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A Virtual Simulation Experimental Platform for Smart Home based on Unity3D

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Abstract

Smart home provides people with a more convenient and intelligent way of living and it is one of the most widely used application of Internet of Things (IoT). However, building a smart home laboratory for students to visit and learn is labor intensive and time consuming. In order to meet the demand of experimental teaching in higher education, this paper designed and developed a Virtual Simulation Experimental Platform (VSEP) for smart home. Firstly, we introduced goals, platform architecture and functional modules of the system. Then, the development process was discussed. Specifically, the model of smart home was quickly built in SketchUp and imported into Unity 3D project, and both the scene roaming and interactive functions were achieved by coding C# scripts. Finally, we described the key methods in details and accomplished the development work. The proposed platform provides an immersive virtual environment for students to learn concepts and principles of related theoretical knowledge, and offers a new method for experimental teaching.

Keywords

Smart Home; Virtual Simulation; Experimental Platform; Unity 3D; Sketchup; ZigBee; Wireless Sensor Network.

1. Introduction

With the development of modern computer-related technologies, the control systems of smart home, which are developed base on the Embedded Systems, Wireless Sensor Network (WSN) and IoT technologies, have brought more convenience to people's lives [1]. However, a real smart home experimental environment requires high equipment investment and a long time in construction. In contrast, a virtual simulation platform has the advantages of low cost and high efficiency. A large amount of expensive lab bench equipment is not required, and students can have access to virtual platform in and after class. Thus, it can well solve the problems of limited experimental equipment in the teaching process, which plays an increasingly important role in university experimental teaching [2]. In recent years, China proposed National Project of Virtual Simulation Experiment and developed a public-service platform (https://www.ilab-x.com/), called "Experimental Space", which focuses on experimental education worldwide covering a wide range of subjects and specialties. As of June 2023, a total of 2591 courses were online, of which engineering and science experiments accounted for about 79%. The courses are designed to solve the problems when real experimental conditions are not available, involve high risks, or require a high cost [3].

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At present, scholars have designed VSEPs for their own research fields, and have made some progresses. For example, Wang et al. introduced the Godot engine to the development of multimedia teaching VSEP, which was an effective supplement to the real experiments and enriched online experimental teaching resources [4]. In the context of filming, the teaching equipment of traditional program shooting are expensive, and it is impossible to share the footage between teachers and students. Hence, targeting the disadvantages mentioned above, Bi et al. constructed a platform for film and television program shooting based on virtual reality technology [5]. Besides, Chen et al. designed and developed a VSEP to meet the needs of robot instructional display. Their results demonstrated that the platform could successfully meet the real-time requirements of virtual robot simulation movement [6]. Zhang et al. [7] and Lu et al. [8] established VSEPs for the teaching and practice of oceanography and hydraulic fracturing, respectively. Moreover, Liu et al. designed an interactive simulation-experimental teaching system of virtual shipyard and marine, providing an experimental platform that integrates learning, experiencing and testing together [9].

During the development of the VSEP, different techniques are applied to achieve researchers' goals. For instance, Tang et al. [10] developed an open VSEP of random signal analysis using Flash and Java languages. Due to the superior cross-platform applicability, Unity3D technology is widely applied in game development, virtual simulation, education teaching and many other fields [11]. An et al. [12] developed a simple desktop virtual platform for material mechanics course with Unity3D. Besides, in target of the common problems in the teaching of intelligent manufacturing related courses in universities, Liu et al. utilized Unity 3D software and developed a VSEP with vivid images and strong interactive functions [13].

Despite the fact that studies have made good progresses in various fields, there are only a few simulation platforms for smart home, with many of them focusing merely on the simple interactive functions such as roaming in the scene and controlling the switch of a device. Chen et al. [14] designed a model for virtual scenarios of household appliances and environmental monitoring devices. Xu [15] developed a virtual simulation smart home system, which contains basic interactive control of lights and curtains. Furthermore, Wu [1] introduced a virtual simulation system based on Proteus and Unity3D, which is able to control scene and hardware in a bidirectional way, and provide a good reference for the design and function verification of smart home control system.

In order to solve the problem of inadequate facilities in experimental teaching, and improve students' understanding of networking and communicating within a wireless network in smart home, this paper proposes a VSEP based on Unity3D. The system provides rich interactive functions for the users to deploy virtual sensors. Additionally, a simulated cellphone is applied to configure the network and control the smart devices. We design this virtual smart home system to help students to gain a deep understanding of the theoretical knowledge with good experience and interactivity, and hope that it lays a good foundation for experimental teaching related to IoT.

2. System Design and Development Process

2.1. Characteristics and Goals

The VSEP for smart home aims to build a platform where users could participate in the design of virtual scene, highlighting the student-centered experimental teaching philosophy. Teaching contents are designed carefully, accurately and appropriately. Specifically, the learning task of ZigBee network formulation is broken down into several steps and there is a sequence between them. Thus, the students should fully understand the steps and interact with the platform to finish the experiment. The main objective of this system is to cultivate talents who can think independently and solve problems by themselves. It is intended to establish a virtual

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experimental environment, enabling students to experience the entire workflow of WSN configuration and connection with smart devices in an immersive situation.

2.2. System Architecture

The platform is designed with Client/Server (C/S) architecture, including data layer, business layer and presentation layer. The detailed design structure is shown in Fig 1. In this structure, the data layer is used to provide the basic data information required by the platform, such as user information, teaching resource bank and the component library. The business layer is mainly responsible for all kinds of the logical services of the platform, completing the communication between the data layer and presentation layer. Finally, the presentation layer is applied to accept user requests, call the middle layer for business logic processing, and return data to the user. Users can roam in virtual home, view the experimental guide, and configure the network of devices. In addition, the intelligent control system can automatically adjust the sensor devices according to the environmental monitoring data. The platform also provides an assessment system to help the students consolidate and review the knowledge.

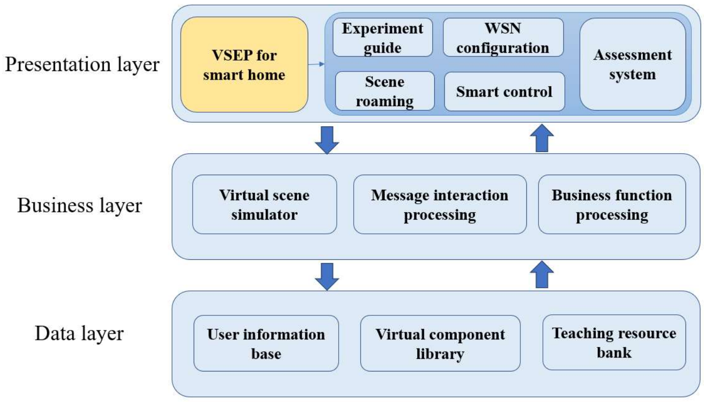

Fig. 1 System architecture

2.3. System Functions

The VSEP for smart home should allow users to roam in room and control devices remotely. As an experimental platform, it instructs experimenters to deploy smart sensors in virtual scene and finish the work of networking based on WSN. It can also record students' practical performance. In particular, the designed functions (seen in Fig. 2) are as follows:

(1) Roaming and interaction. The VSEP provides instructions for users on how to roam in virtual home by using mouse and keyboard. It also provides tips to guide students to fully utilize and interact with the platform.

(2) Configuration of WSN networking. For a smart home, the basic function is the remote control of the devices or sensors, which is usually based on wireless network. Therefore, it is necessary to configure the network before controlling the sensors, including the configuration of ZigBee devices, gateway, routing and other parameters. The key points lay in the addressing of mechanisms, and students must learn how to calculate the address of each device within ZigBee wireless network. This module is designed for students to practice and repeat experimental steps without limitation.

(3) Smart control. Smart control includes the control of temperature, light, doors and windows, and smart TV. The platform can monitor the parameters in the simulated environment and turn on/off the smart devices according to the preset threshold. In this system, it can monitor the temperature and humidity in the room, the density of combustible gas and water level in the pool. According to measured data by the sensors, users can adjust the temperature and humidity to make the living environment more comfortable. In addition, when the combustible

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gas concentration or water level is higher than the preset threshold, the kitchen stove or water tap will be turned off. Meanwhile, users can receive message reminders in the simulated cellphone to warn them of potential accidents hazards such as fire and flooding in the kitchen.

(4) Assessment system. In this module, the user should log into the simulated cellphone and complete the arrangement of the devices according to the task list. Then, the addresses of the gateway, ZigBee coordinator and routing nodes are calculated and configured to complete WSN networking connection. All the operation steps will be verified and scored by the platform, providing an assessment of the experimenter's performance.

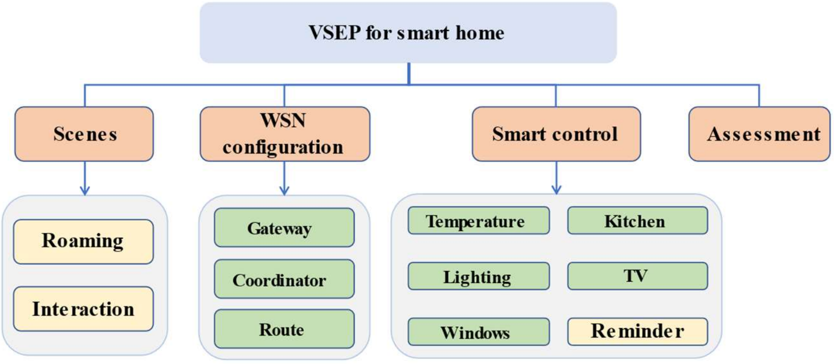

Fig. 2 Functional framework

2.4. Development Process

The VSEP for smart home is a multi-functional virtual platform and contains images, sounds, scripts and other teaching resources. It is mainly developed based on Unity3D engine. The development process is shown in Fig. 3. Firstly, we use SketchUp software to model a virtual smart home quickly, and then import it into Unity 3D. It is well known that a friendly user interface (UI) will substantially improve the user's interest in learning. Hence, the Unity Graphical User Interface (UGUI), a powerful and use-friendly UI system provided by Unity3D, is applied to design the user interface. Then the scripting program written in C# is adopted to accomplish the logical events of the virtual simulation and finally complete the interaction activities between the user and the system.

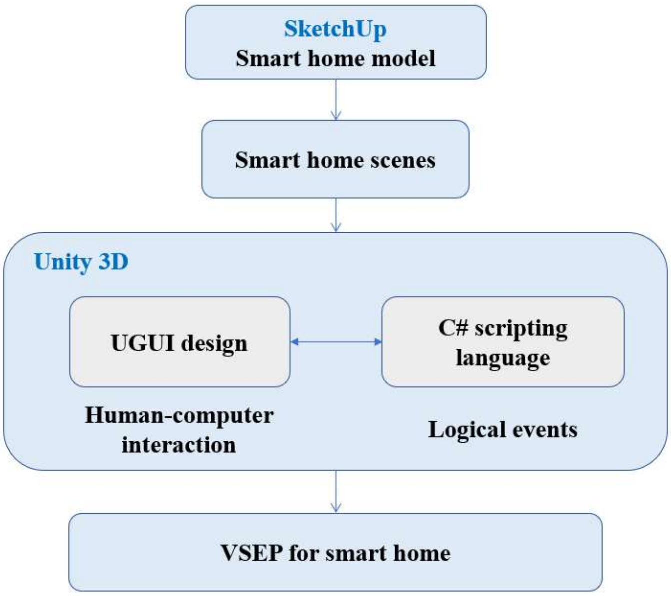

Fig. 3 Flowchart of development

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3. Key Methods

3.1. Wireless Sensor Networks

A WSN is a network of small, autonomous devices called sensor nodes with wireless communication and limited processing capabilities. These nodes work together to monitor and collect data from the environment, such as temperature, humidity, light intensity, and other physical or environmental conditions. The collected and processed information will be sent to an observer [16]. The sensor nodes in the network are flexible, and can self-organize and manage the configuration of the network structure to cope with changes in the environment. Wireless sensor network offers several advantages over traditional wired sensor networks, such as easy deployment, flexibility, and cost-effectiveness. It is one of the mostly used technologies when the wireless network is formed in smart home.

3.2. ZigBee

ZigBee is a versatile and reliable wireless communication protocol that provides low-power and low data-rate connectivity in communications between sensor nodes [17]. It contains two types of devices called full function device (FFD) and reduced function device (RFD). FFD can operate as a personal area network (PAN) coordinator, a router or an end device, while RFD is commonly referred to as an end device.

ZigBee networks can be configured to operate in one of three topologies [18]: Star, Tree and Mesh. We apply Tree topology to describe the communication and relationship between the coordinator, routers and end devices within the network. ZigBee also defines various channels to avoid interference with other wireless technologies operating in the same frequency range [19]. Moreover, students are able to learn about the hierarchical relationships between nodes and calculate the addresses according to a distributed address assignment mechanism [20].

3.3. Collision Detection

Collision detection is mainly used to simulate interactions and collisions between objects, and it is a simulation of the instinctive reaction of objects when they encounter obstacles in real situations [21]. In Unity3D, collision detection is implemented through collider and rigidbody components. A collider is a component applied to detect collision, while rigidbody is to simulate the physical motions of objects. In the VSPE for smart home, the two components can be added to objects to perform the detection of obstacles, such as walls and doors.

3.4. Particle System

Unity3D provides the particle system, a technology for creating particle streams to represent effects that are normally difficult to portray. It includes several modules and the most commonly used modules are the initialization module, emission module, shape module, collision module and the material module [22]. We can change the specific number and shape of particles by editing those module parameters, and finally creating the water flowing and flame burning effects in smart home.

4. Implementation of VSEP

When users open VSEP for smart home and enter the main interface of the platform (as shown in Fig. 4), they can roam in the smart home scene, and click on the instruction and guide icons to find out about the details on how to use the system, as well as the purpose and principle of the experiment. They can also repeat the core experimental content without limitation in WSN configuration module. Additionally, the experimenter should create an account and log into the simulated cellphone to remotely control the terminal devices.

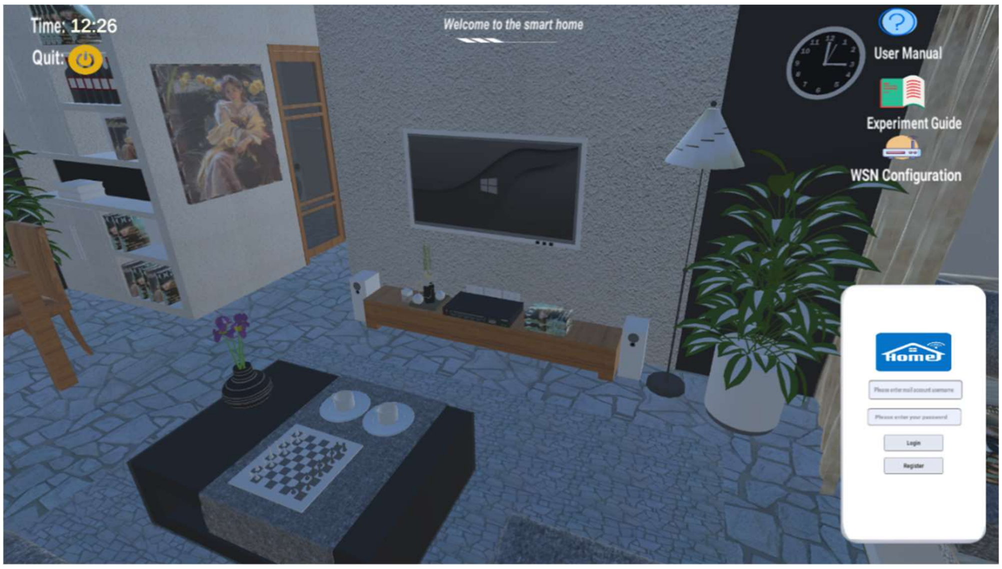

Fig. 4 Main interface

The cellphone-controlled interface includes 9 items: assessment system, WSN check, WiFi connection, temperature control system, lighting system, door and window system, kitchen system, smart TV, and information tip (as seen in Fig. 5). If the WSN is successfully configured and all the devices are connected to the network, the experimenter can then use the simulation cellphone to control devices. Many of the systems mentioned above support both automatic and manual modes of adjustment. For instance, the temperature control system can automatically adjust its temperature according to sensors' collected data (Fig. 6). The user can also manually enter the temperature value and change the mode by using the simulation cellphone (as shown in Fig. 7). Information tip function can also be used to receive messages from sensors, especially to warn the user when the water level or combustible gas concentration exceeds pre-defined threshold.

Fig. 5 Interface of simulation cellphone

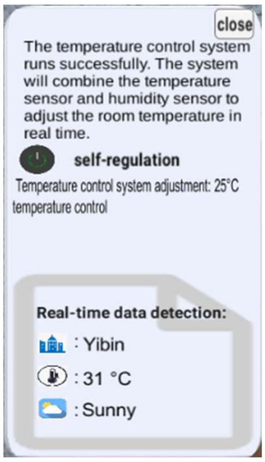

Fig. 6 Automatic mode

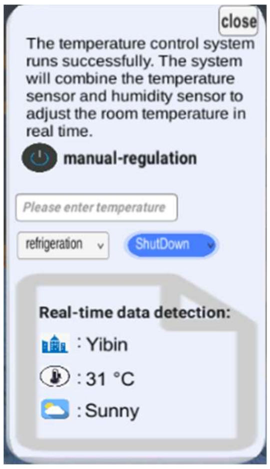

Fig. 7 Manual mode

The assessment system is the core function to evaluate students' performance. Firstly, users should complete deployment of the devices in the smart home according to the given list of tasks. Fig. 8 shows the list of tasks with completion progression indicators. A corresponding score will be obtained after completing each task in the list (Fig. 9). The system also provides tips to help users conduct the experiment (Fig. 10). They need to configure the WSN networking,

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including the settings of smart gateway (Fig. 11a), ZigBee coordinator (Fig. 11b) and route node (Fig. 11c). After all devices have the right addresses, users can connect to wireless network to control the sensors remotely. The platform will record each operation step mentioned above, which will then be used as a comprehensive assessment of the experimenter.

Fig. 8 List of tasks

Fig. 9 Score of the task

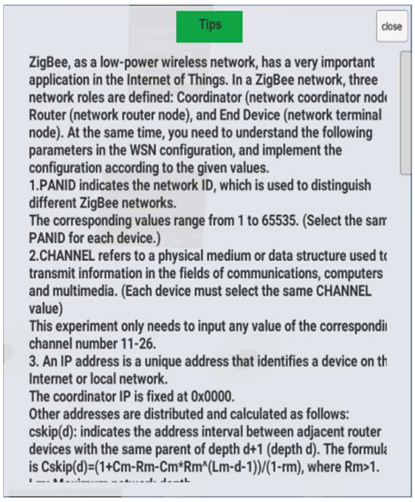
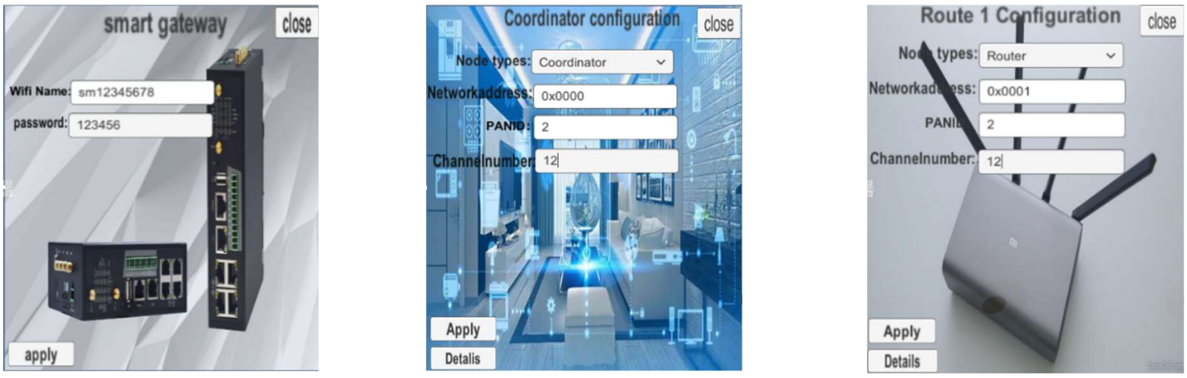


Fig. 10 Tips



a) Smart gateway b) Coordinator c) Route

Fig. 11 Configuration of the network

5. Summary

This paper designed and developed a VSEP for smart home based on SketchUp software and Unity 3D engine, and it introduced characteristics and goals, the architecture, functions and the development process of the system, with the key methods discussed in details. The system provides an immersive environment for experimenters, where users can interact with the platform and learn in depth about the theoretical knowledge of WSN. Besides, it breaks the time and space restrictions in teaching and learning with low cost and high reuse rate, and enhances user's learning interest. We will strive to explore a variety of WSN application fields, such as smart farming and smart library, and hope to build more scenes to improve the experimental interactive experiences in future.

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