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Virtual Entity Based Rapid Prototype Developing Framework (VE-RPDF) for Intelligent Robots

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Abstract—**To facilitate the development of intelligent robots, a virtual entity based rapid prototype developing framework (VE-RPDF) is proposed. It aims at helping design intelligent robots through the following steps: rapidly setting up a robot prototype, coding for the control strategy and algorithm, and optimizing the robot design by testing it on both virtual entities and real robots. With VE-RPDF, two types of robots, including wheeled robot and humanoid robot, are developed, and the latter one is introduced as a case to verify the validation of VE-RPDF.**

I. INTRODUCTION

ROBOT developing is a complex project. To facilitate robot developing, many assistive softwares are designed. For example, ROBSIM[1] designed by Saarlandes University provides methods of analyzing and synthesizing the robotic system and offline programming. DYNAMAN[2] produced by the Maryland University is capable of building dynamic model for robotic arms, generating simulation programs in FORTRAN and the Jacobian matrix of robotic arms. IGRIP[3,4] developed by Deneb is used to simulate the robotic workcells with multi-device; moreover, it contains a library for widely used robots[5].

However, the softwares mentioned above are not suitable for developing intelligent robots. Most of them are designed for some specific industrial robot models and verify control strategy for process-oriented workflows. Generally, intelligent robots have diverse structures which have many different sensors and executors, and they run under such a pattern that their controllers determine their behaviors according to simultaneous and random feedbacks collected from neighboring environment through various sensors. To facilitate the developing of intelligent robots, a virtual entity based rapid prototype developing framework (VE-RPDF) is proposed, which has following features:

Firstly, a modeling tool to establish the rapid prototype is included, in which necessary sensors and executors, such as cameras, laser range finders, motors, etc. are contained. Thus, it is convenient to create and modify the prototype of various intelligent robots.

Secondly, a real time high-fidelity simulation environment where intelligent robots work in is provided. Intelligent robots usually work in non-structured environment, so the simulation environment must support both structured and non-structured environment.

Thirdly, the simulation environment and the intelligent robot controller can interact with each other effectively, and therefore they constitute a closed-loop control system. The robot controller can acquire status information through the sensors from the simulation environment and the robot itself. According to the information, the robot controller makes decisions and sends control command to the executors, and then influences the simulation environment indirectly. Thus, the simulation environment and the robot controller form a closed-loop control system.

Finally, the robot controller can be compiled into executable code which is able to run on diverse operating systems, and the executable code can be downloaded to target robot hardware.

II. VIRTUAL ENTITY BASED RAPID PROTOTYPE DEVELOPING FRAMEWORK (VE-RPDF)

VE-RPDF is a framework which facilitates the developing of intelligent robot. VE-RPDF expedites setting up the rapid prototype of intelligent robots and designing the robot controller. To find out whether the prototype robot and its controller work properly, VE-RPDF offers the function of simulating real working condition in the virtual environment. Moreover, VE-RPDF compiles the control codes and downloads them into robot hardware.

Traditionally, the process of developing robots always includes the following steps: requirement analysis, designing mechanical structure and electrical system, establishing rapid prototype of the robot, coding for the controller of the intelligent robot, and evaluating the prototype robot. But with VE-RPDF, according to developer's conceptual design, a virtual entity based prototype of intelligent robot can be built up in a short time. Then robot controller can be developed to implement some intelligence for the robot. After that, the robot controller can run to control virtual robot and verify its design in a high-fidelity simulation environment provided by VE-RPDF. If the virtual robot and the controller work well as expected, the real robot prototype is produced, and the VE-RPDF downloads the executable code of robot controller to the real robot's hardware. Otherwise, the robot prototype and its controller should be modified. This developing process with VE-RPDF is shown in Fig. 1.

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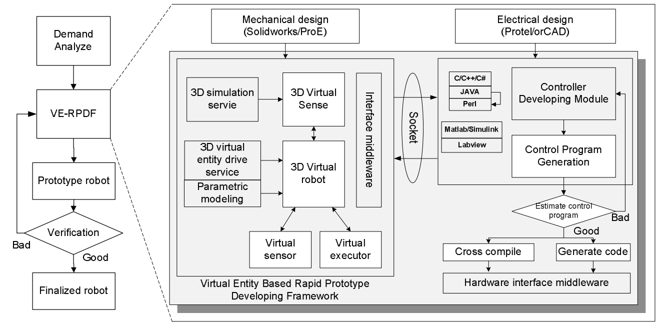


Fig. 1. Process of Developing a Robot with VE-RPDF

To realize the functions described mentioned above, VE-RPDF is composed of three parts: high-fidelity simulation environment, controller developing module and compiling and downloading module.

A. High-Fidelity Simulation Environment

High-fidelity simulation environment provides the robot developer with an effective way to establish and verify their robot prototype and the robot controller. The structure of simulation environment is shown in Fig. 2.

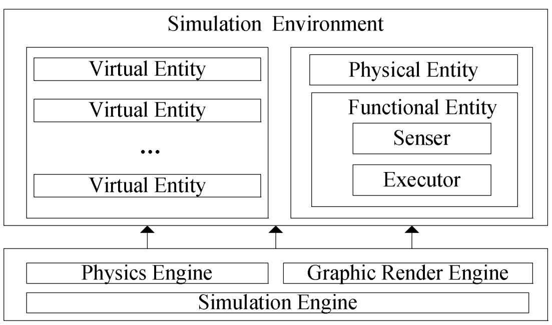


Fig. 2. Structure of Simulation Environment

As shown in Fig. 2, high-fidelity simulation environment simulates lots of virtual entities, and the rapid prototype of the intelligent robot is also a virtual entity. A virtual entity is made up of a series of basic entities including physical entities and functional entities. Physical entities are the foundation of the virtual robot in the environment, which can be cuboids, spheres or cylinders. Functional entities approximate to the sensors and executors mounted on the robots. They have no geometric appearance, but they can realize some useful functions. For example, sensors collect information from the environment and the robot itself, and executors implement the commands from the robot controller, such as driving the robot to a target position.

To facilitate assembling these basic entities into the rapid prototype of the robot, robot and scene design module is provided. With this module, developers can easily establish and modify their virtual robot prototype.

The physical entities and functional entities are simulated by the simulation engine. Since the simulation engine simulates every visual entity, it is the foundation of the simulation environment. Simulation engine updates the status of the virtual environment, and provides developers with an interface to access the sensors and executors. The simulation engine is composed of two parts: physics engine and graphic rendering engine. The simulation engine has an accurate physics engine. The physics engine provides parametrical simulation for complex physics entities, including basic physical principle simulation, kinematics simulation and dynamics simulation. The detail parameters which the physics engine handles are listed in Table I. Moreover, the simulation engine has a graphic rendering engine to render physics entities.

TABLE I
SIMULATION PARAMETERS

Simulation Subject	Simulation Parameters
Basic Physics Principle	coordinates, collision, shape limits
Kinematics	position, velocity, acceleration, angle, angular velocity, angular acceleration
Dynamics	force, moment, friction, energy, momentum, angular momentum

High-fidelity simulation is a reliable basis for robot design. Taking advantage of the powerful physics computing and graphic rendering ability of the simulation engine, the simulation environment has the capacity to simulate the dynamic performance of intelligent robots, and provides a safe environment to help people study the parameters and behavior features of the robot. Thus, dynamics and kinematics features can be revealed, and problems encountered in the process of designing and testing robots can be solved.

B. Robot Controller Developing Module

Robot controller is the key to realize the intelligence of the robot, which is developed in the controller developing module. The robot controller processes the information from the sensors on the robot to collect the status of the environment and itself. According to the designated task, the controller makes decisions and controls the executors on the robot to perform proper actions. The process of controller design involves two parts: control architecture design and control algorithm design. The relationship between the controller developing module and the simulation environment is shown in Fig. 3.

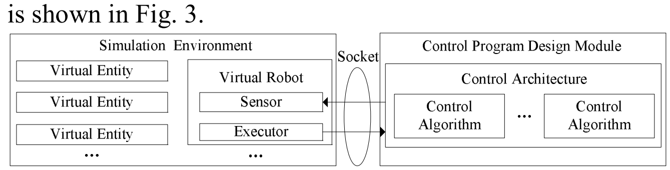


Fig. 3. Relationship between Controller Design Module and Simulation Environment

The control architecture is a structure that coordinates information acquiring and analyzing, motion planning, decision making, and executor controlling.

C. Compiling and Downloading Module

The compiling and downloading module enables the controller to run on diverse operating systems and hardware platforms. By cross-compiling, the code for the robot controller can run on Windows, Linux, and some other operating systems. To make the code compatible, the compiling and downloading module provides various compliers for different hardware platforms, e.g., DSP, ARM, etc. Through the interface, the code can be downloaded to the hardware easily. Moreover, the compiling and downloading module also provides the function of hardware-in-loop simulation [6], which benefits developers for they can modify the code online.

III. Humanoid Robot Development with VE-RPDF

According to the idea proposed above, VE-RPDF is utilized to develop two types of robots, including wheeled robots and humanoid robots. These robots prototypes were adopted as the official competition platform in China Robot Competition in 2008. Meanwhile, the VE-RPDF is practically used to assist the participants to design and develop their own robot system, which tremendously increases the efficiency of the work. In the following paragraphs, as an instance, the process of developing humanoid soccer robot with VE-RPDF is introduced:

1) Establish Structural Prototype:

According to the actual situation of competition, a biped robot is designed. Considering that, the soccer robot does not need to walk on rough ground but merely flat ground in the competition, six degrees of freedom on each leg are assigned. The robot arms are designed to keep the balance, so three degrees of freedom in each arm are enough. In addition, the head should have two degrees of freedom, because the robot must observe the surrounding. Therefore, the humanoid soccer robot has twenty degrees of freedom in total. Fig. 4 shows the size of each part of a humanoid robot.

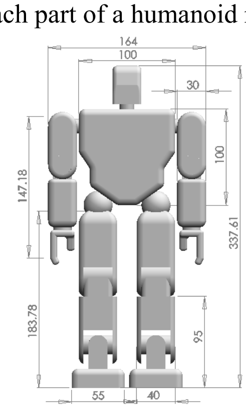
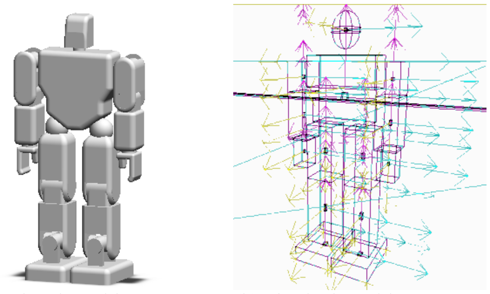


Fig. 4. Size of Humanoid Soccer Robot

After designing degrees of freedom, sensors and executors are designed. The soccer robot includes three kinds of sensors, i.e., camera, gyroscope and angular sensor. The detail design is: one camera is mounted on the head, one gyroscope is fixed to the torso, and angular sensors are installed on each joint. The executors in robot are steering gears mounted on each degree of freedom. The final prototype is shown in Fig. 5.



(a) Rendered Rapid Prototype (b) Physical Rapid Prototype

Fig. 5. Rapid Prototype of Humanoid Soccer Robot

2) Develop the Robot Controller: The design of the robot controller includes two levels: controller architecture design and control algorithm design.

Robot controller architecture for the soccer robot is to integrate the different modules such as perception module, strategic module, execution module, etc., and therefore it can complete tasks in dynamic environment. The humanoid soccer robot makes decision every 30ms. Its strategic process is shown in Fig. 6.

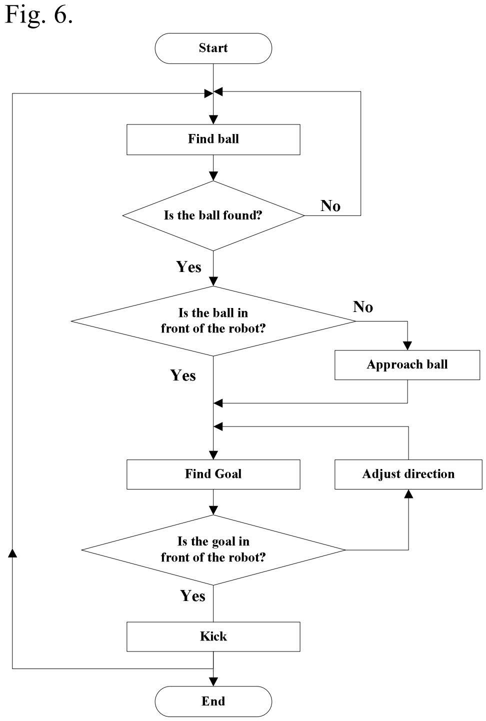


Fig. 6. Controller Architecture

The control algorithm of the soccer robot focuses on how to control the robot. To get the information of the ball position, images acquired from virtual camera are analyzed with the image recognition algorithm. To coordinate the task of each soccer robot, a task planning algorithm is adopted. The gait planning algorithm is used to ensure that the robot walks stably.

$$p_x = x - \frac{(z - p_z)\ddot{x}}{\dot{z} + g} \qquad (1)$$

$$p_y = y - \frac{(z - p_z)\dot{y}_i}{\dot{z} + g} \qquad (2)$$

Where x and y are the x- and y-axis coordinate of the gravity center of the humanoid soccer robot. $\dot{x}$, $\dot{y}_i$ and $\dot{z}$ are the x-, y- and z-axis acceleration of gravity center of the humanoid soccer robot. p_z is the height of ground[8].

4) Verify the Robot Controller on Hardware: The controller verified by the simulation environment is associated with robot hardware and the hardware-in-loop simulation is implemented. Consequently, the controller is converted into executable code and downloaded to the corresponding hardware platform.

Finally, only with some slight adjustment to joints' parameters, the resulting gait from VE-RPDF could be applied to real robot. The comparison between the gait of virtual robot and real one is shown in Fig.7. The difference of critical joints between simulated and real robot is shown in Fig. 8.

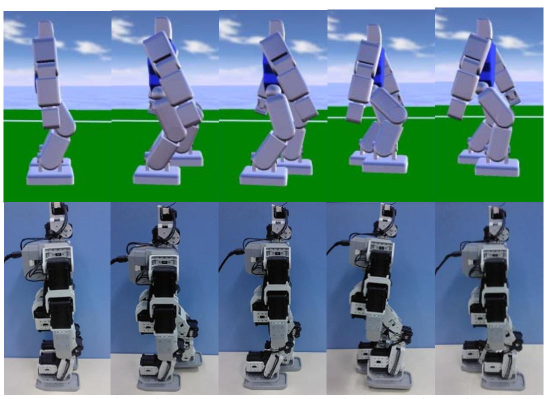


Fig.7 Comparison between Gait in Simulation and Real Situation

IV. Conclusion

In order to facilitate the developing of robots, the virtual entity based rapid prototype developing framework (VE-RPDF) is proposed. It includes three parts, i.e. the high-fidelity simulation environment, the controller developing module and the compiling and downloading module. On the basis of this framework, a wheeled robot and a humanoid robot are developed, which are adopted as official competing platform for simulating game in China Robot Competition Tournament in 2008.

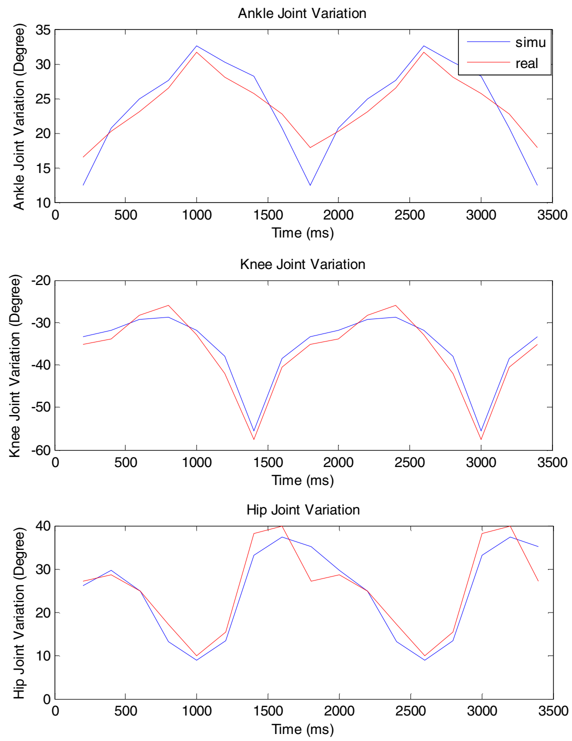


Fig. 8. The difference of critical joints between simulated and real robot

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