Design and Implementation of AR Assisted Assembly System

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Abstract

Assembly workers mainly rely on paper manuals for assembly in the industrial operation site, which is inefficient and error prone. Augmented Reality (AR) is introduced to the assembly site in this paper to improve efficiency and reduce error rate in assembly process. In this research, we aimed at the assembly technicians, on-site workers and system administrators. Based on Unity3d and C#, an augmented reality assisted assembly system with multi-terminals and multi-users that support PC and HoloLens in a way of online management and real-time guidance is developed as follows:

Firstly, a set of AR oriented assembly process aiming at the verification scenario is designed, including assembly process, guidance information in assembly operation, interaction mode and visual display mode.

Secondly, after analyzing the requirements of AR assembly process guidance system, according to the requirements and combined with the designed assembly process flow, the assembly process guidance scheme based on augmented reality technology is designed. Also, the design of the technical architecture, functional architecture and main business logic of the system is completed in this part.

Finally, the AR assembly process guidance system is realized. The real-time guidance of workers wearing HoloLens glasses is realized based on Unity3D and ARToolKit SDK. The user management system, process management system and HoloLens real-time collaborative guidance system on PC are developed with Visual Studio 2019 and C#. The network communication is realized based on TCP/IP protocol with Socket. The functions of the system are verified by an example and the expected effect is achieved.

1 Introduction

In our current industrial field, assembly operations exist low efficiency and error-prone problems. Under the background of Industry 4.0, the manufacturing industry is ushering in a stage of digital transformation, which aims to utilize Big Data, Artificial Intelligence and Blockchain to help enterprises embrace a more intelligent and efficient production mode. Quality and Efficiency are the key factors of manufacturing products appreciation[1]. Therefore, it is worth doing research on how to improve quality and efficiency.

With the development of holographic digital display technology, interactive technology and image processing technology, Augmented Reality (AR) has been transformed from a concept into a technical means[2], which could integrate the virtual and the real objects[3]. AR can be implemented and widely used in the design of new products in many fields[4].

In the past, workers needed to read the technical manuals at the assembly site, or even use a calculator to calculate in real time. AR can be introduced to enable workers to call and view the current assembly information and assembly status in real time by wearing head-mounted display devices[5] (as in Figure 1). It can greatly improve the assembly efficiency and accuracy especially in complex assembly scenes.

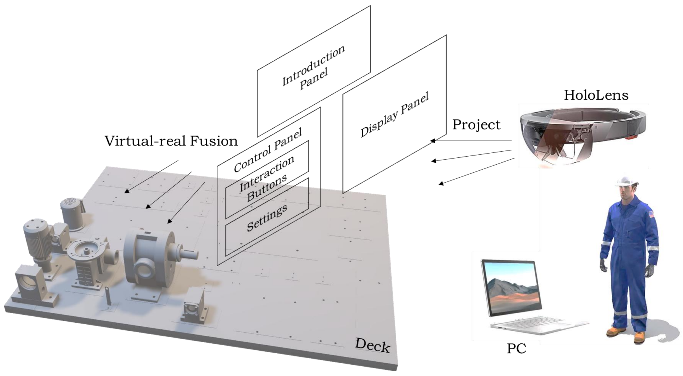


Figure 1. An example of augmented reality assembly scenarios

There are four essential features to point out to realize AR:

1) Data organization. With the instruction and the assembly process designed, user Information, assembly data, 3D models and other Information are organized in the system database, which is supported by PC. Makris S[5] and Shan Lan[6] organize and manage assembly boot information with XML files. Walczak[7] manages guide information using Semantic Web.

2) 3D registration. The virtual objects are stuck to the given place of real objects. Specific to the HoloLens, registration can be finished based on the Vuforia[8] or AR tool kit. Wang Y and Ran Liu[9] used natural feature extraction and matching.

3) Real time interaction. Man-machine communication is everywhere. It's necessary to realize the communication between PC and HoloLens so that Different parts of the whole system can cooperate with each other. Gesture[10], voice[11], and eye-movement[12] are used to realize human-computer interaction respectively by Huan Liang, Qiong Dong and Iftene A.

4) Virtual-real fusion. The virtual and real objects can be mixed visually in real time in different devices. The virtual model can be displayed on the headset device[13], projection equipment[14] and AR glasses (MS HoloLens[7], Google Glass, Magic Leap etc..).

Most of the current researches only involve the technical research and implementation of enhancing a certain part or several parts of the assembly system. Therefore, this research focuses on the completeness of the system and completes the comprehensive design and implementation of various platforms from database, PC to HoloLens through Unity3D, C#, MySQL and other platforms. A set of assembly process guidance system based on augmented reality was completed with its functions designed for several types of personnel: (1) Enterprise managers, through this system can clearly grasp the assembly progress of each assembly personnel, and register or cancel accounts for all types of personnel and manage all account rights; (2) Assembly technicians. The process information can be increased, reduced, modified, and checked in order to adapt to the adjustment of the process in time; (3) Assembly operators, wear glasses to directly read their last assembly information sent from PC server software, or directly identify the current assembly state, and start real-time guided assembly.

This study provides an effective digital innovation solution for low efficiency problems in industrial assembly field.

2 Methods

Going back to what is explained in Introduction about key technologies to AR Aided Assembly System, Steps can be summarized as follows.

1) Design a set of assembly technical schedule and auxiliary information used for the application scene.

2) Design and build a database with assembly process and user information.

3) Develop AR module, and complete the HoloLens three-dimensional tracking registration.

4) Complete the HoloLens virtual information display, the actual model fusion effect.

5) Realize the HoloLens human-computer interaction, including gestures, voice, etc.

6) Develop the PC applications, making database able to be add, delete, modify, and search.

7) Realize the Local Area Network (LAN) communication between PC – HoloLens.

3 Design

In this chapter, the process and auxiliary information design, function design of each part, hardware platform and overall framework of the augmented reality assembly process guidance system are elaborated. In the part of process and auxiliary information design, this paper will complete the installation process design of eight workpieces; In the part of function design, the database, 3D tracking registration, gesture interaction, process information push, equipment communication, computer vision processing and other functions are designed. Finally, the overall design of the AR assembly process guidance system will be given and explained.

Workers install eight workpieces based on the cabin board. The three-dimensional model of the assembly scene, the actual environment and part models are as in Figure 2.

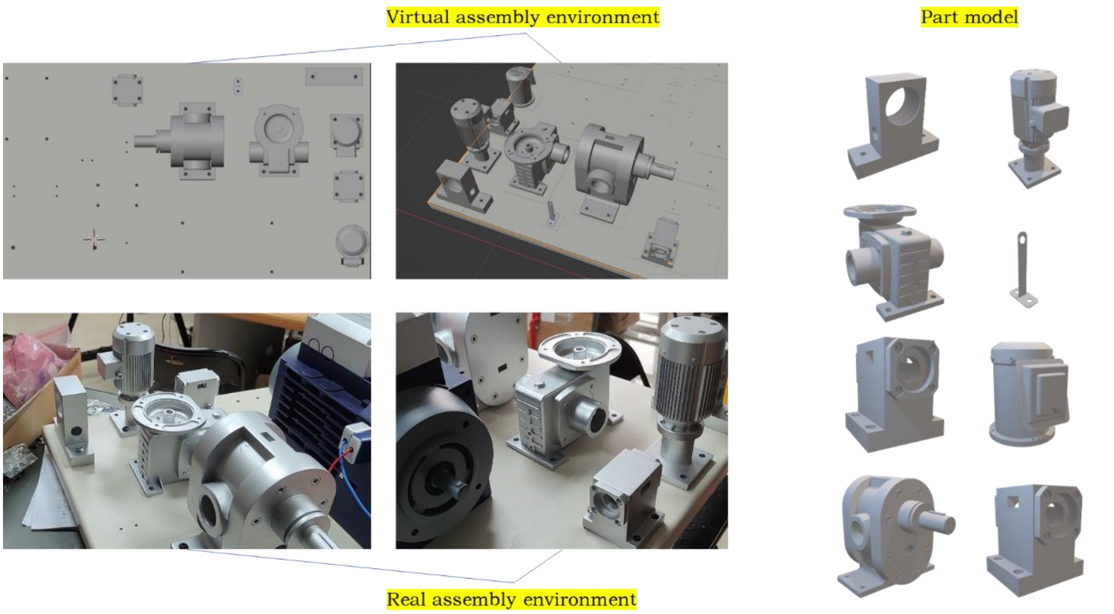


Figure 2. Assembly environment and part models.

In this assembly process, basic workpieces 1 to 3 are positioned on the cabin board as the initial state, and work pieces 4 to 8 are installed successively. The process design is shown in Figure 3.

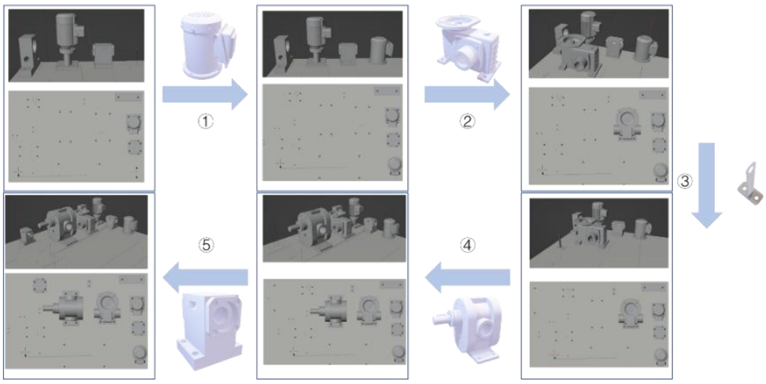


Figure 3. Assembly step design.

When installing each workpiece, bolts and gaskets should be matched, appropriate torque should be used, and special operations should be paid attention to. The final assembly process card is shown in Figure 4.

总装作业指导书		产品代号		工序代号	01	页码	01/01
		工艺编号		工序名		工位号	

装入件明细					补充要求
序号	零件代号	名称	数量	备注	技术文件
1	model31	工件4	1		
2	model32	工件5	1		
3	model33	工件6	1		
4	model34	工件7	1		
5	model35	工件8	1		
6	GB/T 9145-2003 M6 X 20	螺钉	18		
7	GB/T 9145-2003	垫圈	18		
8	GB/T 9145-2003	弹簧垫片	18		质量安全要求
					a. 严格执行防静电措施，严防多余物；
					b. 操作设专人监督防护，严禁磕碰产品；
					c. 严格过程质量控制，各阶段工作均留影像记录；

装配步骤			
序号	名称	操作内容	
01	总装	1.1 定位工件4； 1.2 安装垫圈、垫片、螺钉； （螺钉 4个； 垫圈 4个； 弹簧垫片 4个；） 1.3 紧固工件4,按照垫圈、垫片、螺钉的顺序，按照10N·m的力矩大小进行紧固，此外还需要满足…技术要求；	
05	检验	检查工件4安装状态： 5.1 检查工件4是否紧固； 5.2 实施（某种）措施（例如涂胶、接地、热控等）；	
10	总装	10.1 定位工件5； 10.2 安装垫圈、垫片、螺钉； （螺钉 4个； 垫圈 4个； 弹簧垫片 4个；） 10.3 紧固工件5；	
15	检验	检查工件5安装状态： 15.1 检查工件4是否紧固； 15.2 实施（某种）措施（例如涂胶、接地、热控等）；	
20	总装	20.1 定位工件6； 20.2 安装垫圈、垫片、螺钉； （螺钉 2个； 垫圈 2个； 弹簧垫片 2个；） 20.3 紧固工件6；	
25	检验	检查工件6安装状态： 25.1 检查工件4是否紧固； 25.2 实施（某种）措施（例如涂胶、接地、热控等）；	场景示意图片
30	总装	30.1 定位工件7； 30.2 安装垫圈、垫片、螺钉； （螺钉 4个； 垫圈 4个； 弹簧垫片 4个；） 30.3 紧固工件7；	
35	检验	检查工件7安装状态： 35.1 检查工件4是否紧固； 35.2 实施（某种）措施（例如涂胶、接地、热控等）；	
40	总装	40.1 定位工件8； 40.2 安装垫圈、垫片、螺钉； （螺钉 4个； 垫圈 4个； 弹簧垫片 4个；） 40.3 紧固工件8；	
45	检验	检查工件8安装状态： 45.1 检查工件4是否紧固； 45.2 实施（某种）措施（例如涂胶、接地、热控等）；	

工装工具设备辅料				
序号	名称	规格	数量	备注
1				
2				

作业时间		作业人员	编制		标审	
			核对		会签	
版本号			审核		批准	

Figure 4. Final assembly operation instruction design.

The purpose of the design of the assembly process guidance system based on augmented reality in this paper is to establish a virtual assembly information registration system based on artificial identification and natural features, so as to automatically guide the assembly system under the instructions of assembly workers. With the real-time image collection, online analysis and process record at the PC end, real-time state analysis and state preservation can be carried out. An online digital twin system can be set up at the PC end of the assembly site.

On the PC side, the login interface should be set first. The following situations are encountered respectively: (1) After the assembly worker logs in, the system shall be responsible for receiving HoloLens instructions to read the database information in real time, and send it to HoloLens; at the same time, it shall be responsible for receiving the picture information sent by HoloLens online, and converting the picture RGBA encoding into the picture form for processing; (2) After the administrator logs in to the system, the system should read the current user information and enable the administrator to manage the user information. (3) The assembly process administrator logs in and enters the system, the system reads the original assembly process information, and the administrator can adjust and modify the process information.

At the HoloLens end, the system mainly recognizes markers, registers and displays virtual models, and starts assembly guidance. After connecting the system through TCP protocol, it is responsible for receiving the process information returned by the PC in real time, so as to guide the operation of the workers in real time. It can also send the current photo online to the PC side of the system for real-time analysis.

According to the above purposes, the system shall have the following functions:

1) Enhance the database management of the assembly guidance system

The system needs to face multiple types of user personnel. For the user administrator who enhances the assembly and guidance system, it needs to provide the user information management function, which can add, delete or modify the user account name, password and authority. For the assembly process information manager, it is necessary to provide the operation authority of the assembly process database to adjust or modify the process, work step and guide content.

2) 3D registration and virtual-real integration

The registration of virtual cabin board and virtual workpiece is completed based on markers, so that the virtual object information is integrated with the real environment, and the correct position and pose display of the virtual model in the real assembly environment is guaranteed. This project completed 3D tracking registration based on Vuforia and ARToolKit, and finally the system chose open source ARToolKit for virtual model registration.

3) Gaze, gesture, voice control

After wearing the HoloLens device, workers need to interact with the system, which mainly recognizes and detects human gestures and voices through the device, so as to complete corresponding functions under instructions. This part mainly includes: (1) Gaze, the head movement drives the glasses to change the Angle of view, if there is a virtual object or a system recognition and detection object in front of the eye gaze, the user gaze object shows a small circle, this part is usually combined with the next part to achieve the corresponding goal; (2) Gestures: When the target object appears a small circle, the user can use the gesture AirTap, that is, click in front, the camera of the glasses will capture this action and give feedback, in addition to the design of continuous click, long press or other gestures; (3) Voice control. During the operation of the system, the hands of assembly personnel may be bound. You can add voice control function.

4) Push virtual information actively

When the assembly operator touches "Next" or "Back" by gesture or voice control function, the system will automatically complete the push and presentation of the next or previous step of process information, including the presentation of the virtual model of the workpiece and the text guidance information.

5) Communication between devices

Communication between HoloLens and PC is realized based on TCP Socket, which is mainly used for the two devices to transmit information to each other, including two aspects of information. On the one hand, HoloLens sends "Next", "Back" and "Restart" requests, and sends photo coding when "Send Picture"; on the other hand, PC sends corresponding steps of the process guidance information, computer vision processing results, etc.

6) Computer vision processing

When the assembly operator touches "Send Picture" by gesture or voice control function, HoloLens automatically completes the sending of photos encoded in fixed format. After receiving the encoding, PC reconstructs the image and carries out visual processing on the image, such as feature point capture and state matching.

The framework of the assembly process guidance system based on augmented reality is described from four levels (as in Figure 5) : hardware layer, data/software layer, function layer and presentation layer. The system proposed in this paper takes HoloLens camera as input device, HoloLens holographic display as output device, PC and HoloLens processor as core computing and processing equipment. Through artificial identification and natural features, 3D registration is completed to realize the integration of virtual model and actual working scene. By invoking process information, user information and other information through MySQL database, communication between PC and HoloLens is carried out based on Socket, so as to complete the push of process information and the visual analysis of images captured by HoloLens. Through human-computer interaction between PC and HoloLens, real-time on-site assembly guidance task is finally completed.

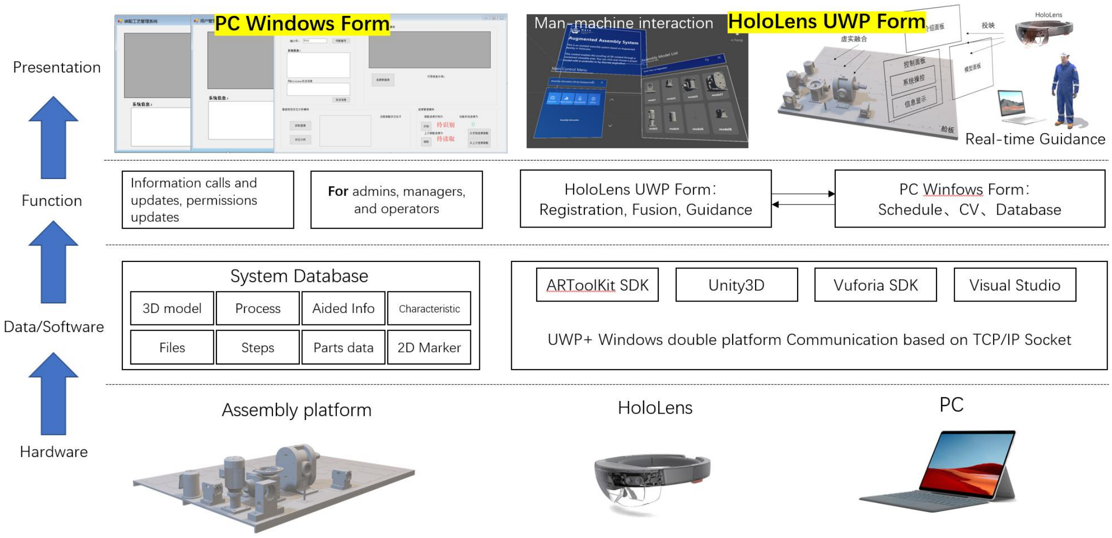


Figure 5. The framework of the assembly process guidance system.

The platforms adopted in the research and their implementation functions are shown in Table 1.

Table 1. Platforms and programming Language/SDK/Protocol adopted in the research.

Device	Platform	Function	Programming Language/SDK/Protocol
HoloLens Platform	Unity3D 2019.3LTS	Man-Machine Interaction Devices Communication Assembly Assistance	C#
		Image processing 3D Registration	Vuforia ARToolKit
PC Platform	Visual Studio 2019	Interactive Functions Load Data Devices Communication	C# MySQL
		Image processing	OpenCV
Devices Communication	Visual Studio 2019	Communication Interaction	TCP

4 Results

The function verification of each part of the system is as follows.

1) AR aided assembly System Database

The database of this system is based on MySQL, including user data, process data, 3D model data and other data. The user data contains the login information of user administrator, assembly personnel and process management personnel. The login information will be matched during system login, and the corresponding interface will be entered if the matching is successful. Process data includes parts data, assembly sequence, auxiliary information, assembly process information, etc. In the real-time assembly guidance process, the database is retrieved in real time, and the system pushes the retrieved information to the HoloLens device. 3D model data include natural features, artificial identification, model data, spatial relationships, etc. These data are not stored in MySQL, but stored in HoloLens' system. The system has completed the encapsulation of these data during the packaging and deployment. Other data include step record, information feedback, etc. Step record is mainly used to save the current progress, which can be directly read when entering the system next time, and enter the last progress, while information feedback is used for assembly personnel to record the corresponding problems during assembly, which can be reflected to the process manager, so that the process personnel can adjust accordingly according to the suggestions. These four kinds of data (as in Figure 6) together constitute the database of AR assembly process guidance system.

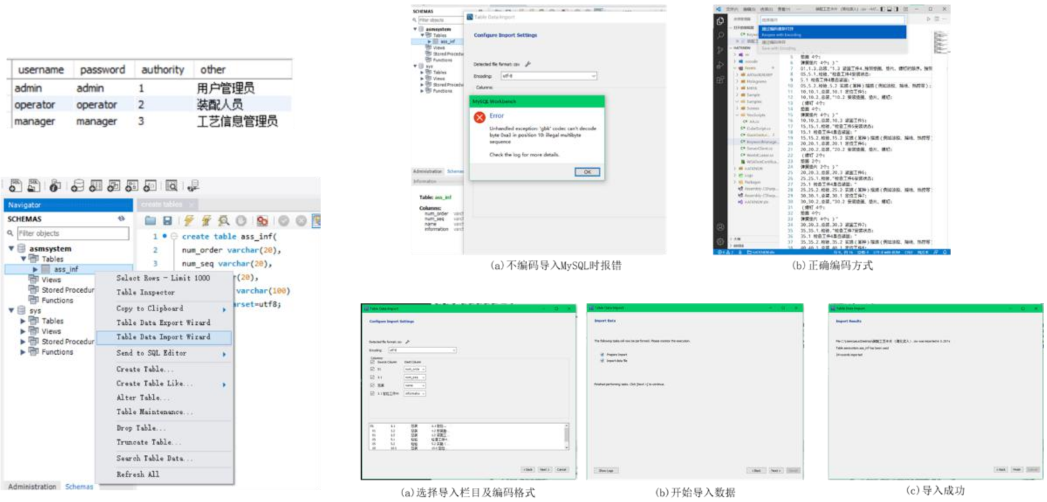


Figure 6. MySQL Database.

2) 3D registration and virtual-real integration

With its advanced sensors, high-definition 3D optical lens display and surround sound, HoloLens superimposes virtual objects on the surrounding real environment and allows users to interact with the virtual-real world around them through gazing, gesture, and voice. Based on Vuforia or ARToolKit, 3D tracking registration and virtual-real fusion was realized (as in Figure 7).

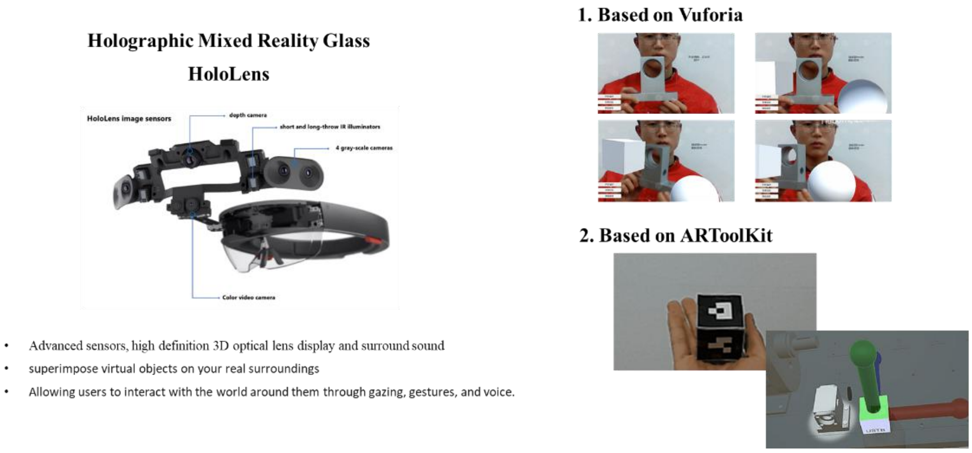
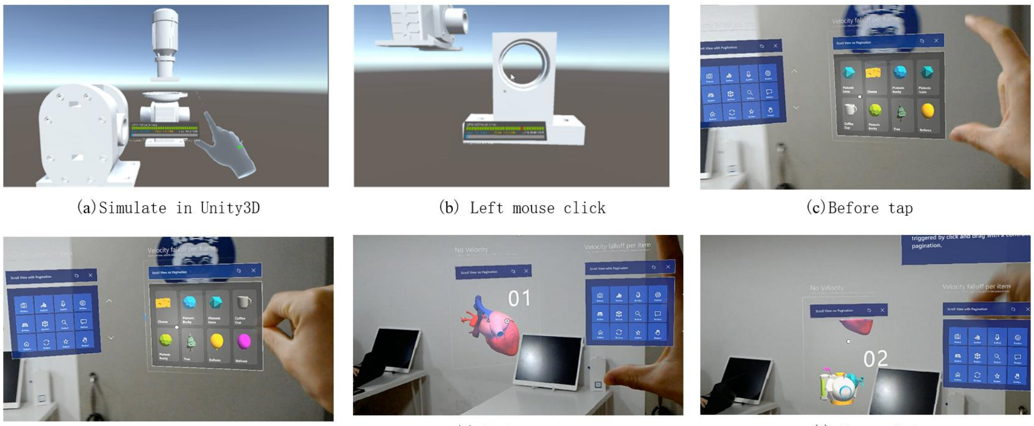


Figure 7. 3D registration and virtual-real integration.

3) Gaze, gesture, voice control (as in Figure 8)

Gesture recognition and voice recognition are important input methods of HoloLens interaction. Gesture recognition is a high-level API used to identify gestures based on input sources. By default, the system uses the GestureRecognizer to complete gesture recognition, add a gesture recognition instance in Unity3D, specify the gesture type, and subscribe gesture events for it. After the gesture is recognized, the system will trigger corresponding events. Speech expression is one of the most direct ways of expression for human beings. The biggest advantage of voice control is that it can liberate hands. Especially in industrial assembly scenes, assemblers may not be able to spare their hands. There are three types of Voice input on HoloLens, namely Voice Command, Dictation, and Grammar Recognizer. Add the officially provided KeywordManager.cs script component to the project, add the voice command key, add the handler and the passed parameters, and call the required functionality.



(a)Simulate in Unity3D (b) Left mouse click (c)Before tap

(d)Tap and drag (e) Before tap (f) Tap and drag

Figure 8. Gaze, gesture, voice control on HoloLens.

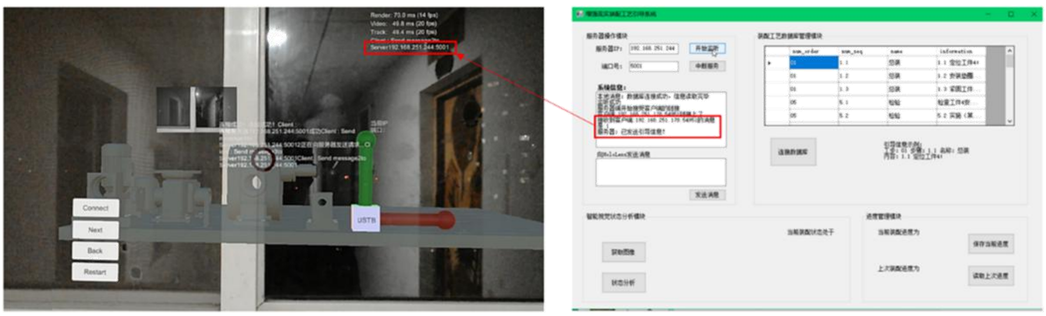
4) Push virtual information actively

Workers' voice or gesture indicates the next step, and the guide information is transmitted from the PC server to the HoloLens in time, as is shown in Figure 9.

Figure 9. Active information acquisition.

5) Communication between devices

As a server, the PC establishes Socket and starts to listen. After receiving the connection request from HoloLens, the PC responds to establish the connection. As a client, HoloLens does not support synchronous socket communication. It must be asynchronous (as shown in Figure 10).



a) HoloLens b) PC

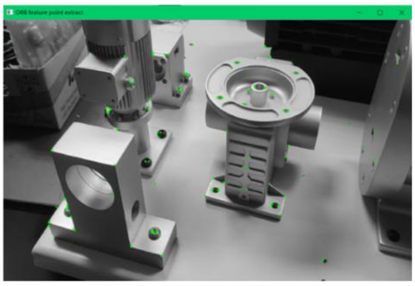
Figure 10. Asynchronous socket communication between PC and HoloLens.

6) Computer vision processing

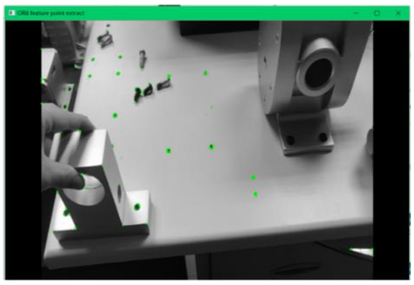
The HoloLens takes photos and sends them online to the PC for visual analysis, which mainly includes image encoding and decoding, image processing and assembly state recognition. Feature extraction is an important part of scene recognition. In this paper, a feature extraction method of assembly scene image based on ORB algorithm is proposed. ORB algorithm can be used to quickly create feature vectors for feature points in the image to achieve the purpose of feature extraction. Moreover, it combines FAST and BRIEF algorithms and proposes to construct a pyramid to add directions for feature points extracted by FAST method. Therefore, ORB algorithm has rotation invariance. ORB algorithm mainly extracts, describes and matches the corners of the image. The results are shown in Figure 11.

a) Assembly Scene 1

b) Assembly Scene 2



c) Assembly Scene 3



d) Assembly Scene 4

Figure 11. ORB feature extraction from the assembly scenes.

5 Conclusion

In this research, An AR aided assembly system is designed and implemented. The database on the server side is mainly built through MySQL8.0, which is used for client to call and modify user information and process data. Applications on HoloLens are mainly built through Unity3D 2019.3LTS. Functions such as human-computer interaction, device communication and assembly guidance are realized through C# scripts. Image recognition and 3D registration are realized through Vuforia or ARToolKit. The application on the PC server is mainly built by Visual Studio 2019, and the interactive function, database call, device communication and other functions are realized by C# code. The interaction between HoloLens and the server mainly considers the problem of HoloLens' computing power. It adopts the scheme of separating partial image classification and recognition from HoloLens devices, puts the image processing and recognition module in HoloLens on the server, and transmits the pictures taken by HoloLens to the server through TCP protocol. HoloLens voice module is also mainly used to receive user commands and send commands to the server. The research map is shown in Figure 12.

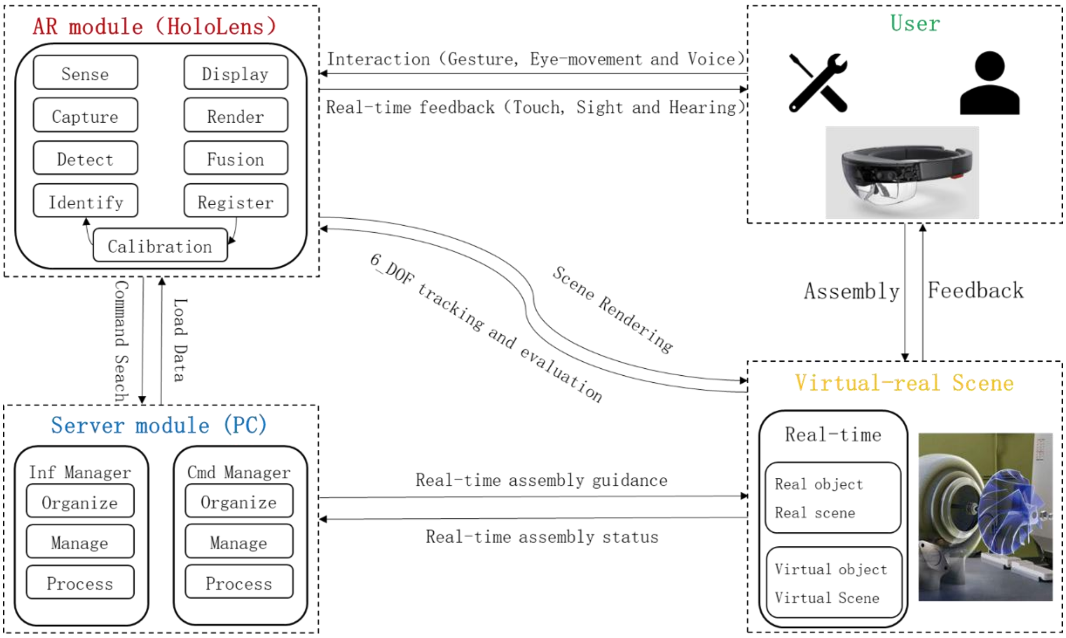


Figure 12. AR aided assembly system research map.

A framework of interactive AR aided assembly system was proposed in this paper. Two methods of 3D tracking registration are designed, and their realization in HoloLens is explained. With Socket asynchronous communication, an AR aided assembly system with hardware and software for multiple types of users was constructed and verified. The corresponding interface of PC is developed for user administrator, assembly personnel and process administrator respectively, and multiple users can cooperate with each other. Assembly personnel complete HoloLens sending information request and picture sending by gesture and voice control, and return the result after processing by PC. Finally, assembly operation is completed.

However, the research still leaves much to be desired. Such as

1) Enhance system versatility.

This paper only verified the guidance effect of the current assembly platform, but after changing the assembly scene, the process information could be adjusted and continued to be displayed. However, the 3D model was packaged in the program of the HoloLens terminal and could not be changed at will. The adaptability of the system will be greatly enhanced if the model file can be transmitted as a data stream and displayed at the appropriate registration position in HoloLens. How to manage the server's 3D model file and its corresponding data under the current communication mode puts forward higher requirements for database research.

2) Decrement assembly based on non-fixed assembly sequence.

This paper mainly studies incremental assembly based on fixed sequence, which may involve assembly reduction and modification in practical application. Some complex components need to be disassembled after installation. Since augmented reality adds virtual information to the scene, how to guide operators to take out some components through augmented reality requires further research.

3) Establish assembly digital twin system.

At present, domestic enterprises are in the stage of digital transformation. The essence of concepts such as digital twin and digital twin is to establish a virtual world that synchronously displays the current production process of enterprises, so as to monitor, anticipate, make decisions, optimize and other choices, and manage the whole life cycle and process. This project designs and implements an assembly process guidance system based on augmented reality technology. With the help of the augmented reality glasses worn by workers, the current assembly state can be timely feedback to the server. According to the state data, the server can establish a digital twin system for the industrial site of enterprises and an assembly digital twin system.

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