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# REMOTE CONTROL SYSTEM OF WEB-BASED 3D SMART HOME

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Abstract. *Since the concept of smart home was proposed, great progress has been achieved in this field. This paper introduces a new design for smart home which is based on 3D web technology. In this web-based 3D smart home, Flash 3D engine are used to create a remote virtual home in users' web browsers. Users are able to monitor and control their homes remotely in the virtual smart home in the web-based 3D virtual reality world using the mouse and keyboard. The 3D virtual homes and the real homes are synchronized through the Internet. To guarantee the synchronization among the web server, the web client and the home appliances, a four-layer communication structure is designed in the system. When users login the web client, they can "walk around" in the virtual home and get immersed in it similarly as they do in real homes rather than just clicking on the tags of the two-dimensional web pages. The layouts of the virtual 3D homes are customized according to the real dimension of their homes so that the users feel like they are wandering in their real homes. Due to the adoption of B/S (browser-server) structure, users are able to access the system using any devices with a web browser such as PCs, tablet devices and smart phones without the restriction of their platforms and its corresponding operation is accomplished without the necessity of installing software on remote terminals. The 3D web-based smart home can provide great convenience, flexibilities and immersive visualization to users.*
**Keywords:** Smart home, Remote control, Web-based applications, 3D virtual reality

1. **Introduction.** The concept of smart home is not new and it has been put forward for a couple of decades [1,2]. In the last twenty years, major developments have been achieved in home automation in USA, Japan and Europe. However, these works were done independently and driven by different objectives, which led to the appearance of many different architectures, incompatible with each other like those proposed in [3-5]. A client-server architecture designed in [4] is composed of system kernel, adapter components and home devices structure. A software designed especially for this architecture needs to be installed on the client-side if users adopt this one. The design and implementation of more complex smart homes have been introduced in the work of [6-8]. In [6], the SOAP-based residential management for smart home system's appliances control is presented. In SOAP-Based structure, all instructions are based on the Simple Object Access Protocol. The main components of SOAP-Based residential management for smart home systems consist of residential application gateway configured using an embedded CPU, network interface, switching module and remote terminal. The complexity of this architecture is based on the costs of much more software design and hardware's.

The present state and future challenge of smart home is presented in [9,10]. The work of [9] presents that, nowadays, households spend a large fraction of their income on cars, computers, etc. and very little is left for home automation devices. Still, the progress of remote management and elderly assistance is mentioned in [9]. The concept of smart home refers mainly to comfort, leisure and healthcare. However, the last 20 years of development have failed to achieve anticipated results. Demand has been slack, and the supply of smart home technologies is too low [10]. A few years ago, remote control in smart home could only be predicted [9], and there are in fact applications of remote control as mentioned in the work of [11,12]. The surveillance camera can instruct the heating system to switch on the heater, control the lighting system to switch on the lights in the hall and the living room, and manipulate the television to play the preferred channel when the owner approaches the front door. As time goes by, the rapid changes in smart home systems will be far beyond predictions.

Smart home technologies are not built in one day. Various technologies which can be potentially applied for smart homes are gradually developed, such as wireless power outlet introduced in [13] which integrates a ZigBee radio and acts as an actuator node in the home automation networks for remote control operations, telecare services [14], interoperability among heterogeneous systems [15], constructing resource relation graph [16], smart services [17], etc. The application of these technologies enables the architecture of smart home simple and well-organized. With the development of science and technology, smart homes are becoming more and more intelligent. There are many methods to control smart home, by TV [18], mobile [19], even voice recognition [20]. For the early version of smart homes, users can only access their home appliances locally [21], which brings inconvenience to them. With the development of Internet technology, Internet-based control has been gradually applied to the remote control of smart homes [22]. Users are able to monitor and control their home when they are away through Internet communications. For example, users can turn off the lights or heaters which are left on after they leave home, turn on the air conditioners before arriving at home, and close windows while it is raining. These years, web-based 3D technology which was first used in the computer games [23-25] has been developing rapidly. 3D technology can provide users with virtual scene and immersive visualization in which users can get wonderful experience of presence [26]. It just gives out the new directions and perspectives of smart homes [27]. Now web-based 3D technology has been used in many applications such as web-based 3D remote laboratory [28,29], 3D intelligent street lighting [30], etc. In the 3D remote laboratory [29], a new framework with virtual reality interface is adopted which provides rich user interactive features. With 3D interface, users can "walk into" sub-laboratory and select test rigs so that they can get immersive visualization.

While web-based 3D technology is applied in smart home [31], users can experience their homes remotely from first person point of view [32]. When the client web is opened, a scene of home appears in front of them. It is just like the home scene in real time using 360-degree photography and immersive video – allowing for recording of every direction at the same time. The user can "walk around", "look at" what is happening in their home, control the household electric appliances like lights, air conditioners, televisions and refrigerators, and also collect the information of electricity consumption [33,34] of each home appliances.

However, most of the existing smart home systems adopt C/S (Client-Sever) structure and users have to install client software in their computers, which could bring in new inconvenience and also limit the application of the systems. In this paper, a new web-based 3D smart home is proposed. In this system, the whole 3D virtual smart home is constructed inside the web browser. Users are able to access the system using any devices

with a web browser without any platform restrictions and any client software installation. The new framework designed for this smart home system makes it possible for the users to customize their own smart home according to their real homes. In addition, the layout of the furniture and household electric appliances can be customized by the users easily in the 3D interface.

2. **Concept of Web-based 3D Interface.** There are several solutions available for web-based 3D virtual realities. WebGL (Web Graphics Library) which uses the HTML5 canvas elements is a set of JavaScript APIs for rendering interactive 3D graphics within any compatible web browsers. Google Native Client (NaCl) provides a set of 3D APIs for web-based 3D rendering. BIFS (Binary Format for Scenes) under MPEG-4 standard is another solution to represent 3D scenes and objects in web-based applications [35]. Stage 3D which is a part of Flash 11 is a new method in 3D rendering. It supports a set of low-level GPU accelerated APIs. For the convenience of the developers, there are also a few 3D engines based on Stage 3D available and most of them are open source software. Even though the expansion of WebGL, NaCl and BIFS has been very fast in recent years, Adobe Flash still has the biggest market share and has been installed in more than 95% of Internet-enabled PCs so far, according to a survey conducted by Millward Brown in July 2011, which is high above other competitors. The web-based 3D smart home adopts Flash as the 3D graphic engine; therefore, it is compatible to most web browsers due to the popularity of Flash. As long as the Flash is supported, the whole system can be easily transplanted to many mobile platforms such as mobile phones, tablet devices, etc.

3. **Architecture of the Smart Home.** The smart home system consists of the design of hardware and software. To monitor and control the smart home in the 3D virtual world, a four-layer communication structure is designed in the system to guarantee the synchronization among the web server, the web client and the home appliances. In the software design, a B/S structure is adopted to transcend the restriction of the platforms.

3.1. **System structure.** The hardware architecture of the 3D smart home system consists of 4 layers. They are the client layer, server layer, control unit layer and home

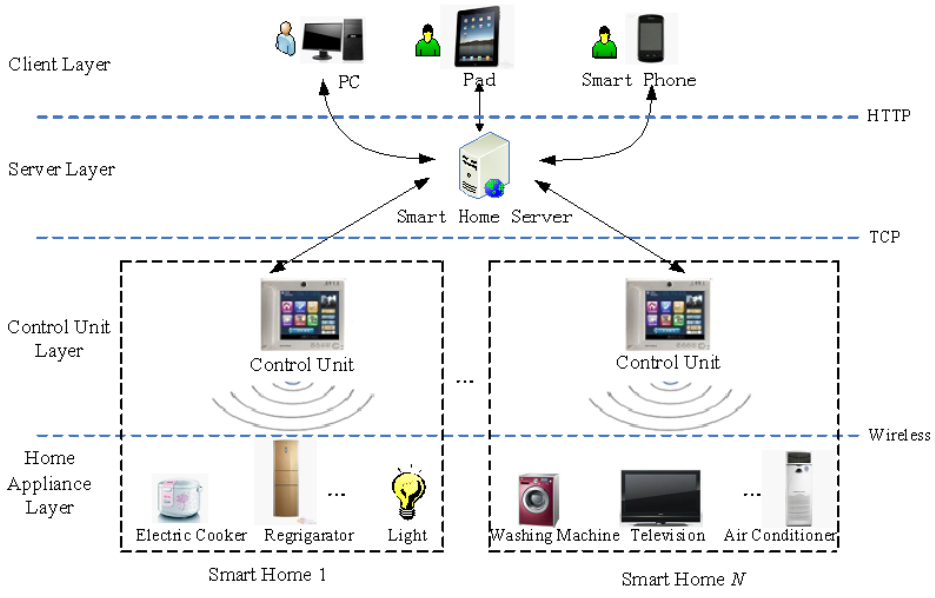


FIGURE 1. Hardware architecture of the 3D smart home system

appliance layer as shown in Figure 1. In the home appliance layer, the home appliances are modified, so they can be accessed and controlled via wireless communication. The Control Units located in the users' home have a LCD touch screen and Internet communication interface. Users can manage and control their home appliances on the LCD screen locally and it can also receive the control commands from the Smart Home Servers. The Smart Home Server is deployed in the property management center. It is able to integrate many smart homes and provide the web services for the remote smart home control and management. Users are able to access their Smart Home systems remotely using various platforms according to what they like. The software structure of the 3D smart home is illustrated in Figure 2. When users want to know what is happening in their homes, what they need to do is to open the web browser and then login the smart home web address. Then the communication between the Control Unit, Smart Home Server and the Web-based Client is established. The users are able to immerse into the 3D smart home, monitoring their home and controlling the home appliance remotely. There are two kinds of communications. One is from the Smart Home to the Web-based Client, by which the users are also to send control commands (such as the switch on of a home appliance) remotely to their homes. The other is from the Control Unit to the Web-based Client. The information such as the status of the security alarms, electricity consumptions are collected by the Control Unit locally and uploaded to the users through Smart Home Server.

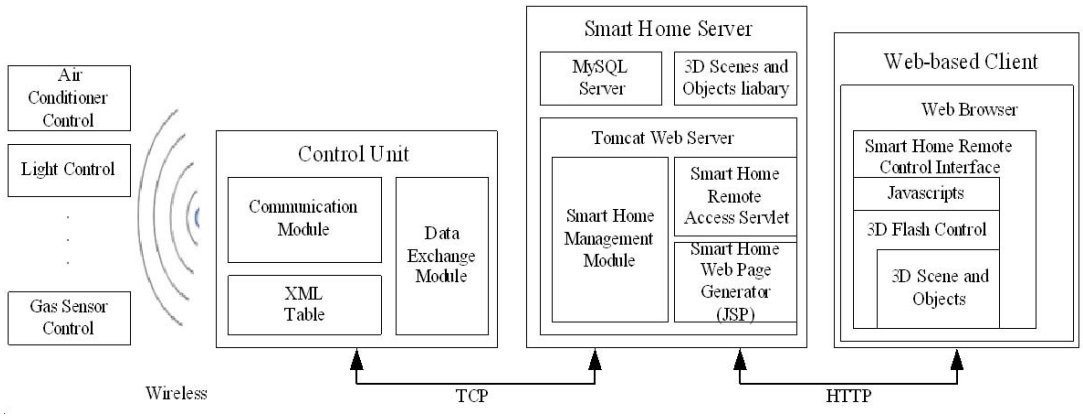


FIGURE 2. Software architecture of the 3D smart home system

3.2. **Inside of the smart home.** For each smart home, there is a central Control Unit and many home devices such as home appliances, security sensors. The Control Unit and home devices are connected using wireless communication. The photo of the smart home Control Unit is shown in Figure 3. The operating system running in the Control Unit is Linux and the embedded software is developed by using Qt which is a cross-platform application and UI framework.

The users are able to access their home devices locally using the UI interface on the LCD screen. Remote access services are also developed in the Control Unit, so it can also exchange data with the Smart Home Server via Internet connections. The kernel part of the Control Unit is a XML table which stores all the information about the home appliances and security sensors. Each device has a corresponding element in the XML table, where its ID, type, locations and status, etc. are specified. If there is any change (such as the trigger of the security alarm) on the home devices, a message will be sent to the Control Unit. When the communication module in the Control Unit

FIGURE 3. Smart home control unit

receives the message, it updates the new status in the XML table. The Data Exchange module detects the changes on the XML table and then notifies the Smart Home Server through a TCP connection. On the other hand, if the Data Exchange module receives any command (such as the switching of a light) from the Smart Home Server, it would also make corresponding changes on the XML table. The Communication Module keeps looking at the XML table. When it notified the changes, control commands are generated and sent out to the corresponding home appliance via wireless communications.

3.3. **3D virtual smart home remote control interface.** In order to provide web-based remote control services, a Smart Home Server is deployed in the property management center. The Tomcat web service and MySQL database are deployed in the Smart Home Server. The information such as the users' account numbers, passwords are stored in the database. Inside the Tomcat Server, a Smart Home Management Module is developed to manage the TCP communication with the Control Units. For each Control Unit, there is a corresponding XML table created inside the Smart Home Management Module. It is synchronized with the Control Unit through TCP connections. When a user logins the Smart Home web service, the web browser starts to request the web-based interface from the Smart Home Server. JSP pages and JavaScript codes are generated dynamically according to the XML device table by the Smart Home Web Page and downloaded to the client side through HTTP connections. The JavaScript running on the client side loads the 3D Flash Controls and 3D objects, so the virtual homes can be reconstructed in the user's web browser. When a user wants to control a home appliance remotely, he/she can move to the corresponding appliance in the virtual home and manipulate its status using the mouse and keyboard. The 3D Flash Control sends the changed status to the Smart Home Server, which modify the XML table and transfer the command to the Control Unit in the user's home via TCP connections.

4. **Implementation of 3D Virtual Home.** To implement the 3D virtual home, a lot of things should be considered include building 3D models for real objects, rendering the models, creating the virtual reality environment, etc. Above all, constructing a system based on the web which is used to show the 3D virtual home to users is very important.

4.1. **3D modeling.** To construct a 3D smart home in web-based virtual reality, 3D models for rooms, furniture and home appliances need to be modeled in 3D first. There are many commercial software available for the 3D model design, such as 3DS Max, Solid Works and Pro/E. The original 3D models to be displayed in the web-based interface were

firstly designed by using the software and then converted into a common format which could be recognized and decoded by Flash 3D engines. In the case of smart home, 3D models are constructed in 3DS Max. Figure 4 shows a sofa as an example of 3D models constructed in 3D Studio Max environment. The models designed in the 3DS Max are exported into the Wave front .obj format for the Flash 3D engine. When designing the 3D models, the quality and the complexity of the 3D models have to be balanced carefully. High quality 3D models always result in big target files, which could cause long delay when downloading these files in the Internet environment.

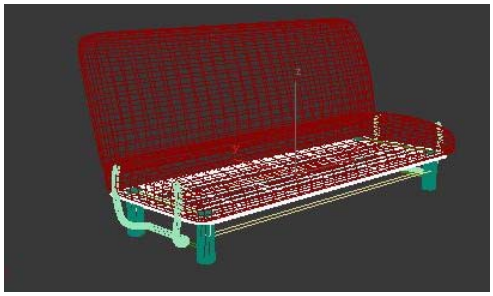

FIGURE 4. 3D model of a sofa in 3D Max

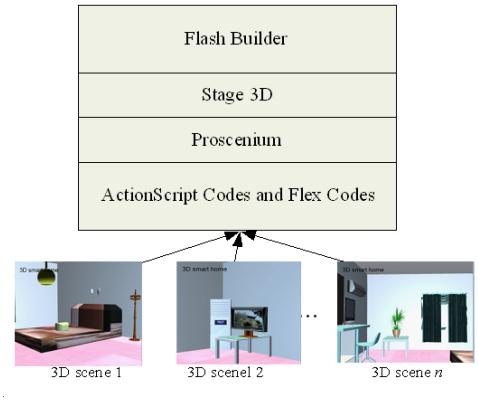


FIGURE 5. Structure of 3D flash control

4.2. **3D flash control.** The release of Flash 11 has changed the situation. Flash 11 starts to support hardware accelerated 3D rendering, which makes it possible to design more complex 3D applications. Stage 3D which is a set of 3D APIs in Flash 11, enables advanced 3D capabilities on both PC and mobile platforms. In order to help developers to design web-based 3D applications quickly, Proscenium, which is an Action Script code library built on the top of Stage 3D, has also been released. By using Proscenium, models designed using 3D design software can be easily imported and rendered into Flash Controls. The structure of 3D Flash Controls in the Smart Home is depicted in Figure 5. By using the resources provided by Stage 3D and Proscenium, 3D models designed in the 3DS Max environment are imported into Flash Controls, which are embedded into web browser. Therefore, they can be embedded and displayed in the web-based interface. Figure 6 is a 3D smart home scene rendered in 3D Flash Control.

4.3. **Web-based 3D smart home.** Figure 7 depicts an example of how a 3D smart home is displayed in the web browser. All the home appliances, furniture are modeled in 3D with real dimensions. The layouts of the real homes are measured and the configurations are stored in the database deployed in the smart home server. When the 3D Flash Control running in the user's web browser initialize, it requests a XML table from the web server. The XML table is created dynamically by the Smart Home Server according to the real layout of the user's home stored in the database. All the home devices and furniture are listed in the XML and the detailed information such as the ID, model name and position is also specified. The 3D Flash Control parses the received XML, loads the 3D models of the rooms and home appliances according to the information obtained from the XML and reconstructs the smart home scene in the web-based 3D environment. After the 3D smart home scenes are created, the users are able to use their mouse and keyboard to "walk into" the virtual reality home. The 3D Flash Control keeps requesting the latest status from the Smart Home Server every a few seconds. Therefore, any changes on the

FIGURE 6. A 3D scene of smart home rendered in flash control

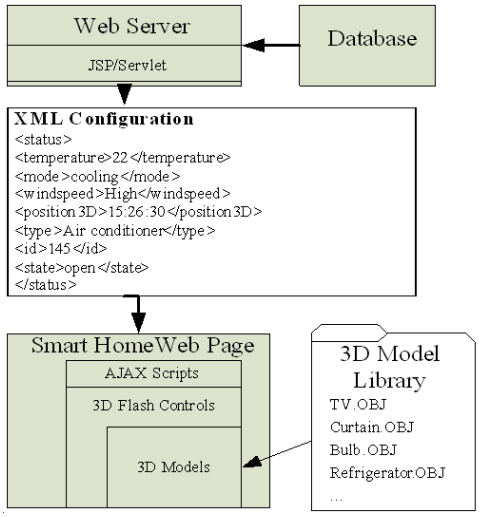


FIGURE 7. 3D smart home display

real home would be reflected in the web-based virtual world. When the user operates on the home devices in the virtual world, the 3D Flash Control interprets the operation and sends a command to the Smart Home Sever which transfers it to the corresponding Control Unit.

5. **Experimental System.** The experimental version of Smart Home system has been implemented in a laboratory in Wuhan University, China. All the household appliances like air conditioners, refrigerators, smoke sensors, bulbs, etc. have been placed in the laboratory to form the proposed smart home system. To improve the similarity between the real and virtual scene, all of the models are created according to the dimensions of the real objects.

Figure 8 depicts the web-based 3D interface of the smart home system. Home appliances like air conditioners and refrigerators are presented. Among all the home appliances, the 3D remote control of the air conditioner and the curtain is selected to show how the system works.

5.1. **The 3D remote control of air conditioner.** In order to control all of the home appliances, a wireless control rig is designed and installed as shown in Figure 9. Apart from the wireless communication, the control rig also has an infrared module installed which

FIGURE 8. The web-based 3D interface of the smart home

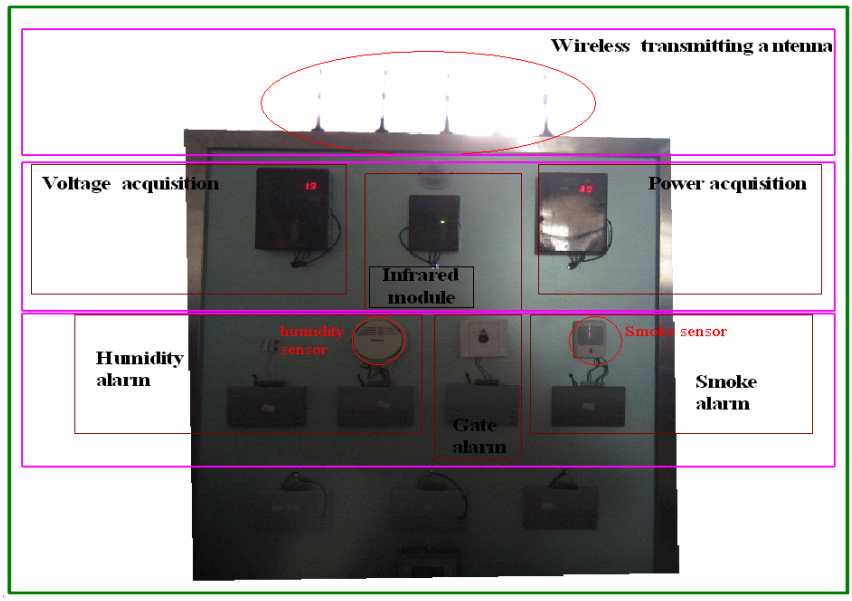


FIGURE 9. Control rig of home appliances

is able to encode and send infrared remote control commands to the air conditioner. It can receive the control commands from the Control Unit via wireless communication and manipulate the air conditioner using the infrared module. When users login the smart home website, the 3D virtual scene of the smart home which is constructed according to the laboratory configuration is presented to them. If the real air conditioner in the laboratory is switched off, the corresponding virtual object in the 3D virtual interface is displayed with the louver closed.

If the user wants to switch on the air conditioner, he can walk towards the air conditioner using the mouse and keyboard and click on the 3D model. A dialog box will be popped up as shown in Figure 10. In this dialog box, users can choose the specific parameters like the state (such as cooling or heating), wind speed, temperature. When the switch button is clicked, all of the instructions which change the status of the air conditioner will be passed down to the Control Unit through HTTP (hypertext transport protocol) communication and the Control Unit will send the corresponding commands to the air conditioner control rig where the infrared signals are sent out to switch on the real air conditioner. At the mean time, the status of the 3D model on the client side is also changed with the louver blades moving up and down, which indicates the real air conditioner at home is switched on at this moment as shown in Figure 11.

5.2. **The 3D remote control of curtain.** In order to control the curtain of the laboratory, a micro motor must be installed which is depicted in Figure 12. The opening degree of the curtain can be changed by controlling the rotation direction of the micro motor which is controlled by two different electromechanical relays. If the user wants to change the opening degree of the curtain, he can "walk towards" the curtain to click on the 3D model and a dialog box will be popped up shown in Figure 13. In this dialog box, users can choose the opening degree of the curtain ranging from 0 to 100% and submit the change of this operation to the Control Unit by clicking on the submit button. After this instruction is passed down to the Control Unit through HTTP communication, the Control Unit will send corresponding commands to control the status (on or off) of the electromechanical relay and the opening degree of the real curtain in the laboratory will be changed accordingly. The result of this operation is shown in Figure 14. Using similar


FIGURE 10. Air conditioner dialog box

FIGURE 11. Air conditioner from closed to open

FIGURE 12. Curtain with electromechanical relays

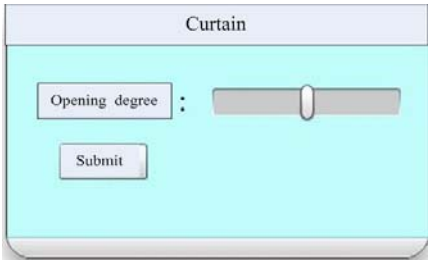


FIGURE 13. Dialog box of curtain

FIGURE 14. The change of the opening degree of the 3D model and the real curtain

methods, users are able to control other home appliances and monitor the security sensors remotely in the web-based 3D virtual reality interface.

6. **Conclusions.** In this paper, a web-based 3D smart home which can provide great convenience to users has been presented. As the new system adopts the Flash 3D engine to realize the 3D virtual reality interface, it can be implemented inside the web browser. In order to secure the communication between the home appliances, Control Units, server and web-based remote access interface, a four-layer structure is proposed and deployed in the system. With the new web-based 3D smart home, users can "walk around" in the virtual home with a sense of real present and immersion rather than just clicking on the tags of the two-dimensional web pages. In addition, Users can control home appliances in the web-based 3D interface using the mouse and keyboard remotely just like what

they do in their real homes. Considering the convenience and immersion of web-based 3D interfaces, virtual reality could be a future trend for the development of smart home technology. With the rapid development of the network and virtual reality technologies, it is both challenge and critical for the future smart home system to keep up with these new progresses.

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