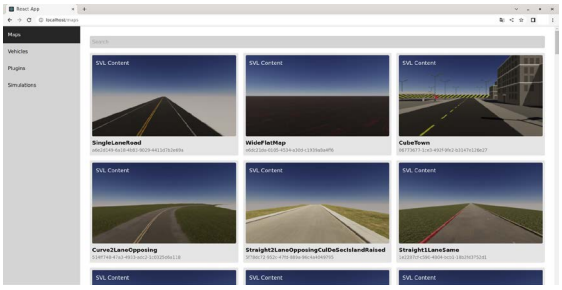

Fig. 5: Example Scene of Local Cloud-based SVL Simulator

Built by LG, the SVL simulator was initiated to develop the autonomous driving features of the virtual vehicle as the primary purpose, and the robot became one of the available devices for the simulation. [3], [4] Since its base engine is the Unity game engine, it kept extending its features and capability to cloud and digital twin integration. Since the simulator uses autonomous models based on ROS2, the three main components are built and applied: sensors, perception, and control modules. For the sensors, SVL allows the users to select the sensors for the model, including Lidar, radar, camera, and GPS. In addition, users can apply their customized version of the sensors. Although the official support of the SVL simulator was suspended in 2022, the open-source version is still ongoing with numerous participants and contributors.

D. Application 4: NVIDIA Isaac Sim

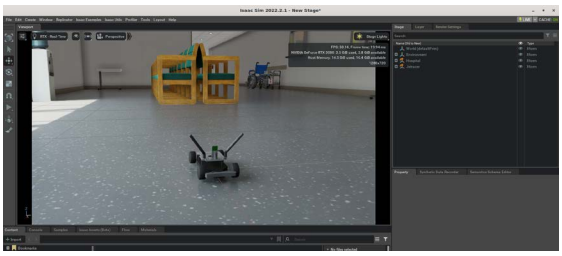

Fig. 6: An Example Scene of NVIDIA-Isaac-Sim

Although NVIDIA is famous for its graphic processing unit (GPU) product, the company extends its development scope into the device and infrastructure development in the virtual space using its GPU. [5] With the development platform known as Omniverse, NVIDIA aims to develop, test, and operate the device in the virtual environment for the developers. Using the Isaac Sim package, NVIDIA enables users to test and improve the robotic performance using virtual sensor data collection via operating the robot sensors in driving mode.

IV. Main Consideration

With our investigation and research on virtual robot development environments, we could identify a few critical considerations for robotic development. The first is the realization that virtual development must be considered as the initial, not fully detailed, physical development. Even if it is cost-effective and capable of rapid testing on existing resources, VDEs and virtual development platforms are the controlled environments and spaces where unexpected events, interference, malfunction, and random object appearance rarely happen. For robotics development, the developers always need to consider the limits of the virtual space.

Limited features and functions are other significant downsides but also considerations. Even if the virtual environments can imitate the overall operation and features of testing robots as almost the same as possible, the features and functions of the robots operating in the virtual space would be limited due to the platform design, virtual space structure, and computing resources. In that case, physical testing of those features must be carefully considered, or if necessary, the developers need to operate the verification process in parallel with the physical testing for rigorous evaluation.

V. Conclusion

In this paper, we investigated and discussed the details of virtual robot development environments. We first described and provided the basic structure and details of the virtual development environments and illustrated real application cases. After that, we discuss the critical considerations for the virtual robot development environments.

For future works, we need further investigation of the detailed structure and architecture of the virtual robot development environments from the perspectives of software modules and components. We also need to evaluate the usability and reliability of each environment and suggest possible issues for later improvement.

Acknowledgment

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