AR Safety Education Software: Remind the Child and Make the Child Aware of Danger by Interacting With Indoor Items

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July 2021

Abstract

Children are the most vulnerable group among members of society and are vulnerable to various external factors. Children's physical and mental development is at an immature stage, with a low level of exercise and poor coordination. In addition, children's cerebral cortex cells are highly excitable, and they are curious about surrounding things, showing the characteristics of being active and difficult to control, and they are very prone to injury accidents. Therefore, safety education for children is very important.

But nowadays, the main safety education method is using safety knowledge, pictures, photos, videos and other media, through the organization of special activities to achieve educational goals.However, traditional safety education methods are usually only conducted collectively in schools, and there is no way to achieve personalized safety training. In addition, traditional education methods lack interaction, interest, and poor educational effects. Of course, there are also many software or systems that use virtual reality (VR) technology to simulate the occurrence of disasters and conduct safety education in simulated scenarios. These systems all satisfy the interactivity and fun, but the scenes simulated by VR are fixed, and they are quite different from the real life environment in which children live, and there is no way to achieve personalized education.

In this paper, we designed and developed an AR safety education software. In our system, first by combining Vuforia and MRTK, we have achieved a more precise "spatial perception" function, allowing the system to achieve virtual and real interaction. Secondly, we use Unity3d for development and write corresponding scripts for each virtual object to realize their interactive functions. We also use gesture recognition to decide whether to turn on the disaster training part and turn on the voice permissions of the system. We have also developed a function that allows users to customize disaster training plans according to their actual surroundings through voice.

In summary, our system can not only provide personalized safety education in combination with the user's surrounding environment, but also interact with virtual objects to add interest and immersion in education.

Keywords: Augmented Reality, Safety Education, Interactive

Acknowledgements

First of all, I would like to express my sincere gratitude to my supervisor, Prof. Jiro Tanaka, whose suggestions and encouragement have given me much insight into Human-computer interaction. Thank him for accepting me as a member of IPLAB in May 2020. It has been a great privilege and joy to study under his guidance and supervision. Thanks to him for giving me a lot of creative suggestions and expensive research equipment.

BesidesI would like to thank all IPLAB members. I am glad to have meet them and spent a precious time together during these 2 years. They have provided me so much help not only on my study, but also on my life away from home country.

Last but not least, many thanks go to my family for their unfailing love and unwavering support. Thank them for supporting all my decisions and encouraging me throughout my student life.

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Chapter 1

Introduction

1.1 Introduction

Because the family is usually the place where the children spend the longest time, most of the child safety accidents occur in their own families[1]. Especially when the parents do not have the energy to keep an eye on the child, the child alone may come into contact with some dangerous objects in the family or make some dangerous behaviors. During the period of children, a small accident may cause harm to the child for a lifetime. Therefore, family safety education for children is very important.

But there is still a problem that needs to be solved. This problem is-how to carry out family safety education? At this stage, most of the education of children is carried out through two-dimensional media. But our world is a three-dimensional world. The content in these 2D media is difficult to integrate with children's real life scenes. This form of learning may reduce children's interest and are not interested in what they are learning. But if real objects such as lighters are used in training, it may bring real harm to children. So we imagine if AR technology can be used to combine educational content with real life scenarios, then this new educational model will significantly enhance the effectiveness and interest of teaching[2].

According to Ron Azuma[3], AR technology needs to meet the following three points: It combines real and virtual content; It is interactive in real time; It is registered in 3D.

Therefore, to a certain extent, AR technology can apply virtual information to the real world and be perceived by human senses to achieve a sensory experience beyond reality.

In this research, We designed an application software on HoloLens 2 using AR technology. It mainly has the following three functions:

1. Children can recognize dangerous objects in real life scenes through this software;

2. Virtual dangerous objects can interact with children and can also react with objects in the real world.

3. This software can make children aware of the hazards of certain objects through hazard warnings and injury displays.

4. Children can conduct safety drills accompanied by their parents.

Through the above functions, children may clearly know which items are dangerous, which behaviors can cause harm, and how we should deal with these dangers.

1.2 Organization of the Thesis

The rest of the thesis is organized as follows: In chapter 2, we will introduce the background of the thesis. In chapter 3, we will introduce some related works. In chapter 4, we will describe the goal and approach of our research and show the use case of designing our system as well. In chapter 5, we will introduce the concept of the system design. In chapter 6, we will show the implementation details for the system development. In chapter 7, we will make a conclusion and talk about future possibilities.

Chapter 2

Background

2.1 Augmented Reality for Education

As a new type of human-machine interface and simulation tool, AR has received more and more attention, and has played an important role, showing great potential. Nowadays, AR technology has many application fields. Such as the medical field, military field, industrial maintenance field, education, entertainment games and other fields[4]. With the continuous decline of input and output equipment prices, the improvement of video display quality, and the practical use of powerful but easy-to-use software, the application of AR is bound to grow day by day.

When a new technology first appears, researchers usually try and use them in an educational environment. Augmented reality is no exception. Especially in the last ten years, AR technology has been tested in many different educational applications[5]. These experiments show that in some cases, AR can help students learn more effectively and increase the knowledge retention rate compared to the traditional 2D desktop interface[6]. AR was first introduced as a training tool for airline and Air Force pilots during the 1990s[7] . It is used today in every level of schooling, from K-12[8] to the university level [9]. For example, the Anatomy 4D mobile application designed by DAQRI was used as the educational AR tool, as shown in Fig 2.1. Using this software, students can learn more information, and vivid 3D models can also help them master the knowledge they want to learn.

Now more and more AR education software shows the potential educational advantages of AR technology. Even simple AR scenes can be used to motivate children in a classroom. Results show that AR's high level of interactivity enhances learning, particularly for students who learn through kinesthetic, visual, and other non-text-based methods. After trying the technology one teacher said that there is "no question that AR will prove to be a highly e!ective medium both for entertainment and education." [10]

2.2 Child Safety Education

Injuries at home constitute the majority of accidental injuries in children aged <6 years old, sometimes with devastating consequences for the child's well-being[11]. Home accidents comprise 35% of all unintentional injuries in childhood. Falls, thermal injuries and poisonings are the most common causes of emergency department (ED) attendances and hospital admissions[12]. For Example, child involvement with fire is a prevalent national problem. Statistics indicate that children playing with fire were responsible for 98,410 reported fires in the U.S.A., causing an estimated $300 7 million in direct property damages, 408 civilian deaths, and 3130 civilian injuries in 1994[13]. So it is very necessary to educate children about safety. Some findings confirm past speculation that caregiver supervision influences children's risk of medically-attended injury and highlight the importance of targeting supervision in child-injury prevention interventions[14][15].

There are many security risks in children's families, and various disasters may happen accidentally. But the corresponding preventive measures are relatively traditional.

For general consumer safety education, teachers usually explain and publicize scientific knowledge, so that children understand the hazards of playing with fire and electricity, and teach children not to use electrical sockets, gas, stoves, and boiling water to prevent accidents. The other way is to lead the children to visit the fire brigade and watch drills. Ask the firefighters to introduce the causes of the fire to the children, the role of the fire truck, the use of fire extinguishers and precautions, so that the children can master simple self-rescue skills.

However, most of the safety education is conducted in schools, and it is difficult for children to integrate with the life scenes of their own families.

There are also many studies that use VR technology to simulate fire scenes or earthquake scenes, allowing users to train in a virtual environment by wearing HMD equipment.

We can see the fire scene simulated by VR technology. Through VR technology, we can experience a virtual fire immersively. But the use of VR technology also has some unavoidable problems. First of all, the scene simulated by VR technology and the user's real life scene often do not match. Of course, if you need a more realistic scene, you can also model the user's house, but this will require professional sensors. Another problem is that users cannot see the real environment when training in the scene created by VR technology, so they need an empty space every time they train.

In summary, the safety education system developed by us using AR technology can combine the actual environment and objects around the user to give users a more realistic and free experience.

Chapter 3

Related Work

3.1 Safety Education System

There are many occurrences of natural disasters in the world, and people are required to be alert against disasters (e.g., severe earthquakes, heavy rain, and tsunamis). For this reason, many researchers have proposed many systems and applications to improve people's disaster awareness. Nowadays, there are more and more applications of safety education, and it involves a variety of scenarios [16][17][18].

For the fire scene, many researchers have proposed various systems. Sho Ooi et al.[19] propose a virtual reality (VR) disaster prevention training system focused on fire disasters. Their system has three modes, namely, VR evacuation drills, VR firefighting training, and VR comprehensive training. First, VR evacuation drills can be learned by users by gaining experience of evacuation methods in cases of fire. Second, users can undergo VR firefighting training by gaining experience of extinguishing methods. Finally, in general training, the users can experience trial training in case of fires on the basis of the knowledge gained in the evacuation and fire drills. They conducted VR comprehensive training and an IMMS evaluation to investigate whether this system demonstrates an improvement over existing teaching methods.

FireMe[20], a mobile gaming application based on the source material provided by the Bureau of Fire Protection (BFP), was created to support this campaign. The researchers utilized the concept of gamification and applied algorithm to the pathfinding techniques in developing the game.

Sung-Uk Jung et al.[21] present an AR based safety training assistant which recognizes the real space, augments the virtual objects and interacts between the objects and users in real space according to the instruction of disaster situation.

In summary, these studies have applied a variety of technologies, some are based on two-dimensional information on mobile phones, some use VR technology and some use AR technology. The above studies have shown that it is very necessary to conduct simulation training for various disasters in different scenarios, and can significantly improve people's safety education. Moreover, the combination of VR or AR technology can also significantly prompt the user's interest in learning.

However, the above-mentioned research has some shortcomings.First of all, the most important activity scene of all users must include their own family. Therefore, if it is to improve the user's security awareness, we should focus on combining the user's actual life scenarios. In addition, all safety training is not only to interact with the interfaces and objects provided by the system, but also to interact with real objects around the user.

3.2 Interaction in AR Education

Mobile wireless technology in education has been on the research agenda in the 21st century, and mobile technologies with tangible user interfaces have already been widely adopted in the field of education. In one facet of this trend, there is a rapidly growing interest in AR applications in children s education. Research has concluded that AR can become an innovative pedagogical tool, contribute to more effective educational activities, and support cognitive processes in various educational fields. AR provides a platform to establish a (potentially) ideal learning experience, that is, one combining physical experience, virtual content, and the child s imagination.

Elisa Jaakkola et al.[22]present a concept, prototype and in-the-wild evaluation of a mobile augmented reality (AR) application in which physical items from nature are used as

AR markers. During the use of this system, teachers found the use of natural objects to be an appealing approach and a factor contributing to the learning experience.

Chor-Kheng Lim et al.[23] develop an AR teaching aids in enhancing the pleasure of reading poetry, listening to poetry, and even playing poetry. The AR teaching tool developed is an interactive teaching medium that combines both landscape culture and literary poetry. This tool can solve the problem of concentration of students when in the field experience, and make the literature education more interesting and lively, and even more in-depth understanding of the imagery in the poetry.

ZooDesign [24]is a gamified imagination design method centered on educational cards and role-playing games. It helps children imagine how animals use technology by exploring the welfare needs of animals and human participation.

In summary, researchers have used different objects to interact with each other through AR technology. And according to comparative experiments, it can be proved that the use of AR technology can bring better effects to children's education, especially when children interact with objects in real life, they can have a deeper impression and learn more Knowledge. Therefore, in our research, we will pay more attention to the interaction process between children and real objects. Through interface, text or voice feedback, children can get more information.

Chapter 4

Research Goal and Approach

4.1 Research Goal

The goal of our research is to design a new way of safety education for children, which combines virtual 3D objects with real life scenes through AR technology. Users, virtual 3D objects and real environment can interact with each other. Through the triggering effect after interaction, children can know what dangerous objects are around them, what behaviors are wrong, and how to do after the danger occurs. Our goals can be divided into the following points:

1. Use the "object detection" function to detect dangerous objects around the user at all times and prompt the user in time to let children know which objects are dangerous;
2. Designing and simulating disaster scenarios can be triggered by user behaviors, and then shown to users to let children know which behaviors are wrong;
3. A training part is designed. Parents can make a training plan based on the actual situation in this part to let children know what to do after a disaster occurs.

4.2 Research Approach

Our research uses mixed reality HMDs to provide a safety education system that integrates users' real life environments. HMDs are able to enable the user the ability to see both real objects and virtual objects at the same time. As shown in Fig 4.1. We use HoloLens 2 to start our research, which can provide a comfortable mixed reality experience with a strong sense of immersion. "Object detection", "Spatial Perception", "Hand Tracking" and many other functions used in our research are all used on the basis of HoloLens 2.

(a) without AR (b) with AR

Fig. 4.1 View of Mixed Reality

We hope that this system can follow the user's sight and detect in real time whether there are dangerous objects around. Therefore, we use HoloLens to capture images in real time, and use the object detection function to detect the captured images. When a dangerous object is detected, a corresponding voice prompt will be triggered to let children know that the object is dangerous. But at this stage, children only know that the object is dangerous, and don't know what kind of danger it will bring.

In order for children to realize what kind of harm those objects may bring, we need to realize the interaction between virtual objects, users and the real world in our research. Here we distinguish between the real world and virtual objects through the "spatial perception" function. Then through hand tracking, the user can manipulate the virtual object very realistically. In addition, we also gave virtual objects some functions through scripts written by ourselves to make them as real as possible. Figure 4.2(a) simulates the real-life scenario of boiling water, and the user can also directly use his hand to turn the knob on the virtual gas stove. In Figure 4.2(b), the user can control the pouring of the kettle by hand. When the object interacts, the corresponding effect will also be triggered, which is also achieved by our scripting. For example, the lighter will catch fire when it touches the bed; the hand will get burned when it touches hot water, etc. These disaster effects are all displayed virtual effects through AR technology, which will not cause actual harm to children, but will make children aware of the hazards.

(a) Turn off the gas (b) Kettle pouring water

Fig. 4.2 Functions of virtual objects

When the hazard occurs, the children's parents can also start safety education on the basis of "children's disasters". But before safety education starts, children need to give their parents permission on their own initiative. Here we use the "hand tracking" function, we first collect the position of the tracked hand joint points, and then conduct processing and research. We judge the user's gestures by judging the degree of bending of the fingers and the collinearity of adjacent fingers. When the user's gesture meets the conditions, our system will turn on the voice function. Then parents can start safety training through voice.

When parents start safety education, first parents can make a training plan based on the actual situation. Parents can choose different instructions through voice, and then these instructions will automatically generate a training plan. Children can execute the instructions set by their parents step by step. After completing a series of instructions, children can listen to their parents' suggestions and evaluations.

Chapter 5

System Design

In this chapter, we will introduce the system design of our AR safety education software. Figure 5.1 shows the overall structure of our system.

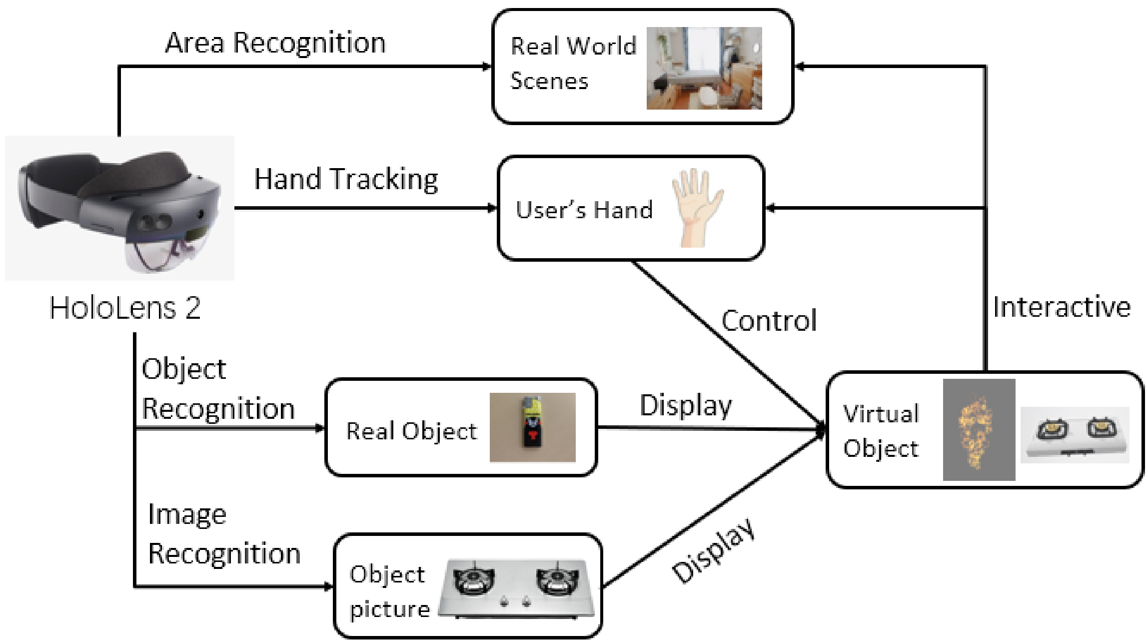


Fig. 5.1 System Design Overview

First, our system scans the environment around the user to understand the real-world scene where the user is. At the same time, the system follows the user's perspective and can detect possible dangerous objects for children in real time. When a dangerous object is found, the corresponding virtual objects will be displayed. The user can directly interact with these virtual objects by hand, or manipulate these virtual objects to interact with the real scene. And the system will warn the user through text and sound.

When a child manipulates a virtual object and does some incorrect behavior, such as putting a lighter on the bed, holding a hot water bottle filled with hot water, etc., the system will use AR technology to show the damage on the human body or surrounding environment. After the accident, users can design a training plan by themselves.Finally, according to the previously developed training plan, users can complete the plan step by step with the company of their parents.

Following subsections are details information about key parts of this research.

5.1 Spatial Perception and Object Detection

5.1.1 Spatial Perception

AR technology is a technology that combines virtual information with reality. This technology superimposes the daily life environment and virtual objects into the same space, giving users the immersive feeling. Therefore, the perception of real-world space is the most critical step in the realization of AR technology. The accurate perception of the real environment also ensures a better combination of virtual objects and the real environment, giving users a more immersive experience.

In this system, we combine Vuforia "Area Target" function with MRTK[25] "Spatial Awareness" function. The spatial perception system created and applied in this system is shown in Figure 5.2.

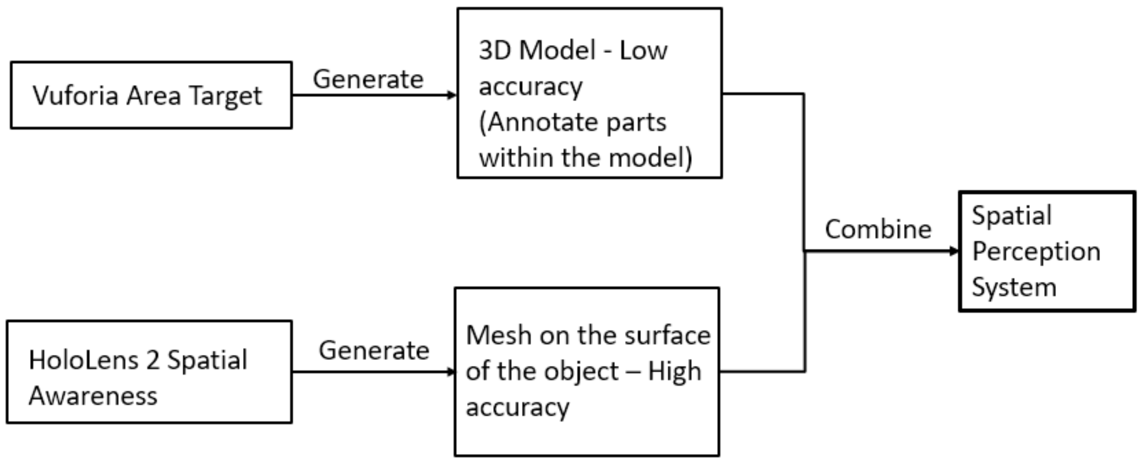


Fig. 5.2 Spatial perception system

Area Targets is a Vuforia powered environment tracking feature that enables user to track and augment areas and spaces. First, the user needs a 3D scanning instrument to scan a certain area. Vuforia Area Targets supports scans made with: ARKit enabled devices with inbuilt LiDAR sensors, Matterport™ Pro2 3D camera, and other professional equipment. The output of the scan process is imported into the Area Target Generator which returns a set of dataset files, meshes, and Unity packages. When we import Unity packages into the unity project, we will get a 3D model as shown in Fig 5.3. But this feature has some unavoidable shortcomings:

- 1: When using this function, the lighting conditions of the real environment must be consistent with the lighting conditions during scanning.
- 2: When using this function, the placement of objects in the real environment must be consistent with the scanning.
- 3: When this function is applied, the user's movement may cause the recognition of the function to be interrupted.

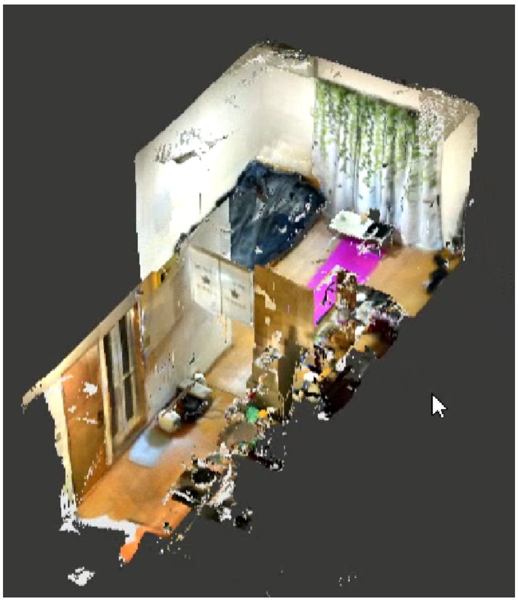


Fig. 5.3 Scanned 3d model

So we combined the “Spatial Awareness” function on the basis of Vuforia “Area Target”. "Spatial Awareness" provides a grid collection that represents the geometry of the environment, as shown in Figure 5.4. After turning on the "Spatial Awareness" function, the grid in the picture can be set to two modes, visible or invisible. But regardless of the mode, the grid is actually present on the surface of the object and is used to mark the real world. Moreover, the grid will change in real time according to the user’s movement and the use of real depth information can always maintain the high accuracy of detection, which ensures the authenticity of the interaction between virtual objects and the real world.

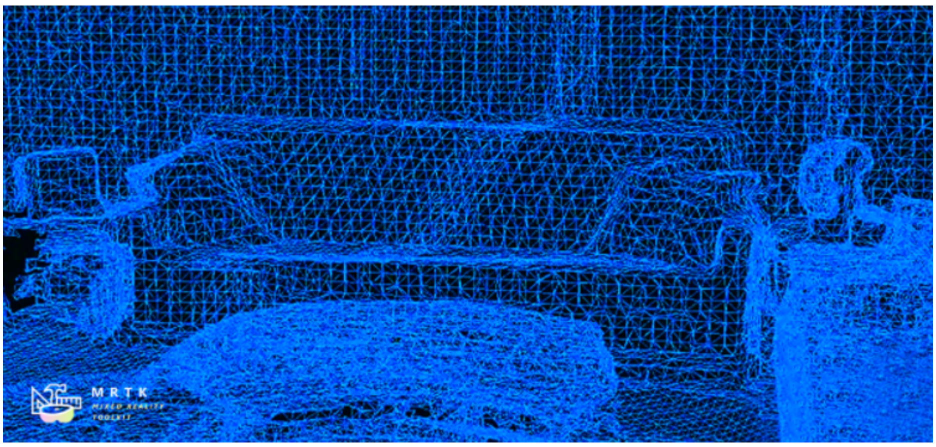


Fig. 5.4 Spatial awareness mesh

5.1.2 Object Detection

During the running of the software, the first process is to detect the surrounding dangerous objects, such as hot water bottles, sockets, lighters and other objects.The Vuforia library[26] and unity are used to implement this function.The specific process is as follows.

First, we created a 3D model database for each object through Vuforia Object Scanner so that we can identify different objects. Second, when a dangerous object in it is detected, the system will issue different warnings according to different objects. Then, a corresponding virtual object is generated based on the detected object, and the generated virtual object replaces the previous real object, so that the user can interact with the virtual object, but it will not cause real harm to the child like the real object. And we have simulated the function of the original object and the reaction to different situations as much as possible by writing scripts. Provide users with an immersive experience.

5.2 Design for Interaction

5.2.1 Interaction between People and Virtual Objects

There are many ways to interact with people and objects, but here we divide them into two categories. The first way is for users to directly manipulate objects with their hands, which is also the most natural way for people to use them. The second way is that the object directly affects the user through some special behavior.

The first way is to use the "Hand Tracking" function of MRTK to directly track the user's hand, obtain the user's hand coordinates and select angle, etc. Through the acquired information, we can directly interact with virtual objects. For example, drag the object, rotate the object, make the object tilt and so on. It can simulate the interaction between us and real objects to the greatest extent.There are many cases where this method is used in the system. For example, the user can directly drag the virtual iron nail to the socket by hand; the user can turn the knob of the gas stove to control the fire; the user can also directly simulate the real situation of pouring water by hand, as shown in Fig 5.5.

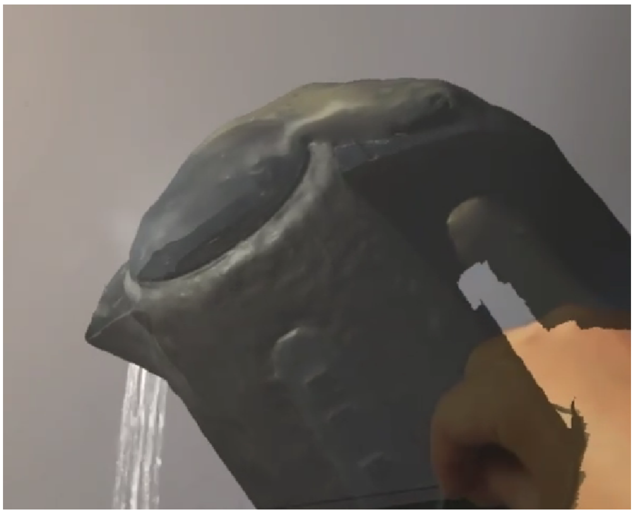
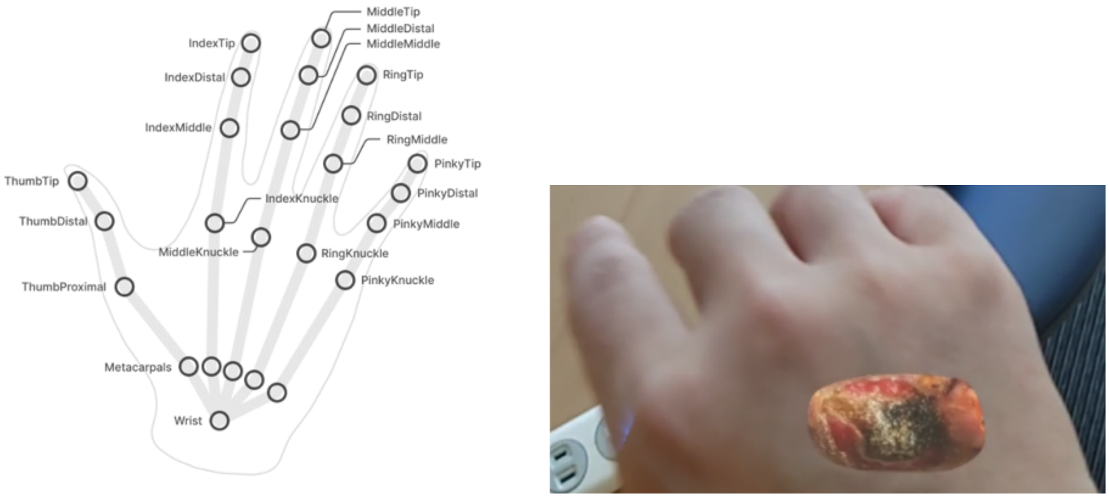


Fig. 5.5 Pour water with virtual kettle

The second way is to show the impact of virtual objects on users. In real life, people will also be affected by the surrounding objects. For example, people will be scalded by hot water. Therefore, in order to make the software display more realistic, the system also designs the effect of people being affected by virtual objects. The purpose of this design is to make users aware of the damage that certain behaviors will cause to themselves.

The realization of this interaction is mainly reflected in the two scenarios of the user being burned by the hot water bottle and the user being injured by the electric shock. The main implementation method of this design is based on the hand tracking function. As shown in picture 5.6(a), these are the joint points of the detected hand. Through the detected joint points, select three of them: index knuckle, pinky knuckle, and wrist. These selected joint points can form a plane area, by calculating the center of the area in real time, and displaying the burn effect on this central point, and finally we can see the realistic burn effect on the user's hand.



(a) Hand joints

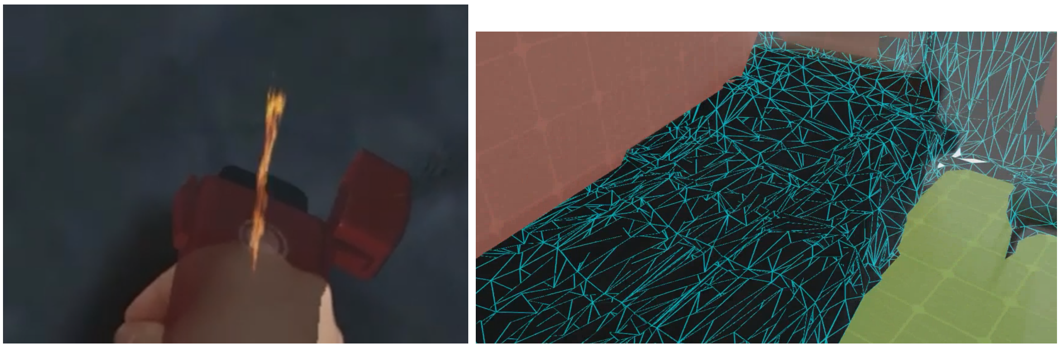
(b) Hand injury effect

Fig. 5.6 Effects caused by virtual object

5.2.2 Interaction between Real World and Virtual Objects

Real and virtual interaction can be realized by using AR technology. Therefore, the interaction between virtual objects and the real environment is very important for AR technology. This system involves many interactions between virtual objects and the real world. For example, the interaction between a virtual lighter and a bed, curtains and other objects in the real world. The process is as follows: After the lighter is detected, the system will detect whether the lighter collides with the bed or curtain in the real world. If the collision is detected, the fire effect will be displayed on the real object.

The implementation method of the above process is as follows: when the object is detected, the virtual object appears. The user can manipulate virtual objects. The system will obtain the space coordinates of the virtual object and start the space perception function, the effect is shown in Figure 5.7 (b). When the virtual object collides with the detected real space, as shown in Figure 5.7 (a). The system will show different realistic effects in the real space according to the different positions of the collision.



(a) Lighter and bed contact (b) Spatial perception

Fig. 5.7 Effects caused by virtual object

5.3 Scene Design

When we open the AR safety education software on HoloLens 2, we will see the interface shown in Fig 5.8. This page shows the four training scenarios designed by the AR safety education software and we can click the button below the picture to enter the training scene of our choice.

Fig. 5.8 Software start interface

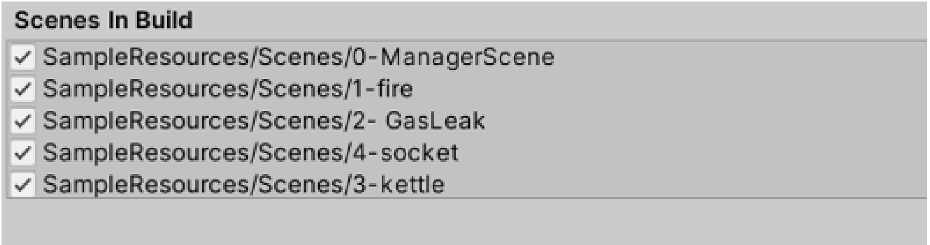


Fig. 5.9 Scenes of the whole system

The system mainly includes four scenarios, which are as follows: Playing with lighter, Gas leak, Scalded by hot water and Injured by electricity. Each scene contains three functions: Remand the child, Make the Child Aware of Danger and Safety Education. Next, I will introduce each scene.

5.3.1 Gas Leak

Picture 5.10 shows the entire workflow of the gas leak scene. First, when the system detects the set gas stove picture, a virtual gas stove will appear. Children can turn the knob of the gas stove by hand. When the knob is turned, the software will automatically determine the rotation angle of the knob. If it rotates to 90°, the gas stove will be safely turned off. But if the angle of rotation is greater than 70° and less than 90°, the fire of the gas stove will go out, but the gas will start to leak.

After a gas leak occurs, the system will warn the user, and a 3D avatar will also appear to show the reactions of people with different levels of gas poisoning. For example, in the early stage of gas poisoning, the patient only has symptoms such as headache, dizziness, tinnitus, vertigo, palpitations, weakness, nausea, and vomiting. In the middle and late stages, the patient will have weak breathing, general weakness, and gradually enter a collapsed coma state. Children can start safety education and training with the help of their parents. First, the child needs to make a movement of unfolding the left palm, and then touch the palm of the left hand with the fingers of the right hand, it will remind parents to help their children or safety education.

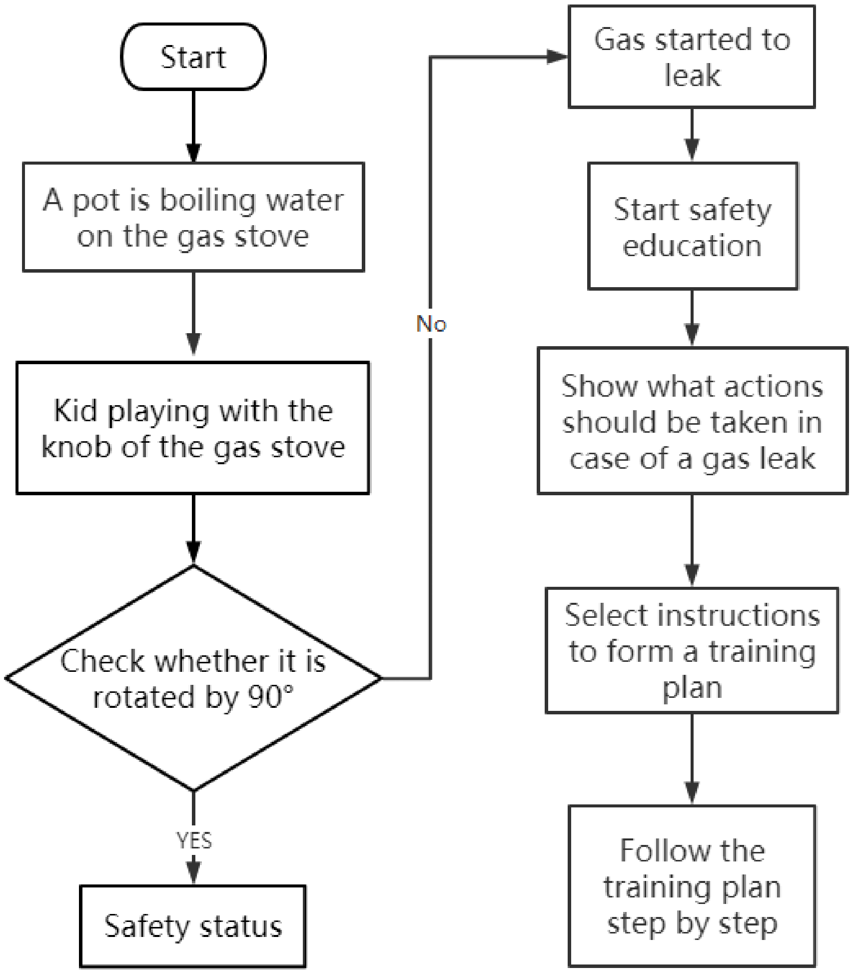
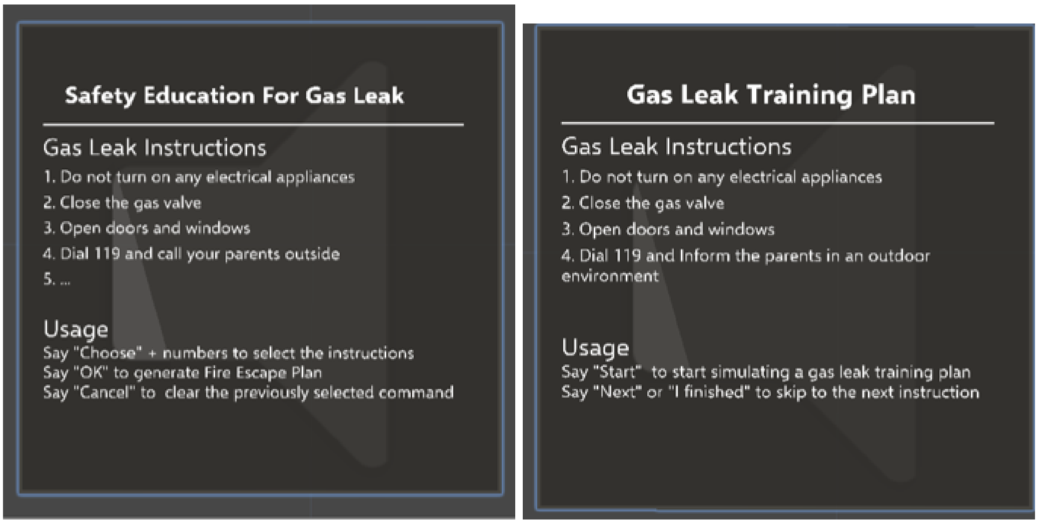


Fig. 5.10 Flow chart for gas leak scenario

After starting the safety education, we will first see the page shown in Figure 5.11(a).This page tells the user how to use the software. The user only needs to select the instructions by voice, and then a personalized training plan can be generated, as shown in Figure 5.11(b). At the same time, for each instruction, the system will have a corresponding picture or 3D model to guide the user how to complete the instruction.

When the child completes the instructions step by step, the child's parents can also use the Microsoft HoloLens software to view the child's completion of each instruction in real time, and give their own evaluations and suggestions based on the child's performance.



(a) Instructions for gas leak (b) Gas leak training plan

Fig. 5.11 Safety education for gas leak

5.3.2 Playing With Lighter

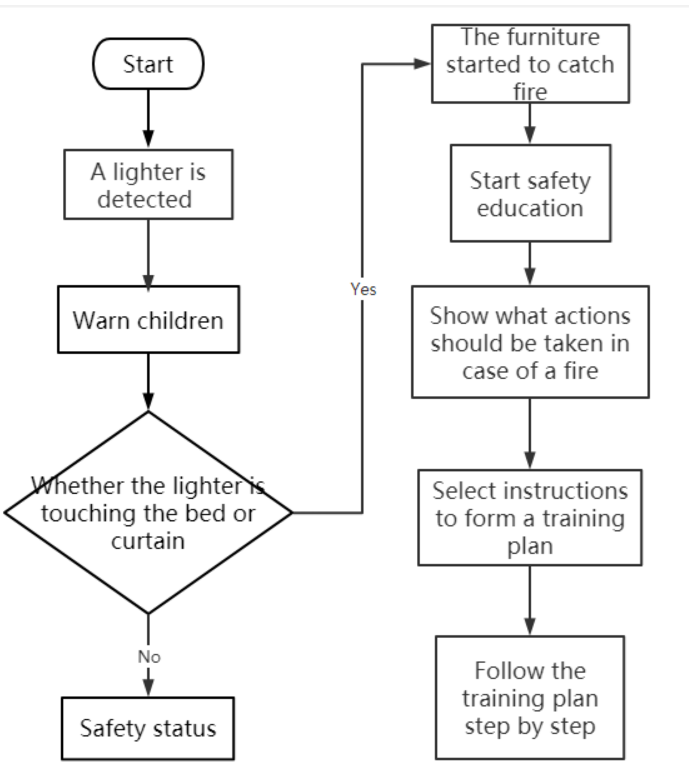
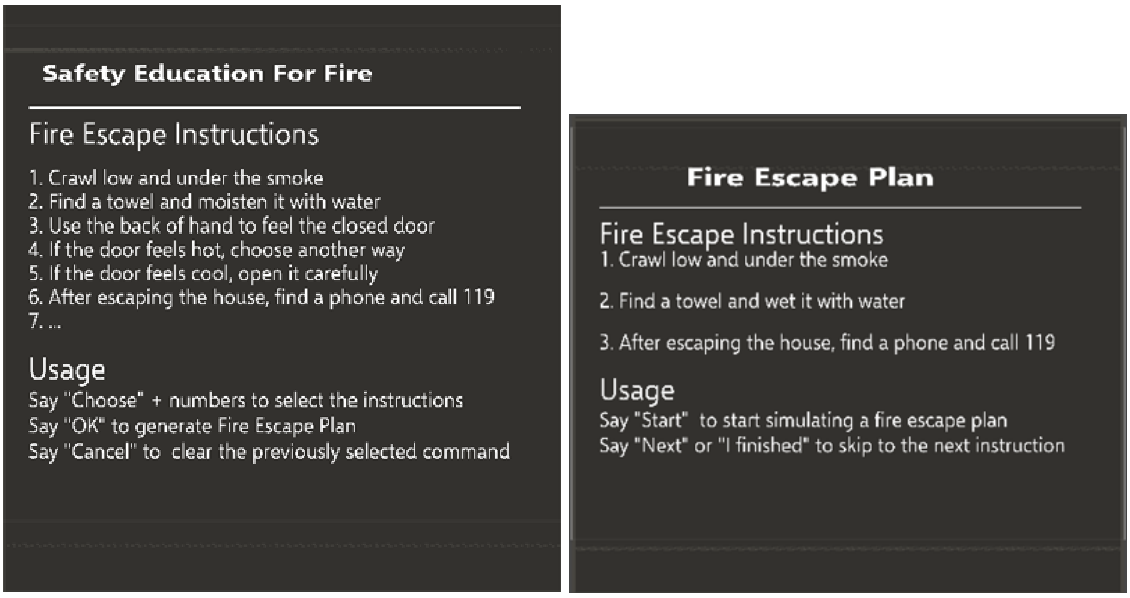


Fig. 5.12 Flow chart for fire scenario

When a dangerous object such as a lighter is detected, the system first warns the user to let the user realize that the object is dangerous. Then a corresponding 3D model will be generated to replace the real dangerous object. The user can interact with the virtual object but will not cause any real harm. When the virtual lighter is detected to touch the real bed or curtain, in HoloLens 2 we can see flames burning. Through this effect, children are aware of the dangers of playing with lighters indoors.

When a fire breaks out, users can also start safety education in the scene at that time. After starting the safety education for fire, we will first see the page shown in Figure 5.13(a). The user can select different instructions for different scenarios. After selecting the instructions to be executed, the system will generate the training plan shown in Figure 5.13(b). When executing each command, the system will have different prompts. For example, for the first instruction, an avatar crawling on the ground will appear in the system. The user needs to imitate its actions and follow the prescribed route. When the instruction is completed, the user can get comments, suggestions and other feedback from the parents.



(a) Instructions for fire (b) Fire training plan

Fig. 5.13 Hand manipulation in real size preview

5.3.3 Scalded by Hot Water

As shown in Fig 5.14, when the electric kettle in the house is detected, a virtual 3D kettle will appear in the system for users to operate, as well as voice and text warnings.

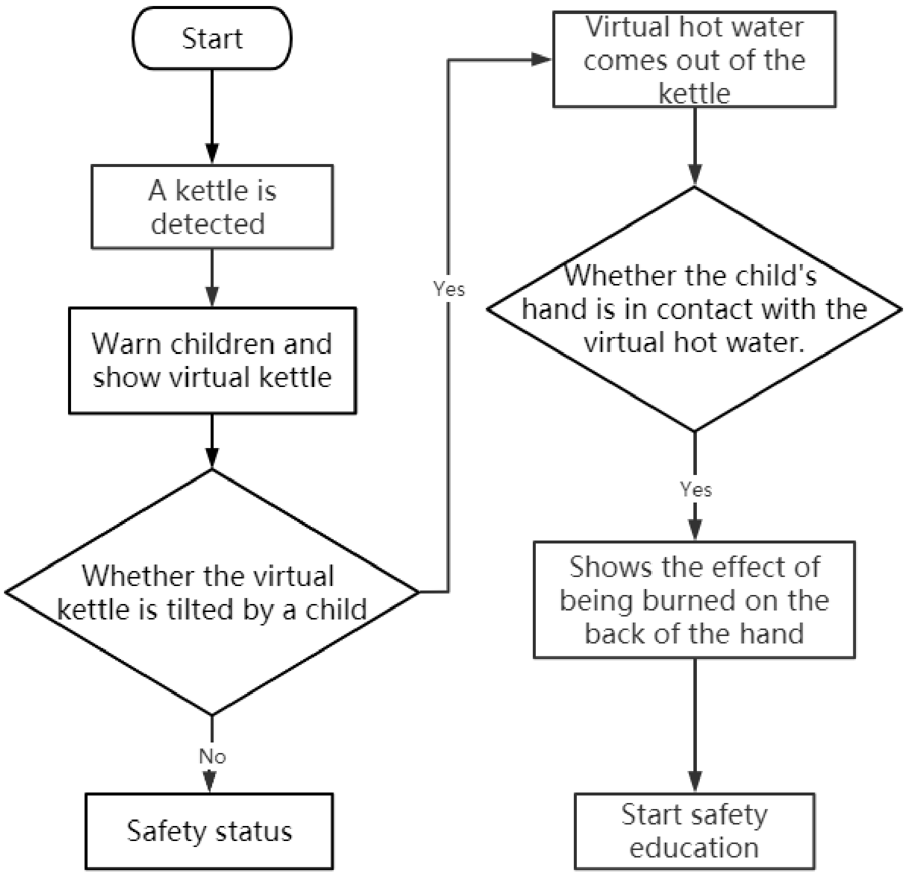


Fig. 5.14 Flow chart for scald scenario

The user can manipulate the virtual 3D electric kettle to realize actions such as pouring water(The kettle and water or hot water mentioned later in the paper are all virtual 3D objects). But because they are all virtual objects, the possibility of real harm to the user is avoided. When the user starts to pour water, the system will judge the tilt angle of the kettle. If the angle exceeds the angle set by the system, hot water will flow out of the kettle. If the hot water is just poured out, it will not have other effects on the user. However, if it is detected that the user's hand is in contact with hot water, the user's hand will show the effects of being burned, such as redness of the skin and blisters. By displaying these effects on the user's hands, children can realize how serious the harm that may be brought to themselves by playing with a real electric kettle.

When the user's hand shows the effect of being burned, the user can start the safety education part. First of all, the user's parents can make their own burn training plan in the numerous instructions after burns. For example: notify parents immediately; rinse the burned area with clean water; soak the burned area in cold water; go to the hospital for treatment of the wound, and so on.

After the user has made the training plan, the user can complete it step by step according to the instructions in the plan. In this part, we hope that the user's training simulation level should be as high as possible, such as directly flushing the wound with a realistic faucet and so on. But if the user is unable to perform on-site simulation due to special circumstances, the system also provides other virtual 3D objects for use.

When the user is operating these 3D objects, if the user interacts with the objects or triggers certain conditions. The status of these objects will also be immediately fed back to the system, and the system can autonomously determine whether the user has completed certain instructions in the training plan.

5.3.4 Injured by Electricity

Similar to the previously mentioned scenario, the flow of the electric injury scenario is shown in Figure 5.15. When the scene of being injured by electricity is loaded, the system will follow the user's movement and the change of sight to detect whether there is an electrical socket in real time.

When the electrical socket is detected, there will be a hazard warning. At the same time virtual nails will appear around. Users can interact with iron nails and electrical sockets. Of course, the electrical socket at this time is in a power-off state.

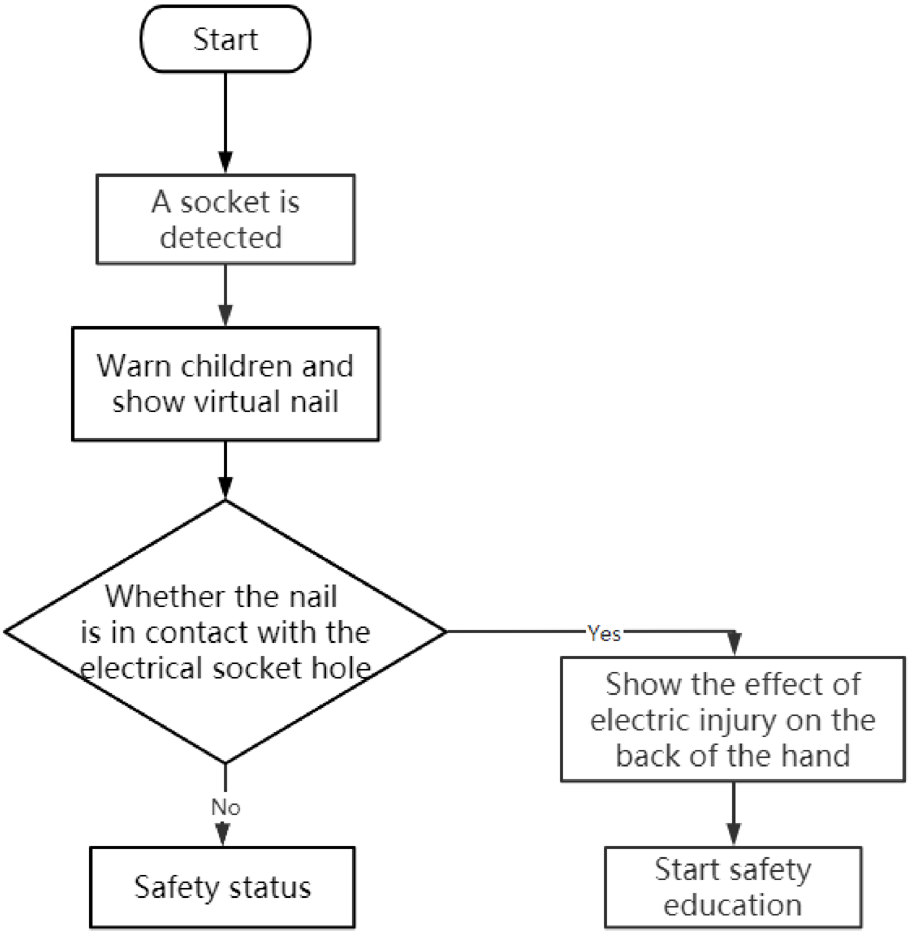


Fig. 5.15 Flow chart for electric injury scenario

Children under the age of 5 are usually curious about the holes of electrical sockets. In the realization of life, it often happens that children hold objects to plug in the holes of electrical sockets, which leads to tragic events. Therefore, in our system, virtual iron nails are used instead of real iron nails. Users can interact with virtual iron nails and power-off electrical sockets. After certain conditions are met, the effect of electrical injuries will be displayed on the back of the user's hand. Through the harm effect, children can be aware of the extremely dangerous consequences that their incorrect behavior may bring to them.

After children are aware of the hazards of electrical sockets, we can educate them on safety. For example, for younger children, teach them to stay away from electrical sockets; for older children, show them how to use electrical sockets correctly.

5.3.5 Conversion from Disaster Part to Safety Education Part

Our system mainly has four scenarios. Each scene can be divided into two parts: the first part is to produce disaster effects through the interaction of virtual objects and users or the real world, so that children can realize the harmfulness of certain objects or certain behaviors. The second part is that the parents specify the training plan for the child in the hazard situation. The child completes the training plan made by the parent step by step and listens to the evaluation of the parents. Fig 5.16 below shows the two-part conversion process.

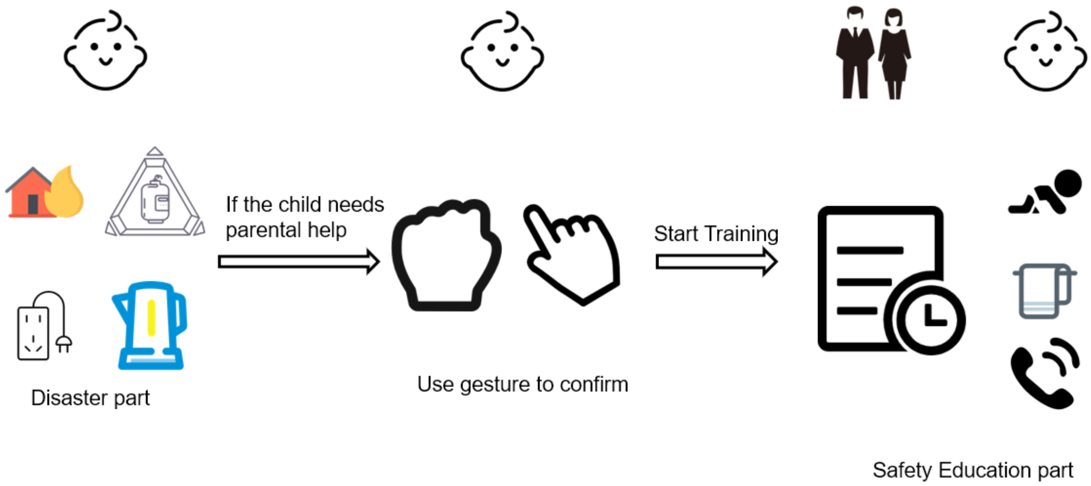


Fig. 5.16 Flow chart for Two-part conversion

From the picture above, we can see that the first part is only for children. They can create a disaster scene through various behaviors. The latter part of the safety education system involves the participation of parents and children. Parents are responsible for formulating a special plan based on the specific conditions of the indoor environment, evaluating the child's performance and giving suggestions. What the child needs to do is to complete the training plan made by the parents step by step.

But from the first part to the back part, the child's permission is required. At this step, the child needs to make their left hand into a fist, and then tap the fist with the fingers of the right hand. After this, the voice system of the software will be opened. The user's parents can select the commands that the child needs to execute through voice. Here we deliberately set up gesture recognition[27] to avoid accidental touch operations. If the child only touches the left hand with the fingers of the right hand, there will be no response.

Chapter 6

System Implementation

6.1 System Hardware

In our AR safety education software, we want to increase the immersion of the system as much as possible. This software should meet the following requirements:

1. Allow users to touch, grasp and move the hologram in a real and natural way. Virtual objects can be dragged, pulled, rotated and even given corresponding feedbacks like real objects following the user's manipulation.

2. Users can use smart microphones and natural language voice processing to implement voice commands in noisy environments. When the user's hands are manipulating the virtual object or the user's attention is interacting with the virtual object, the user can switch the system workflow more conveniently and naturally through their voice.

3. The 3D objects around the user can be recognized through the picture captured by the camera.

4. A depth camera that allows the system to perceive the surrounding space environment to distinguish ground, walls, ceilings, etc.

5. Support users to move freely without obstacles such as cables or external accessories.

6. The user's parents can watch the scene that the user sees in real time, and the parents can remind the user when the user conducts safety education.

Therefore, our system uses HoloLens 2 as one of the hardware of the system. It provides a perspective holographic lens that allows users to see virtual 3D objects; it provides 4 visible light cameras to obtain real-world images, which can be processed to detect real-world 3D objects; it also has a depth sensor , The system can use it to perceive the user's surrounding environment; at the same time it also provides a microphone array, the system can distinguish and execute voice commands.

Fig. 6.1 HoloLens 2

In addition, we also used a PC with Windows 10 operating system to develop our system, providing a platform for the system to process programs. The configuration information of the PC we use is shown in Table 6.1. In addition to this PC used to develop our system, the user's parents can also use it to view the screen that the user sees in HoloLens 2.

Operation System	Windows10
CPU	AMD Ryzen 7 4800H with Radeon Graphics 2.90 GHz
RAM	8.00GB

Table 6.1 The PC setup information

We also use iPad Pro because it has an inbuilt LiDAR sensor. By scanning for a few minutes, a small room can be turned into an Area Target database instantly, ready to create augmented experiences in the environment.

6.2 Software Environment

The Software Environment support is:

1. Unity 2019.4.19f1c1, It provides us with a platform for developing HoloLens applications, and most of our development work is done through it.

2. Mixed Reality Toolkit 2.7.0 (MRTK v2), it is a Microsoft-driven project that provides a set of components and features, used to accelerate cross-platform MR app development in Unity. It provides many functions, such as: Hand Tracking, Eye Tracking, Spatial Awareness, Boundary System...

3. Vuforia Engine SDK 9.6, we use Vuforia Engine to build Augmented Reality UWP applications for mobile devices and AR glasses. The system mainly uses its "Image Targets", "Object Targets" and "Area Targets" three functions.

Besides, we used Visual Studio 2019 with C# for scripting, debugging and simulation.

6.3 Scanning and Detection of Space

Our project is mainly to combine the user's home environment and make the user aware of the dangerous objects in the house. Therefore, the space recognition in the user's room is very important for the entire project. In the beginning, our system only used Vuforia "Area Targets" function during development. It requires some professional equipment to scan the indoor space, to create our application, we can load our Area Targets into the Unity Editor and author 3D augmentations into the 3D model of the scanned space. We can choose to develop the application entirely with the Unity Editor and deploy the application to HoloLens 2 for testing.

Vuforia Area Targets supports scans made with: ARKit enabled devices with inbuilt LiDAR sensors, Matterport™ Pro2 3D camera, NavVis M6 and VLX scanners, and Leica BLK360 and RTC360 scanners. In our system we used iPad Pro with an inbuilt LiDAR sensors, and downloaded the software "Vuforia Area Target Creator" as shown in picture 6.2.

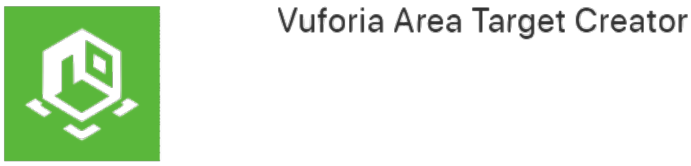


Fig. 6.2 The Vuforia Area Target Creator App

Figure 6.3 shows the process of using this software to scan the house. The scanning process needs to meet certain conditions:

1. For best results, it is best for users to scan only the area 0.5 to 2 meters directly in front of them, and capture objects, surfaces, and the space between them.
2. The user should use a handheld device to move slowly around the room, scanning up and down to capture the room.
3. The scanning process must be completed within five minutes.

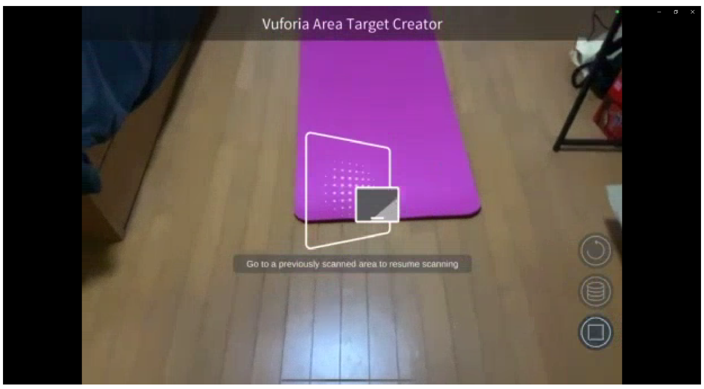


Fig. 6.3 The process of scanning the house

Figure 6.4 is the model displayed after being scanned and imported into unity. We can place our own components on the model and design according to our own goals. When the software is running, the system will automatically identify the surrounding space and match the model.

Fig. 6.4 3D model of the house

But if we only use the function of Vuforia Area Targets, the system will often have various problems. For example, if the position of the real object in the room changes, the position of the virtual object will deviate from the object placed in the 3D model in Unity. The situation shown in Figure 6.5 may occur, if the virtual object and the real object overlap, the realism of AR will be insufficient. Therefore, the collision detection of real and virtual objects is the most important part to ensure the immersion of our system.

In addition, when the user moves indoors, because the model and the real space need time to match, the position of the virtual object will often change. So we have combined Vuforia Area Target with Spatial Awareness of MRTK.

Fig. 6.5 The coincidence of virtual and reality

First, we placed a transparent cube as an anchor point on an object whose position is not easy to change, such as refrigerators, beds, air conditioners, tables, etc. As shown in Figure 6.6. The red cubes in the picture represent the anchor points set by our system. In the application, these cubes are set to be transparent. Since the shapes of these objects do not change frequently, their positions do not change either. So we can use these anchor points to divide our indoor space. So our system can judge the user's indoor large objects such as beds or curtains and tables with a rough area.

However, the current rough division of furniture areas cannot meet the requirements of the system. So we combined the Spatial Awareness function of MRTK together. Through this function, we can divide the area of large objects more finely. This is mainly with the help of the depth sensor that comes with HoloLens 2.

Fig. 6.6 Anchor points in the model

Figure 6.7 shows the effect of using the Spatial Awareness function indoors. We can see that there are triangular mesh covering the desktop, the ground, and the walls. We can choose the visualization of the grid, the number of triangles per square meter, the frequency of refreshing the grid, and so on. Because the rendering of the mesh will take up most of the performance of HoloLens, for the smooth use of the system, we usually set the grid to invisible.

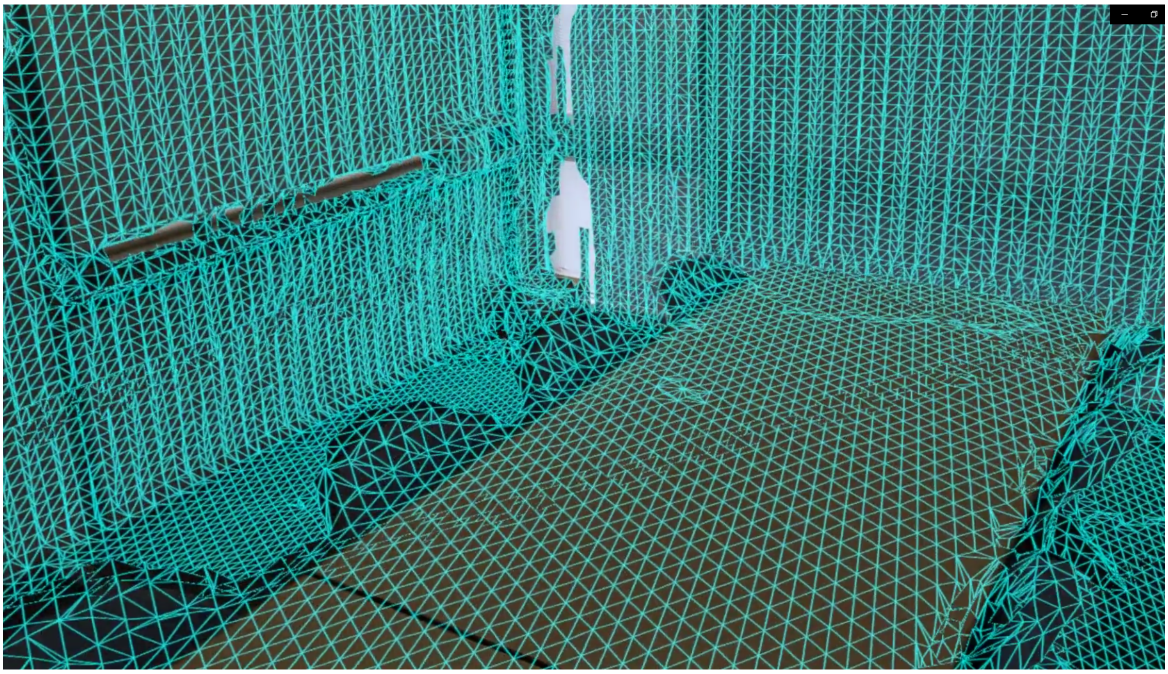


Fig. 6.7 The actual effect of Spatial Awareness

Based on the above, we can analyze the generated grid. Due to the ground and the wall surface is very flat and can be directly judged by the vertical position, so we distinguish the floor, ceiling and wall of the indoor space. Figure 6.8 shows the 3D model we scanned and generated in the dormitory.

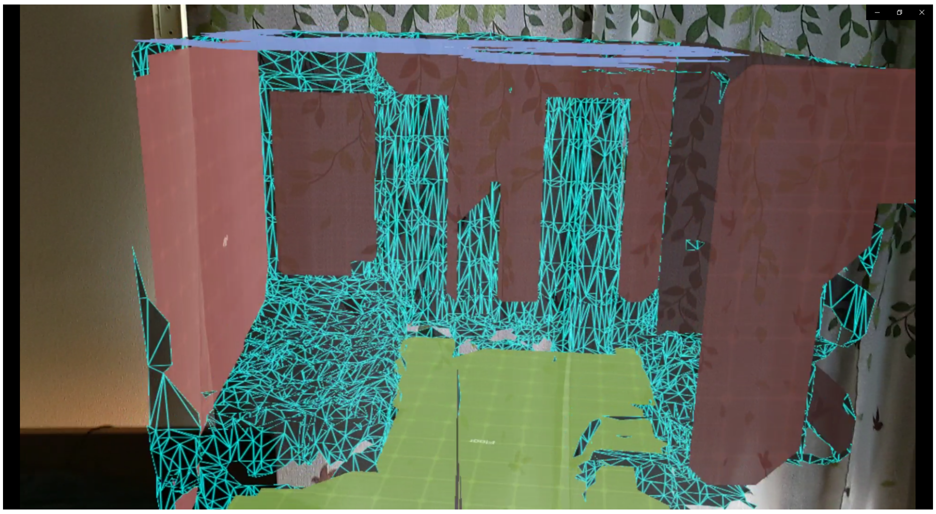


Fig. 6.8 Mesh model of the dormitory

We can see that in the model, the red area represents the wall, the green area represents the ground, and the blue area represents the ceiling. The grid part of the model represents the items in the dormitory, such as beds, tables, air conditioners, and so on. Therefore, with the Spatial Awareness function, we can divide the indoor space more finely,but it is difficult to identify the object.

Therefore, we use the previously used Vuforia Area Targets function to make a rough division of the space with the help of the anchor points we set before, that is, to define a space for large indoor objects. For example, through the previous anchor point, to limit the approximate boundary of the three-dimensional space of the bed. Then use the Spatial Awareness function to detect collisions between the real world and virtual objects.If a collision occurs, the system can determine the area where the collision occurred based on the coordinates of the collision point. Then show different effects according to different areas.

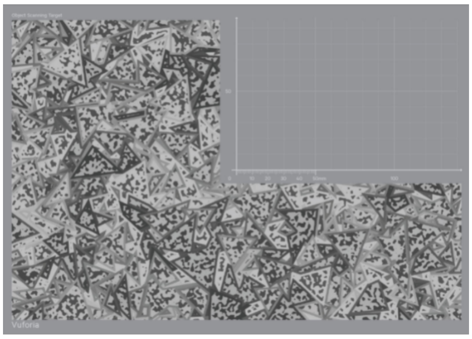
6.4 Recognition and Application of 3D Objects

6.4.1 Scanning of 3D Objects

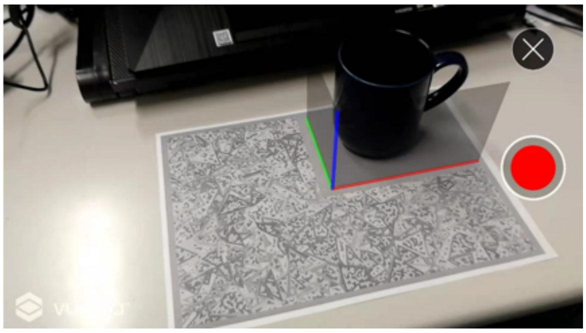
Because our system needs to detect dangerous objects around the user at all times. Object Recognition allows system to detect and track intricate 3D objects, in particular smaller consumer products. So we need to use Vuforia Engine's 3D object detection, and we only used this method at the beginning.

First, we need to download the Vuforia Object Scanner software, which only provides the Android version. We can use this software to scan the object under the background of a sheet of A4 paper. Objects should be scanned under moderately bright and diffuse lighting. Avoid direct lighting. Scan the model in an environment free of background noise. This prevents the introduction of features which are not part of the model. Scanning in cluttered environments can create false tracking points.

During the scanning process, we need the paper shown in Figure 6.9(a). When we scan a 3D object, we can use paper to determine the position and direction of the object relative to the origin of its local coordinate space. The feature region of the paper co enables the scanner to precisely identify the pose of the physical target in the grid region and also defines the culling region of the scanning space. Figure 6.9(b) shows the coordinate system established through this piece of paper, which facilitates the user's subsequent scanning process. The intersection of the red, blue and green lines is the origin when scanning. It corresponds to the local (0,0,0) origin of the Object Target's bounding box.



(a) Paper to assist in scanning

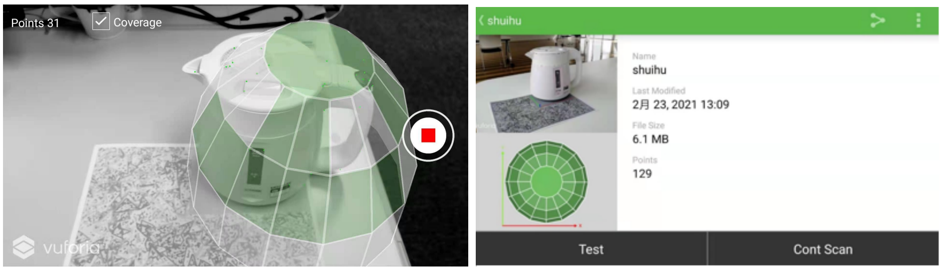


(b) Vuforia Object Scanner

Fig. 6.9 Effects caused by virtual object

Next, we can start scanning. First we need to open the Vuforia Object Scanner app. Next we press the + icon to initiate a new scanning session and confirm that the object is aligned correctly using the axes augmentation. Then we need to press the record button and use the camera to capture the significant vantage points. When a surface region is successfully captured, its corresponding facet turns green, as shown in Fig 6.10(a). Finally, once we have captured the majority of the required surface area, press the stop button to stop the scan. The final scan result is shown in Figure 6.10(b). The more green parts in the figure, the higher the completion of our scan.

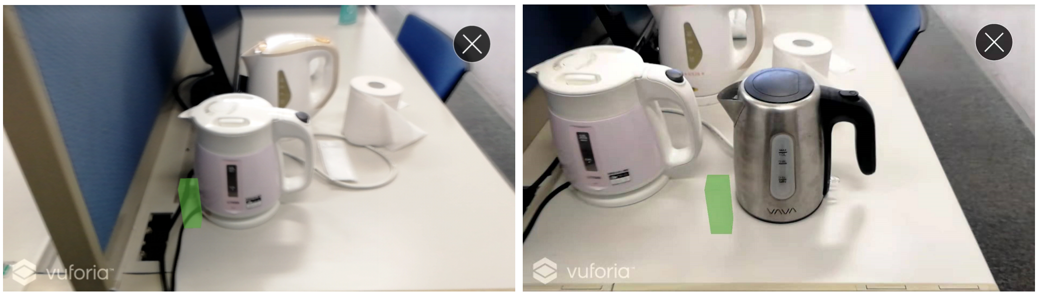
But in some cases, we may need to reduce the size of the object data file. By reducing Object Data file sizes, we can improve load times for device databases containing Object Targets and also reduce our app's memory requirements. Here, the size of the object data file reflects the number of feature points captured during the object scanning process. The upper left corner of Figure 6.10(a) shows the number of feature points. We can reduce the size of the object data file by reducing the number of feature points. So in the scanning process, we can only scan the object faces that are significant to our app's user experience. For example, if our app only uses the front of an object, we will not scan the back or sides.



(a) Scanning process using Vuforia Object Scanner (b) Scanning result

Fig. 6.10 Summary screen

After the object is scanned, we need to test whether the scanned object can be recognized. Here we still need to use the Vuforia Object Scanner app. As shown in Figure 6.10(b), there is a "Test" button in the lower left corner. Press the “Test” button the application will display an augmentation at the world origin where the object is recognized. In order to test whether the scanned object can be detected in various complex environments, we should test as many as possible in different backgrounds. Fig 6.11 shows the results of the test.



(a) Vuforia test for kettle1 (b) Vuforia test for kettle2

Fig. 6.11 Vuforia test

6.4.2 Use Object Targets in Unity

Object Targets enables us to create apps that can recognize, and track objects based on their visual features. In this part, we will introduce how to add Object Recognition and Object Targets to a Unity project. To use Vuforia engine, we need to get the free license from the License Manager (https://developer.vuforia.com/legal/license) and add it to our project if we are looking to track our own objects. The license key of our software is Fig. 6.12. Then we need to add the license key to our project so that we can use Vuforia Engine.

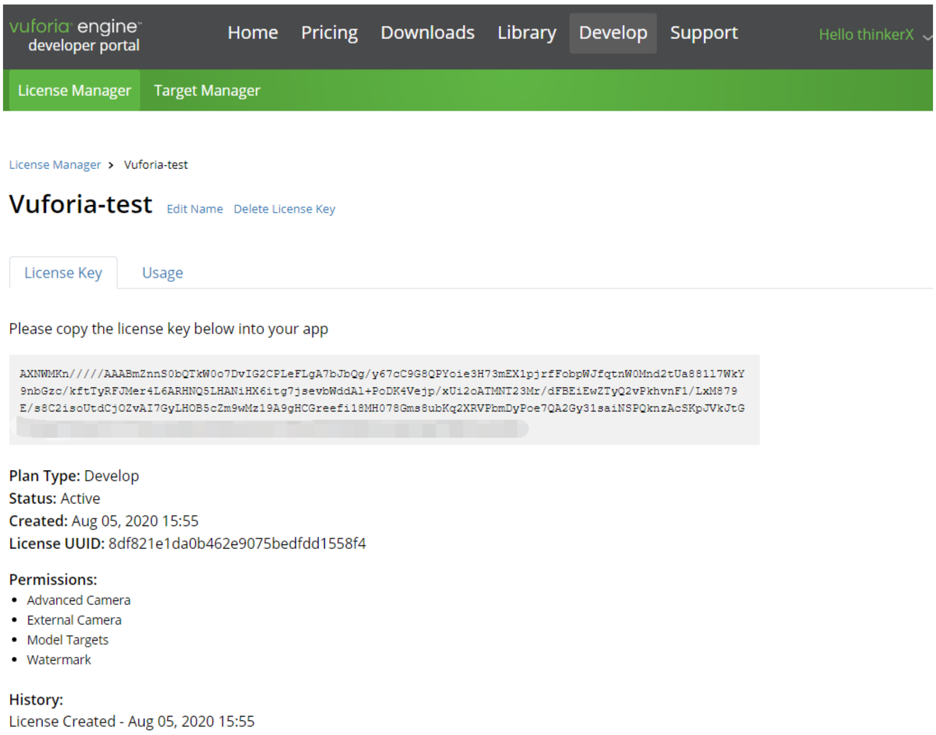


Fig. 6.12 License Manager for software

When we complete the scanning process in the previous section, we need to to upload an Object Data file from a completed scan of an object. Proceed as follows:

- There is a share icon in the upper right corner of Fig 6.10(b), and we can upload the generated file to our computer. The Object Data file can be large, so choose an appropriate method for sending large files. You can also transfer the Object Data file to a PC via USB;
- Open the Target Manager in the developer portal;
- In the database list, select the database in which to add the new Object Target;
- Click Add Target. A dialog window opens. As shown in Fig 6.13;

- Select 3D Object, and click Browse to locate the Object Data (*.od) file for this target;
- Click Add. The Targets tab displays the results of the upload.;

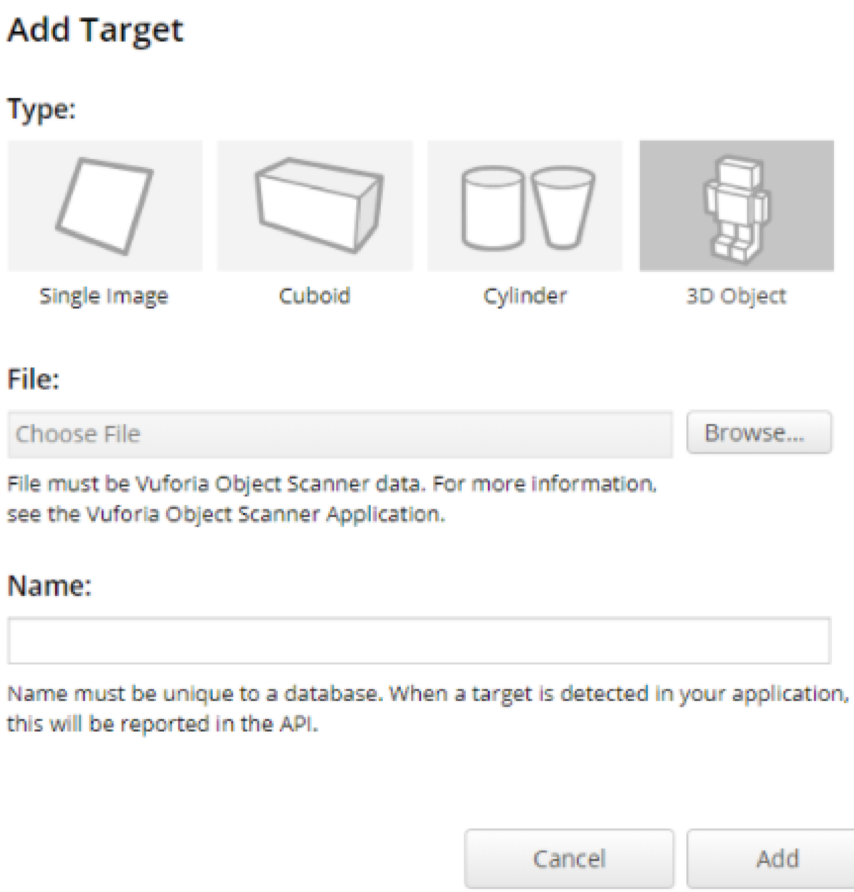


Fig. 6.13 Upload Object Data Files

In our unity project, We need to add an ARCamera GameObject instance to our scene. Remove the default Main Camera from our scene. We can download the Vuforia database from the target manager page and import it from Assets -> Import Package -> Custom Package. Then we can select the ObjectTarget and in its inspector select the Database name and Object Target name that we want to associate with the Object Target instance.

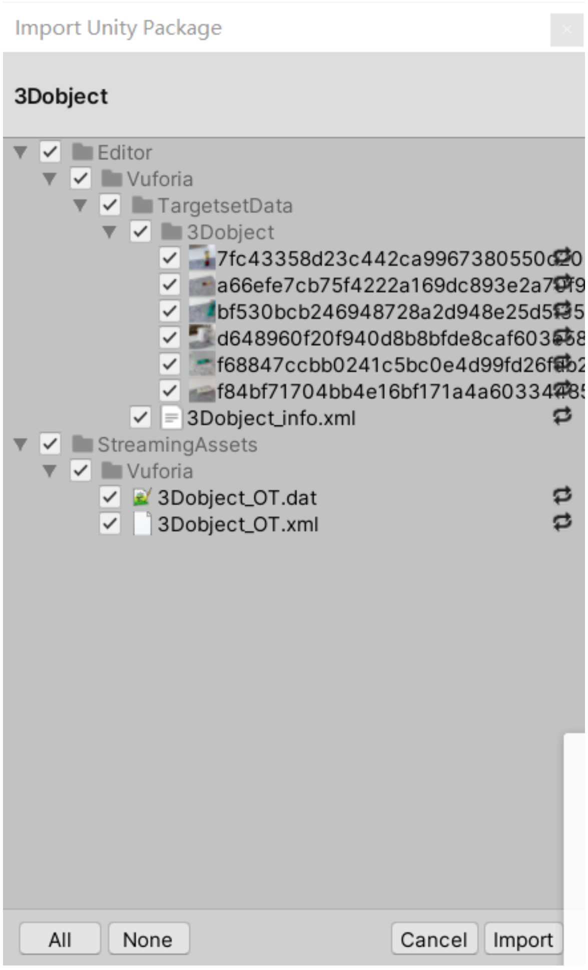


Fig. 6.14 Import the database as Unity package

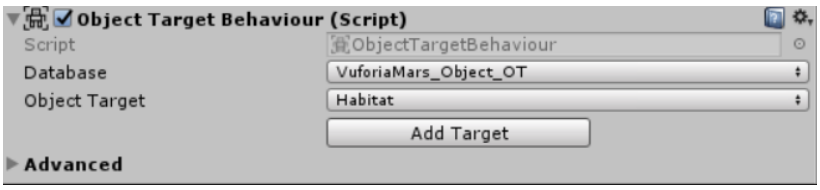


Fig. 6.15 Select the Database name and Object Target name

The following is how we use this function to detect the lighter. When the lighter is detected, a virtual lighter model will appear, and the user can use this model to interact. When an object is detected, displaying the corresponding 3D model is only the most basic operation. We can use scripts to develop some functions for these 3D objects later. In addition, after the object is detected, we can also set some events to be triggered. For example, there are voice or text reminders. Fig 6.16 shows the virtual lighter model that appears after the lighter is detected.

Fig. 6.16 The result after the object is detected

6.5 Generation and Implementation of Training Plan

We not only need children to be aware of the hazards of certain behaviors and objects, we also hope that children can learn how to face these hazards. So there is a part of safety education in our system. In this part, we need children's parents to work together.

We need different training plans for different scenes and children of different ages. So it is very important to have a flexible, optional training plan. For example, in the case of a fire scene, the user's parents can choose what they want from the following instructions

1. Crawl low and under the smoke;
2. Find a towel and moisten it with water;
3. Use the back of hand to feel the closed door;
4. If the door feels hot, choose another way; If the door feels cool, open it carefully;

5. After escaping the house, dial 119.

6. ...

But in our scenario, we may only need children to do the first, second and sixth instructions. Then parents can choose by voice. The selected instructions will be bolded to distinguish them from the unselected commands. At the same time, if the parent's instruction has a wrong choice, they can also say "cancel" to cancel the previously selected instruction and make the selection again.

Those selected instructions will be used as individual components and recombined into a training plan according to the order of selection. When executing the plan, every time the child finishes executing an instruction, he can say "next", "go next" or "I finished" to indicate the end. At the beginning, we set a parameter. Every time the system hears these words, the parameter will increase by one. We use this parameter to confirm the stage of plan execution.

At the same time, children also need to interact with virtual objects when executing certain commands. For example, when performing safety training in the scene of a gas leak, children need to turn off the knob of the virtual gas stove. In this case, we can also judge whether the instruction is completed by judging the state of the virtual object. For example, we can judge the angle of the knob of a gas stove to determine whether the command to close the knob is completed.

6.5.1 Hand Gesture Recognition

In our system, a transition is needed from the part where children manipulate some objects to cause disasters to the part of safety education. After referring to other articles and the design of other systems, we decided to use hand gesture recognition [28]to achieve the conversion of the above two parts. As shown in Figure 6.17, it is the hand joint points that HoloLens 2 can detect. What we need to do is to use these detected hand joint points to customize the gesture.

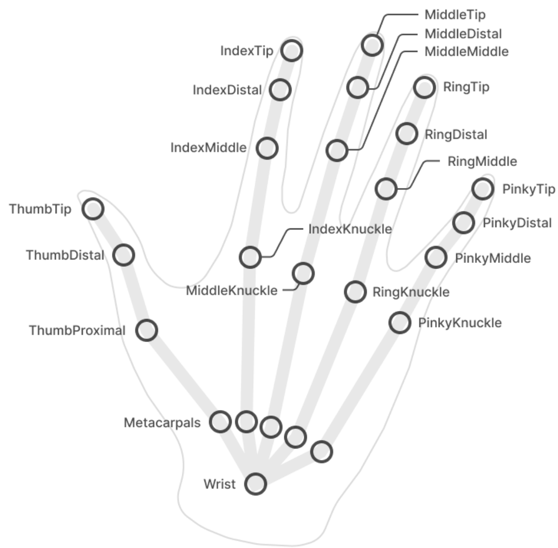


Fig. 6.17 Hand joint points

There are three main gestures we want to implement in this system: open hand, make fist and click with index finger. As shown in Figure 6.17. Below we will introduce the algorithm and implementation of this custom gesture.

(a) Opened hand (b) Make fist (c) Click with index finger

Fig. 6.18 Custom gestures will be designed in this system

The algorithm is as follows:

1. We first set the joints on each finger as a group;

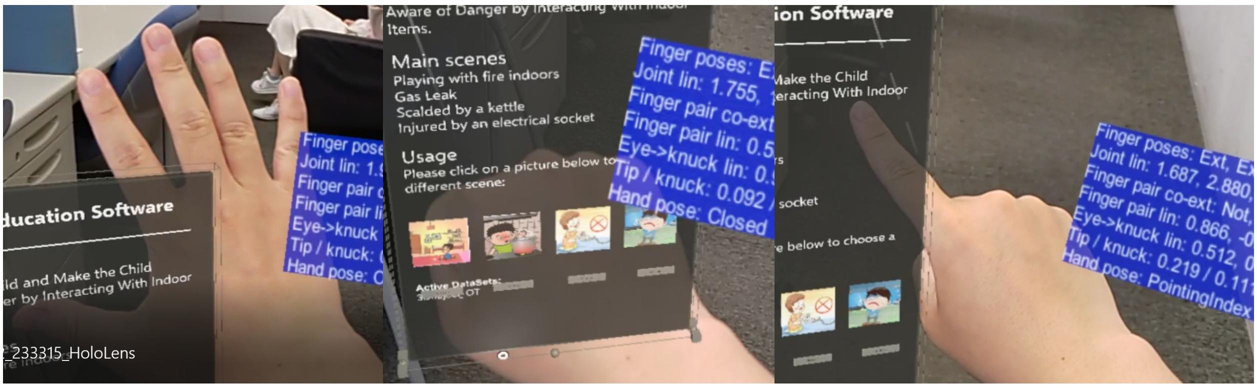
2. Calculate whether each finger is straight or bent. This step calculates the vectors between the joints and normalizes these vectors. Then these normalized vectors are

evaluated by dot product. We know that the point product of normalized vectors that are perpendicular to each other is 0; the point product of normalized vectors that are parallel to each other is 1. So when the vector between these joint points, the value after dot product is greater than the parameter we set, we can understand that the finger is in a straight state.

3. Then we also calculated the total distance of the fingertips. The total distance of the fingertips when the fingers are fully open is set to the maximum; the distance of the fingertips when making a fist is set to the minimum. When the ratio of the total distance of the fingertips value to the maximum value is less than the parameter we set, it can be judged that it is a fist state at that time.

4. The next part is the classification of hand gestures. If all the fingers are bent, and the ratio of the total distance between the fingertips to the maximum value is less than the parameter, we judge the current state as a fist; if only the index finger is straight and the other fingers are bent, we judge this state as clicking with the index finger; if all the fingers are straight and the total distance between the fingertips is close to the maximum, we will set it to the open state.

Figure 6.19 shows the judgment of gestures in our system.



(a) Opened hand (b) Make fist (c) Click with index finger

Fig. 6.19 Custom gestures in this system

Chapter 7

Conclusion and Future Work

7.1 Conclusion

In this research, we developed an AR safety education system to remind children and make them aware of the dangerous objects around and which behaviors are dangerous. This software can also be used by the user's parents to customize a safety training plan for the user to implement, so that they know how to deal with these disasters. We combine the possible causes of disasters, the scenarios and hazards caused by the disasters, and the escape training after the disasters, to give users the most comprehensive safety education.

In the use of this system, we combined Vuforia and MRTK to achieve a more precise "spatial perception" function. This makes the interaction between the user, the environment, and the virtual object more accurate and real, and enhances the user's sense of immersion when using the system. When using the system, each virtual object has a corresponding script to realize its interactive function. This ensures that our system can simulate the process leading to disasters through the interaction of virtual objects. In addition, we also designed an algorithm to distinguish the user's gestures to achieve more convenient interaction.In order to make it convenient for parents to make safety training plans for users, our system also incorporates voice input. Users can use voice to realize the functions of generating, executing and ending the training plan.

In summary, We have designed a comprehensive AR safety education system, from the beginning of a disaster to escape training, and contains four scenes where children are most vulnerable to injury. Through AR technology, our system can simulate the interaction with virtual objects and disaster effects very realistically. In the case of ensuring the safety of children, give children interesting safety education.

7.2 Future Work

In the future, We plan to develop more scenarios, such as food safety education and so on. At present, most of the medicines for children look beautiful and taste good. Therefore, children may take medicines casually and eat them indiscriminately. So this is also a focus of child safety education.

We also plan to optimize the disaster rendering effect. Now due to hardware limitations, when we simulate large-scale disaster scenes, there will be freezes and frame drops. So we should think about how to use the existing hardware level to achieve more realistic disaster scenarios.

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