AR Fitness Coach: Exercise Assistant System for Body-Training Guidance and Motivation

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July 2021

Abstract

Nowadays, people pay more attention to healthy life, self-service fitness at home has become popular especially during the COVID-19 period. Although online fitness provides lots of convenience for people, it also face some challenges. Traditional online tutorials through two-dimensional material makes current exercises assistance lack the spatial information, personalized motivation and interactions, which reduces self-serve exerciser's efficiency, safety and interesting in daily exercise. The advancement of science makes Augmented reality (AR) technology more widely used in daily life. AR enables virtual characters to be displayed in the real world, which allows people to interact with virtual character while participating in nature. Our research intends to improve self-service fitness experience by providing exerciser with intuitive movement training, natural interactions, and personalized motivation with augmented reality technology. In order to simulate the sense of being accompanied by a personal coach for user, we provide a holographic AR-based exercise assistant system with a full-body personalize avatar as fitness coach to support user's self-serve fitness. The virtual coach performs coach's professional duties to give user's guidance and feedback about training performance. Virtual coach displays the fitness actions by its 3D human body to support intuitive motion learning. Combined with the motion capture technology, system supports user's fitness movement skills improvement in the form of providing users with external self-image and action accuracy evaluation. We design three training modes in the system to realize these functions. In terms of functionality and usability, our system provides users with effective motion learning and motion skills improvement mechanism. In particular, the sense of companionship and motivation from the personalized coach has a positive impact on user's fitness training. Our system greatly enhances the fun of users during self-service fitness, and provides a more effective and attractive self-service fitness experience.

Keywords: augmented reality, trainer system, personalized avatar, fitness service

Acknowledgements

First of all, I would like to express my sincere admiration and gratitude to my supervisor Prof.Jiro TANAKA. He is a very respected and responsible supervisor with innovative thinking and rigorous academic attitude. He brought me into the field of human-computer interaction and always guides me patiently and gives a lot of encouragement and help to me. Thanks for his valuable suggestions and equipment assistance in all stages of the preparation of this thesis.

In addition, I would also like to thank all my dear partner in the IPLAB. They always give me a lot of inspiration when discussing with me. Thank them very much for their help in school studies and daily life. Meeting them is a wonderful fate in my life.

Finally, I want to thank my family, friends and all those who love me. For my parents, they gave me financial support and spiritual warm support during my master's study career, and for my friends, they gave me encouragement and company when I meet setbacks. Thank you for their continued support, which makes me full of courage and hope for my future life, I will try my best to work hard and make continuous progress.

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Chapter 1

Introduction

1.1 Introduction

Nowadays, people have a higher quality pursuit of a healthy life, and daily exercise has gradually become the habit of many people. Fitness activities often require users to perform a series of body motion in very accurate postures, otherwise there will be a risk of poor exercise effect or even injury. However, fitness actions are varied and detailed, which make exercisers always have difficulties to remember standard actions. So the inexperienced exercisers often faces the difficulties in completing standard actions and keeping training interest/ perseverance during self-service fitness. With the advancement of technology, the online fitness service industry is developing rapidly, exercisers can use fitness assistance tools to perform self-service fitness at home in a more convenient way. Online video sites such as YouTube and fitness apps provide thousands of physical exercise training videos, covering various skills training from dance to fitness. Traditional online resources such as videos and live courses have great limitations as the motion training media. Although these assistance tools can provide coach's movement information through the playback system, the information is compressed into 2D images and displayed on a flat screen, which may lose the importance spatial details. Due to can only be displayed on a flat screen, current online fitness service cannot be integrated into the user's real environment. They usually do not capture the user's 3D motion information for analysis, and cannot provide timely feedback or personalized motivation.

Augmented reality technology makes it possible to display virtual characters in real environments, it brings digital information and virtual objects into the real physical space. The augmented reality system has three outstanding features[1]:

- Combines real and virtual objects in a real environment
- Register real and virtual objects with each other
- Interactive, 3D, real-time operation

AR supports us in the fields of education, art, sports, and remote collaboration. With the help of AR, we can find some new solutions to traditional problems in fitness activity. In the research on motion training, AR technology combined with external motion capture technology to provide external self-image so that users can adjust their posture to achieve motion skills improvement. This kind of solution is widely used in sports skill training, dance learning and other professional activities about body-movement training. AR support motor learning in 3D forms. Many studies have emphasized the importance of providing body information in some physical task guidance. To demonstrate the coach's behavior 3D form has great potential. In the field of technology-based remote collaboration/guidance, researchers often use the AR-based avatar with human body shape to support the training and guidance of some physical tasks, which has shown good results for user's motor learning.The potential impact of other attributes of virtual avatar on the support of action guidance is worth exploring.

In order to solve the problem of lack of effective guidance and incentives for self-service fitness users, our research focuses on AR technology and virtual avatars. We propose a method to use a personalized virtual fitness trainer to assist users in self-service fitness. Our system reduces the gap between online fitness coach guidance and offline professional coach guidance, and enhances the user's self-service fitness experience. It allows users to obtain intuitive guidance, timely feedback, skill improvement, sports companionship and motivation, in order to gain health The body and the fun of exercise. The purpose of the system is to improve the self-service exercise experience in the following ways:

- Provide user with personalized fitness coach in AR form to simulate a real coach's duties and making contributes to user's fitness training. In addition to the usefulness of motion guidance, we also pay attention to its affect of motivation for sports training.
- Provide user with the convenient interactive environment. Make use of the natural interactions among user, system and physical environment, to provide users a more attractive and immersive training environment.
- Provide users with an effective progress mechanism by designing the suitable training modes. In different training modes, it will provide users with some useful functions for improve training performance, such as self-external image, training evaluation and feedback.

1.2 Organization of the Thesis

The rest of this thesis is organized as following parts: Chapter 2 introduces the background about this research of the thesis. Chapter 3 will describe some related research fields. Chapter 4 will tell the research goal and also the approach will be told briefly. Chapter 5 is the system design part, where the design concept and ideas will be introduced in detail, and the mechanism will also be told briefly. Chapter 6 presents the system implementation part which is about the devices, environment and implementation in detail. Chapter 7 will be about the conclusion and future work part, where we will conclude the previous content and talk about some possibilities for our future research.

Chapter 2

Background

2.1 Self-serve fitness

Exercising is known to be associated with numerous physical and mental benefits such as controlling weight[2], decreasing the risks of cardiovascular diseases and reducing stress [3]. Although aware of the health benefits of exercise, not everyone can exercise regularly and effectively.The Center for Disease Control in the United States estimates that only 20 percent of adults meet exercise guidelines. Performing a regular exercise for different parts of the body would keep the muscles of the body in healthy condition and good shape. Today, with the improvement of people's quality of life, people are paying more and more attention to personal health and begin to engage in daily fitness activities. The rapid growth of gyms, fitness clubs, fitness coaches, and fitness activity forms proves that people's attention to fitness and body shaping is gradually increasing.

With the thousands of gyms and fitness studios shut down during the COVID-19 pandemic, people have to stay indoors as much as possible, thousands of people are on the lookout for their next workout. Plenty of exercisers choose to perform muscle-building exercises in private places such as at home. They apply some home workout equipment such as dumbbells, resistance bands and yoga mats, or using items found around the home to make self-serve fitness happen. Self-service fitness like this allows free place, time and activity options. While there may be no replacement for expert coaching, less formal selfpaced learning may be more desirable and convenient for in-home practice, to supplement professional coaching, or for hobbyists. It meets most of people's daily exercise requirement , which is very popular in these day.

2.2 Online fitness

People's demand for self-serve fitness has given birth to the development of the online fitness industry, some fitness-related online service is very helpful and necessary for people's daily self-service fitness. Due to the problem that inexperienced exercisers meet in self-serve fitness are that they have not enough fitness knowledge about what to exercise or how to exercise, so they need to learn and get guidance. Online fitness can make use of the wealthy network resources to provide users with remote guidance and support users to not be restricted by time and location in fitness movements learning and performing.

In addition, due to advancements in technology and the expansion of the digital health care market[4][5], interest in online fitness has rapidly increased. Compare with traditional face-to-face approaches, technology-based online fitness have shown several advantages, as they enable continuous self-monitoring, and are easily accessible, thus reducing the barriers of transportation and time [6][7]. The unprecedented lockdown due to the COVID-19 pandemic has increased consumer and developer attention of the demand for online home fitness. Online fitness not only to overcome restrictions to at-home spaces and the lack of plan to exercise programs but to solve the physiological and psychological health problems that arise when there are limitations to physical activity[8].

2.2.1 Online Fitness Service

Some online fitness game makes attribute to online fitness service. Exergame has been well-studied as an alternative to traditional exercise, which is a skill-driven physical activity that requires the participant to exercise in order to win the game[9]. Exergaming significantly increased heart rate and energy expenditure with similar effects as traditional physical activities[10][11]. Representatively, there are the Wii and Xbox Kinect exergames.

Some companies provide online fitness services in the form of offline hardware devices combined with online applications. At-home fitness company Mirror began providing a paid online home fitness service using the smart mirror. In addition, there are lots of mobile phone applications that guide proper exercise and provide self-monitoring. Keep[12] is a mobile fitness app that allows users to view fitness videos to train, which contains a social networking service so that customers can share exercise routines with each other. Keep had over 200 million users in September 2019. A December 2018 report published by Sootoo Institute found that there were 38.8 million downloads of Keep between July and September, making it "the most downloaded fitness app in China". Samsung Health 2 [13] provides a dedicated section called programs containing short workout videos for various exercises. Fitness Buddy application[14] is like a virtual personal trainer and nutritionist in one, with hundreds of workouts to tackle at home or at the gym, plus personalized meal plans and recipes. All exercises feature clear instructions and videos, and progressive workout plans make this ideal for beginners or advanced lifters.

2.2.2 Challenges in Online Fitness

Online fitness brings convenience to people's home self-service fitness, tradition online service such as websites and applications provide users with fitness exercise resources, including graphic tutorials, video tutorials, online live courses, etc., which supports independent fitness exercisers perform workouts independently. However, these common forms of online fitness are facing some challenges, including the lack of intuitive information, motivation and companionship.

The first challenge is lacking of intuitive information in online fitness. Online tutorial materials always displayed on screen by text, pictures, animations or videos can only convey two-dimensional information to users. Due to the lack of three-dimensional spatial information, the information conveyed is very limited and not comprehensive. This makes it not intuitive for users to watch the tutorials, and there will be a risk of misunderstandings. What's more, some applications would like to provide professional guidance by online coach, usually only one coach to teach but multiple users to learn. The interaction between coach and user is limitation because there is almost only one-sided communication from online coach to user. This leads to the information from online service to user is not timely and intuitive. Today, the development of head-mounted mixed reality devices and AR technology are expected to enable mobile devices to combine 3D data in real world to deliver

Secondly, due to the unsupervised characteristic of online fitness, the biggest obstacle that still exists is that exercisers may easily lose interest and motivation when training alone. Interest and motivation are usually the power that drives the exercisers to maintain willpower and keep going. It is well-established that active motivation can support physical activity[15][16][17]. According to the analysis of the 2019 Global Sports and Fitness Economic Report[18], the four major reasons that hinder global adult participation in sports and fitness are lack of time, lack of interest, exercise and health status, and lack of motivation and habits (Figure 2.1). The three major reasons that drive adults to participate in sports and fitness are also very obvious. They are maintaining health, decompression and fitness as a form of entertainment. Of course, the requirements for motivating young people to participate in sports and fitness are also very obvious, which is fun. Time and convenience are the main reasons that hinder youth sports. With the characteristics of supporting flexible time and free location, home-based autonomous fitness has solved the problems of time and convenience to a certain extent, however haven't overcome the biggest obstacle that lacking of motivation.

The third challenge is that current online fitness lacks company. Previous work suggests that factors such as pleasant surroundings, an enthusiastic exercise leader, and sympathetic co-exercisers during leisure-time activities are all likely to relieve negative emotions associated with exercise [19][20][21]. A laboratory-based study found that exercising with others helped to reduce stress and produce overall positive effects on energy, calmness and tiredness, compared with a control group exercising alone[22]. Fitness is an activity that consumes energy. Once a exerciser is in a poor training state, it is easy to produce fatigue, boredom and even negative emotions during the body training. At that time, if an experienced sports leader accompanies the exerciser to train, it can relieve fatigue and negative emotions to a certain extent, and enhance the confidence in keeping on training. A personal fitness coach can

Top Barriers to Physical Activity Worldwide	Top Motivations for Physical Activity Worldwide
Adults 1. Lack of time 2. Lack of interest 3. Physical or health conditions 4. Lack of motivation or habit	**Adults** 1. Maintaining good health 2. Stress reduction or relaxation 3. For fun or pleasure
Youth 1. Lack of time 2. Lack of convenient facility or activity near home 3. Not having fun 4. Prefer to do something else	**Youth** 1. For fun, entertainment, or joy of movement 2. To be with friends 3. To be fit or healthy

Source: Global Wellness Institute review of over 75 studies and surveys across 60 countries

Fig. 2.1 Barrier and motivation of Global fitness

play the role of an experienced leader and a co-exerciser to accompany training. However, apart from gyms and fitness studios, it is often difficult for self-serve fitness people have their personal coaches at home. Even with the help of online fitness service, it just usually provide a common fitness coach provides guidance for multiple users. It is difficult to meet the requirements of personalizing a personal fitness coach for each user. In addition, in online fitness, only the fitness coach is displayed on the screen through the network exhibition, and it is difficult for the coach to enter the user's real environment and interact naturally. Currently, online fitness's form is not immersive, which makes it difficult to bring user the experience of being accompanied by real partner.

Chapter 3

Related Work

3.1 MR-based Physical Task Training

To explore how augmented reality (AR) or virtual reality (VR) technologies can assist the users for physical task learning, there are a lot of research on body movement training and guidance has been purposed and developed.

Virtual reality has been leveraged for training movement in a number of specific domains, some studies have explored effect of full body motion tasks training in virtual reality environments. Chua et al. built a Tai Chi Chuan training system in virtual reality environment[23]. Guoyu Sun et al. presents a computer-based system for assessment and training of ballet dance in a CAVE virtual reality environment.[24] Additional work within the HCI community has focused on more specific motor skills improvement. Various surgical simulators have shown promise in improving surgical skill[25]. A virtual ping-pong trainer showed positive effects of training[26]. The use of a virtual 'ghost' for training 3D hand movements showed that a VR environment was no worse than real-world training[27]. Several other VR-based trainers have had similar results showing a custom system performing at least as well as a traditional method [28]. Physical therapy has driven the use of technology for movement learning[29], these researches focus on re-training simple movements and improving range of motion. A number of systems have been developed around gaming and VR platforms in an effort to make the otherwise monotonous or painful movements motivating[30]. However, in the VR environment, users are always completely immersed in the virtual world, so they cannot view his own body movements and real world at the same time, which make user easily to ignore their own performance.

Some studies have explored motor training in Augmented reality domains, AR allows users to watch the virtual and the real world at the same time, they can see the guidance information and their own body movements during the training. Henderson and Feiner developed an HMD-based augmented reality system providing real-time guidance for assembly tasks[31]. LightGuide[32] used a projector hanging from the ceiling and projected visual information on users' hands to guide hand movements. It could only guide users in a fixed space with their hands being under the projection zone. OutsideMe[33] used Kinect to capture the skeleton, RGB and depth images of users. They enabled users to see their body movements as external observers through a video see-through head-mounted display (VST-HMD). AR-Arm[34] showed semitrans parent arms to indicate the correct movement of Tai Chi Chuan. Users could follow the virtual arms intuitively to achieve accurate arm movement.

3.2 Skill Training Supported

Within the domain of motor learning, there is substantial research on the effects of various factors on motor skill acquisition. To provide an assistance tool for work out fitness training, many researches about motion skill training have influenced and supported our work.

3.2.1 External Images

Using external self-image is regarded as an effective way to improve skill and ability in physical activity[35]. The external self-image involves imaging from the perspective outside the user's body, as if observing oneself on video[36]. In many motor training fields such as dance, martial arts, and sports activities, learner usually observe their own movements by looking in a mirror or taking videos then adjust body motions to improve their action skills.

Traditional training and presenting tools are limited, such as using mirrors and video replays. The mirror only provides a viewing angle and cannot be recorded for reference. The camera's playback video supports review, but it prevents users from observing themselves in real time. There have been many studies on providing external images to help learn motor skills in recent years, such as jogging, Swimming or playing football. They usually use escort robots[37][38] or flying machines[39][40] to follow the athletes and capture their self-image, and then present the captured image on a nearby display or handheld device. However, the guiding or feedback information from the system can always show on the fixed display, learners need to pay attention to the display device at all times, and their heads must face the display to receive information [41][35], such external image usually distracts the learner in training. The limitations of these tools make some professional and complex movement training a time-consuming task.

3.2.2 Display Device

Common flat display such as common mobile device's screens, television or projector for physical exercise learning or practicing have shown lots of limitation. Recently, some research have tried to apply Head-Mounted Display as display device for movement training. OutsideMe[42] provides a vision-sync mixed reality system to captures dancer's posture and blends it into scenes from the dancer's original field of view in an interactive frame rate, which enables dancers see their body movements as external observers through a HMD device. In the research on "My Tai-Chi Coaches"[43], Han et al. propose a mixed reality system based on an optical see-through HMD for assisting movement self-practicing. After wearing the HMD, the user can see many virtual coaches surrounding him, also, an adaptive augmented mirror show the user body images captured by the drones, therefore, the student can have a self-reflection information beside the coach for adjusting their action. With the HMD system, some physical exercise need to move around in physical space can be done, because the guiding information can always show in front of students. Therefore, using see-through HMD as an assistance tool[44][45] may be a suitable solution for observing augmented information, body motion and real scene simultaneously.

3.2.3 Avatar-Based Motion Guidance

Avatar is an artificial form for user's body embodiment, which is proved to play a key role in motion learning and guidance. Many studies have highlighted the importance of providing body information in a physical task guidance system. In the area of technology-based remote collaboration/ instruction, researcher often apply virtual avatar to support some physical task training and guidance. Ymamoto et al. compared an avatar-based remote guidance system with a point-based remote guidance system and indicated that, when using the avatar-based guidance the task completion time was shorter and workers experienced less frustration[46]. Wang studied the impact of full-body level virtual avatars on the quality of AR-based distance teaching[47]. By comparing hand-shape avatars with full-body avatars, the result shown that full-body avatars have a better effect on motion task guidance. In the social effect aspect, Smith et al. compared a hand-shaped avatar and a full-body avatar in some remote physical task collaboration system. The results indicated that the full-body avatar increased the immersive, and that participants felt they were interacting with and being accompanied by a real person when interacting with the body-shaped avatar[48]. These results indicate that whole body avatar supports more intuitive human motion learning and training, which shows high usability for physical task guidance activities.

Online fitness teaching and guidance is also one of the categories of remote physical task guidance, which also requires the learner to follow the instructor to learn or perform a series of motion to complete the training task. Some researches have shown that the use of 3D forms[34][44] to show the coach's behavior has the potential, and learners can observe the action from any direction. Some researchers try to use a full-body avatar as a virtual coach to provide learners with physical movement guidance. In the rehabilitation exercise guidance system of Zhao et al[49], they use a 3D full-body avatar to demonstrates the correct motion of exercise on one side of the screen based on pre-recorded motion data, another full-body avatar is used to shown actual patient movement on the other side of screen. Chua et al. also used both coach and user avatars in Tai Chi Chuan training[23], virtual coach is displayed in the front of the user, which perform standard motions on full-body avatar in virtual environment. Integrated with motion capture system, users can see their movement on their avatar in VR and compare it to the coach's movement. Virtual coaches shown in 3D by suitable avatar to perform standard actions for guidance or teaching, which can convey more complete spatial information than 2D picture and video material. Some research also applied avatars in AR environment. Tai-Chi Chuan motion practicing tool from Han et al.[43] provides lots of AR coaches that in different directions to surround the learner respectively. The learner can view the standard motions on full-body avatar in different perspectives conveniently.

However, in previous work, researchers mainly discussed the usability of body-shape avatars for physical task guidance. They usually only use some default avatar to guide users, without considering the potential impact of avatar's attributes such as identity, appearance on other effect of motion guidance. Some potential impact of virtual coach with personalized avatar on sports guidance and training has not been explored. Moreover, previous work's avatar's behaviours and interactions are rigid and unnaturalwhich is kind of unimmersive and unattractive experience.

3.3 Motion Capture for Training Assessment

Motion capture and assessment are important research topics for motor skills training. Motion capture is goal to obtain body images or body data of the user's movements. Assessment means that with the help of captured results, evaluate the similarity or matching rate of the motions by some comparison method or pattern recognition techniques. Some researches try the action recognition for motion training, the system captures user action then recognizes it, and delivers helpful feedback information to the user based on the recognition result, which is often very effective to the user's skill improvement. In related work, Davis and Blumberg[50] built a virtual aerobic exercise trainer. When the user is instructed to "start exercise" or give feedback such as "Good job!", the user's actions will be captured and recognized. The user's profile is captured by infrared light and matched with a set of pre-recorded templates to identify whether the action is correct.

Some studies track and asses user's motion training by wearing smart wearable devices. Common wearable devices including fitness trackers, smart watches, heart rate monitors and GPS tracking devices, such as Fitbit, Samsung GearFit2, Misfit, Garmin and Apple made smart Mobile devices. These devices can be used as a pedometer, and can track heart rate, body temperature, calories, sitting time, sleep time, etc. In addition, some exergame system use mechanical sensors to simply recognize user actions and record user motion data. Usually through these data, some applications can record the user's daily activities and analyze, and finally feedback the user's sports performance. Some somatosensory games use the game-pad as a wearable sensor to track the user's training. Fitness Boxing is a somatosensory game where players can perform simple and effective boxing training at home. Players hold two Joy-Con handles of the Switch with both hands, and follow the coach on the screen to make corresponding punch movements. Ring Fit Adventure is also a famous fitness game, players can install the Joy-Con handle of the Switch into the "Ring-Con" and leg straps that come with the game to identify the user's fitness actions. However, this kind of motion feedback mechanism mainly relies on mechanical sensors, gyroscopes, etc. to roughly record the direction, amplitude and frequency of the action, and cannot record the details of the action to give very accurate training Assessment feedback.

Some researches are carried out around somatosensory devices for more accurate motion capturing. Microsoft Kinect was released as an addition to the Xbox 360 game console, it can obtain the 3D positions of skeletal joints in streams of skeletal frames in real time. The most interesting data supplied by Kinect are the skeletal data, for each fully tracked user, the 3D positions (x, y, z) of up to 20 joints are captured. Hence, Kinect has been used in areas far beyond console games [4], it have been proved to be a suitable tool to support training in professional sports by some researches. Some research focuses on motions capture to generate visible user's external self-images. OutsideMe[42] is based on Kinect that generates an augmented mirror for displaying self-image in the video see-through HMD. Another kind of research focuses on capturing body data of motion then calculate data with some pattern recognition technology or comparison method for evaluation. Zhao et al.[49] provide a kinect-based rehabilitation exercise monitoring and guidance system for rehabilitation exercises monitoring and guidance. They use Kinect to capture patient training then bases some rule to give real-time exercise quality assessment and feedback. MotionMA[33] uses Kinect to analyze and model experts' motion. After comparing to the student movement, the feedback information will show on a screen. Cezary et al.[51] research whether Microsoft Kinect can be as a professional tool for sports training, they proposed an AR trainer system based on the Microsoft Kinect to help improve performance when training high-precision techniques in judo.

Chapter 4

Research Goal and Approach

4.1 Goal

Previous studies have proved that a fitness assistance in self-service exercises is helpful and necessary for the user's movement learning and progress. There is also evidence that making use of avatar for body-movement training is very effective. We are trying to research how an exercises assisted system can improve user's self-service fitness experience from following aspects.

- **Personalized fitness coach:** One of the major challenges faced by exercisers in self-service fitness training is the lack of direct guidance, so it is best to have a fitness coach. We propose a full-body personalized avatar based on the user's face and body type as the virtual fitness coach, our main goal is to study how personalized fitness coaches can provide users with better fitness experience and some positive feelings, such as companionship and accomplishment. The fitness coaches with body-shape avatar to guide user, which supports users motion learning, practicing and improving in a more intuitive way. Moreover, we goal to explore the potential impact of the personalized avatars on user's fitness training. For example, how does the fitness coach's personalized attribute relate to the motivation of the user exercising.

- **Convenient interactive environment:** So far, most body movement training systems lack interactivity. Our goal is to research how to achieve an AR-based interactive exercise environment from two key aspects: 1) Interaction between virtual contents and real world. 2) Interaction between virtual contents and user. The goal here is make use of the natural interactions among user, system and physical environment to provide users a more real and immersive sense of companionship.

- **Effective mechanism for progress:** In real life, exercisers need to know their current performance in order to make targeted improvements. Our goal is to research some effective mechanism to help user make progress. System should be equipped with some related function to analyzes user training performance and provides timely feedback and suggestion for improvement. The purpose here is by these mechanism to motivate user to improve training effect and avoid damage caused by wrong actions.

4.2 Research Approach

4.2.1 Approach

This research concentrated on using Augmented Reality to simulate the experience of being guided and accompanied by a personal fitness coach for users. As the development of Augmented Reality techniques, it becomes possible for people to view virtual objects in an immersive world by wearing an HMD, which makes it possible to display virtual character in the real world. The key approach of our research is in the form of AR coaches to provide fitness assistance. To achieve the goals of our research, we explored the duty and feature of a fitness coach in real life and describe how does our the AR coach in our system simulate the real coach's duties from these categories for making contributes to user's training (Figure 4.1).

As a human being, a real fitness coach must have a human body and some human activities. Human Body contains the basic human body property information such as sex, face, height, and body shape, everyone has own characteristics in the details of human body.

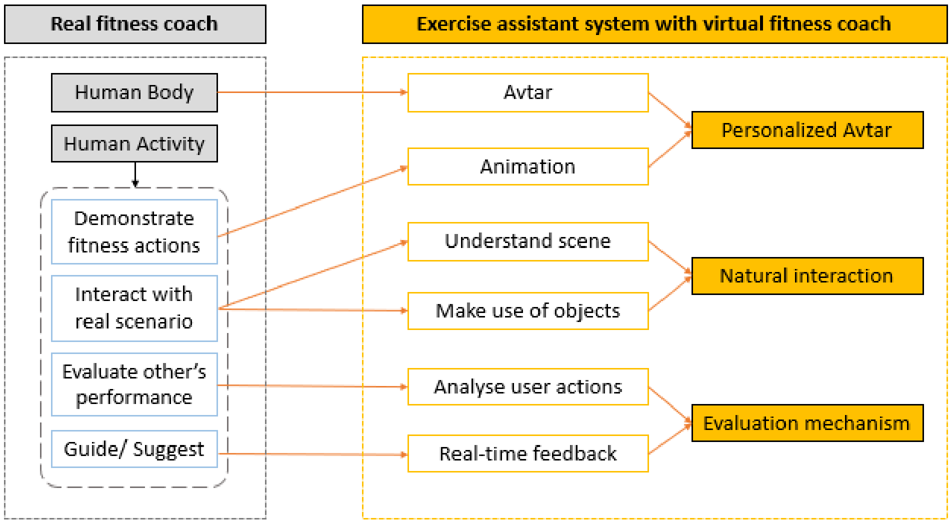


Fig. 4.1 Relationship between real coach and system with virtual coach

During fitness learning, users have the opportunity to view the other human body's action and try the action on their own bodies. We consider who can be the user's coach and how the human body of coach looks like. Our system lets the users themselves as their own virtual coaches and created a personalized avatar based on the users' body figures, face photos, which provide a more familiar and attractive 3D model compared to a default human models. Users can learn and compare motions more intuitively by watching the same human model as themselves. When the avatar communicates with the user by this familiar human body, just like the user communicates with another self, it will give the user a familiarwarm and magical feeling. The generated 3D virtual avatar can be used to perform some human activities to act as a fitness coach to assist user to exercise.

For human activity, we mainly discuss basic daily activities and coaching-duty related activities.

- **Demonstrate fitness actions:** One of the main duties of a real fitness coach is teaching. When he wants to teach a fitness action, the most effective ways is to demonstrate the fitness action to exercisers. With the virtual fitness coach, user can easily learn a new fitness action by viewing the coach's body in 360° in the case of fitness alone. We prepare some fitness motions as animation to combine with the personalized avatar to simulate a real coach to demonstrate fitness actions.

- **Interact with real scenario:** Human beings exist in the physical world and often interact with the surrounding environment. Also, the real coaches sometimes apply some physical objects in the guidance process. For the virtual coach, some natural interactions with real scenario can enhance user immersion and give a feeling of being accompanied by real person. We equip the virtual coach avatar with the feature to understand surrounding scene base on spatial data of real scenario. We allow the virtual coach avatar make use of some physical objects in the real world to perform some activities. By these methods, the virtual coach can simulate a real human to naturally interact with real scenario.

- **Evaluate user performance:** Evaluate user performance: An experienced fitness coach can accurately evaluate the exerciser's performance and know current level. For example, whether the action is standard, which part needs to be adjusted. To simulate the duty of coach's evaluation, virtual coach should have the feature to analyze user actions. Therefore, we make our system get the action and body data from user, and bases on some standards method to calculate and analyze. Bases on the system analyzing result, the virtual coach can act an experienced fitness coach to judge user's performance.

- **Guide/ Suggest:** As a coach, a basic duty is to provide some guidance and suggestion to help the exerciser improve. In order to simulate this responsibility, we designed the function of Real-time feedback for the system virtual fitness trainer. This means that when the user is training, the virtual fitness track the training and convey some useful information to the user through natural interaction with the user, such as sounds and movements, so that the user knows how to improve the training effect. With our virtual coach, the real-time feedback is given to inform the user of the current training situation, for example, score and level, which joint of user body needs to be adjusted, so that the user knows how to adjust the current movement to achieve better effect.

Consider from these aspects, we propose an exercise assistant system with virtual coach. It use a personalized avatar as user's coach to simulate the fitness experience of being accompanied by a personal fitness coach. We make the virtual coach play the role of a real fitness coach as much as possible based on these categories.

With our system, it provide user an interactive environment to exercise with a personal virtual coach in the physical world. User can see the personalized virtual coach to carry out some natural human-being activities in the real surrounding world. User can naturally communicate with the virtual coach by some instructions to trigger some system functions. For the learning process of fitness, firstly, users can learn new actions by observing the actions demonstration on virtual coach's body. Besides, user can know the current problems and receive timely feedback and guidance from virtual coach for improvement by the system's evaluation mechanism.

4.2.2 Use Case

When the user exercises at home by himself, but he feels boring, inefficient and lonely, he wears an AR headset and start the exercise assistance system. At this time, a virtual fitness coach appears in the real world of his visual range.

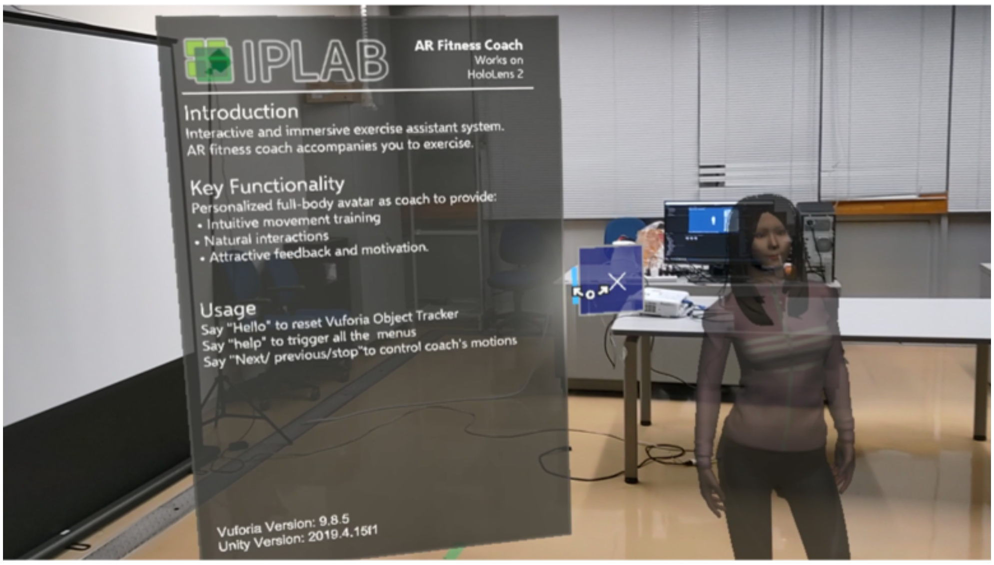
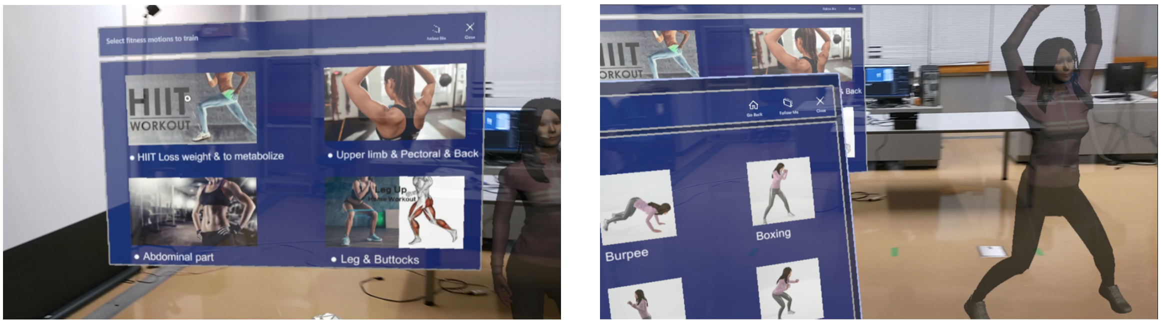


Fig. 4.2 System introduction

The user has just entered the system and hopes to quickly know how to use the system, so he greets the virtual coach and says "Hello" to try to trigger some system functions. The virtual coach responds to user and welcomes him, introduce how to use the system (Figure4.2).

User wants to start a fitness activity but he is not familiar with the fitness action and wants to learn some. So he said "start training" to the virtual coach. The virtual coach invited the him to warm up together and showed a fitness menu (Figure4.3a) to let him choose the action he was interested in. He presses the corresponding button on the menu, the virtual coach starts to demonstrate this action (Figure4.3b), the user watch freely from different angles so that he can be familiar to this new action.



(a) Display fitness menu (b) Coach is performing action

Fig. 4.3 Star training

After getting acquainted with this new action, the user tries to imitate and follow the virtual coach, but he is not sure whether he is doing it correctly. So he says "help" to the virtual coach to seek professional help. The virtual coach respond "what can I help you?" and provides a help menu, the current training mode is learning mode by default. The user selects the mode and clicks the button above to try to change the current training mode.

The user selects the comparison mode. He can see the body with the same actions as his own displayed next to the virtual coach's body. The user compares his own actions and the coach's actions to find out which part is not accurate. Then he tries to adjust the action, but he is still not sure whether his judgment is accurate and whether the adjustment is effective. So he wants to get more professional evaluation and feedback from virtual coach. So the user selects the scoring mode button. At this time, the user follows the coach to perform actions, and the coach scores each action and tells the user how to improve. User receives timely feedback and suggestions from the virtual coach, he clearly knows his current level and how to improve.

4.2.3 Novelty

Compared with other existing fitness training assistance systems, the novelty of our research is mainly reflected in the following aspects:

1. We provide a personalized avatar as a personal fitness coach. Our innovative design allows users to become their own personal trainers and explore its impact on motivation.
2. We provide an interactive system with very natural and rich interactions among the user, virtual coach avatar and real world, which supports the interactive environment during exerciser's training.
3. Based on full-body avatar, we apply the self-image and body pose alignments function to supports sufficient and effective motion evaluation and feedback mechanism for a body-movement training system.

Chapter 5

System Design

In this chapter, we will introduce our system design and each important piece of our approach. To demonstrate the effectiveness of an AR-based body-training guidance and motivation experience, we equipped the exercise assistant system with three key points:

1. **A personalized avatar:** Personalize the appearance and body of users as a fitness coach to provide intuitive guidance.

2. **Interactive exercise environment:** Achieve the combination of physical word and virtual contents, support the natural interactions among user, virtual coach, and physical world.

3. **Training evaluation and feedback:** A real-time feedback experience from system to user, which is based on evaluation result of the motion data on user's body.

5.1 System Overview

Figure 5.1 shows the overall structure of our system. The system contains two main characters, one is the AR fitness coach, another is user. The AR fitness coach performs fitness actions in the real world, user learns and follows to exercise in real body. User's training can be evaluated by system, virtual coach will give user feedback depend on system's evaluation.

Summarizing the framework, our system provides a personalized embodied avatar as user's fitness coach. System also provides scene understanding to recognize user's surrounding physical environment. Combined with the spatial information, the virtual coach can perform fitness or daily movements naturally in the real world. In addition, system is equipped with an external device for user's body data capturing during training. System evaluate these data and give real-time feedback to user.

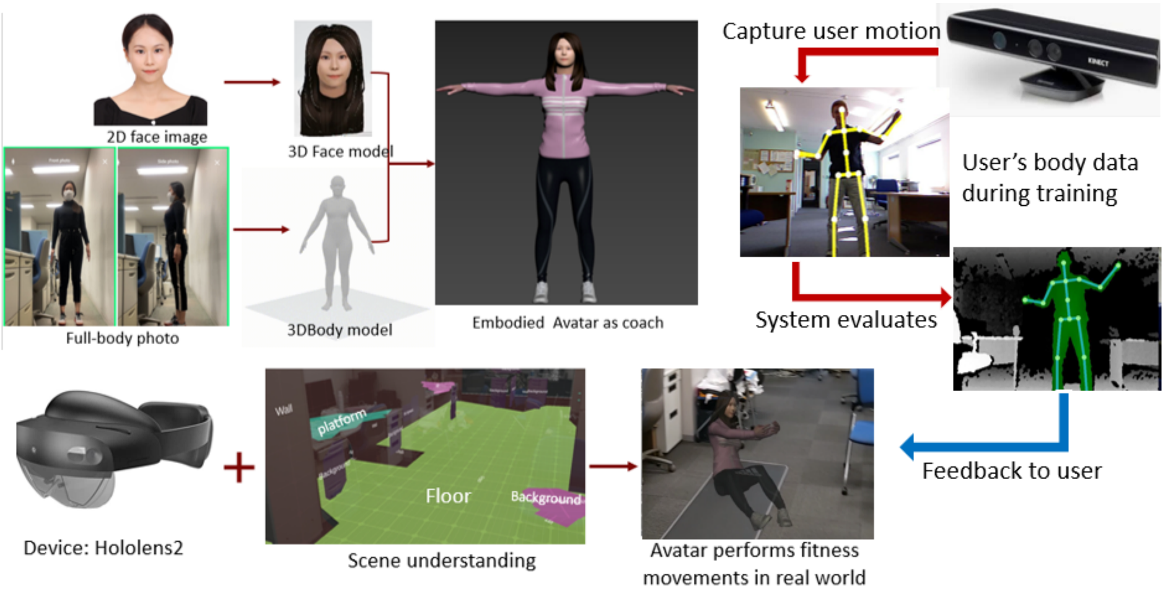


Fig. 5.1 System overview

As we have mentioned above, our research contains three key points and we will divide the system description into three parts:

- Part 1 is about personalized coach's avatar.
- Part 2 is related to achieve the AR-based interactive exercise environment.
- Part 3 introduces the training evaluation and feedback mechanism.

5.2 Personalized Coach's Avatar

Coach always play a key role in a body training system, who can be user's coach should be consider more seriously. Generally, the general structure of the human body is basically the same, but everyone has their own characteristics in the details of body. Due to the variations in human body information among different exercisers, such as height, body shape, the variations of body information between a common coach and different exercisers are also different. If users only sharing the same default virtual coach, it is difficult to accurately judge the differences between user's actual body movements and coach's standard body movements for different exercisers. In addition, a common problem in an exercise system is the lack of motivation, we would like to choose a attractive virtual coach who can enhance the effectiveness of motivation. Therefore, our system needs to provide user with a personalized coach.

In our system, we design to let the user himself/ herself as their own virtual coaches, which means that the virtual coaches have the same appearance and body as the user himself/ herself. Firstly, since the user is more familiar with himself/ herself own body, when the virtual coach performs fitness actions with user's body model, the user can learn more intuitively and familiarly by watching the same body as himself/ herself, which will increase the efficiency of the fitness motions learning. Secondly, the user and the virtual coach share a similar body but have their own body movements. It can be more clearly to compare the differences between user's movement and the coach's standard movement during training. What's more, from the perspective of motivation, user can get encouragement from virtual coach, which means that users encourage themselves, cheer for themselves. It can be a kind of fitness experience with a sense of satisfaction and achievement for exercisers.

Regarding the forms of virtual coach to express, the common ways in body-training system include coach's voice guidance, pre-recorded video teaching, and real-time remote video guidance. However, these methods convey limited information and may lack some non-verbal and spatial information, which may cause some misunderstanding in body training system. A virtual human-like avatar can interact with humans using some verbal language and body motions like humans do, which is more intuitive. Our system will make use of the greater expressive capabilities of human-like avatar, provide user a full-body avatar as the virtual fitness coach.

Summarizing the above opinions, our system provides user a personalized coach's avatar, the avatar should have an appropriate 3D representation corresponding to the user's face and body features. In this section, we will discuss the construction of the personalized coach's avatar.

5.2.1 Avatar model construction

Figure 5.2 shows an overview of avatar model construction, which consists of two parts: face model generation and body model generation. The input is a 2D face image and two full body photos form front view and side view. Use these data to generate the 3D human model that has similar appearance to the user.

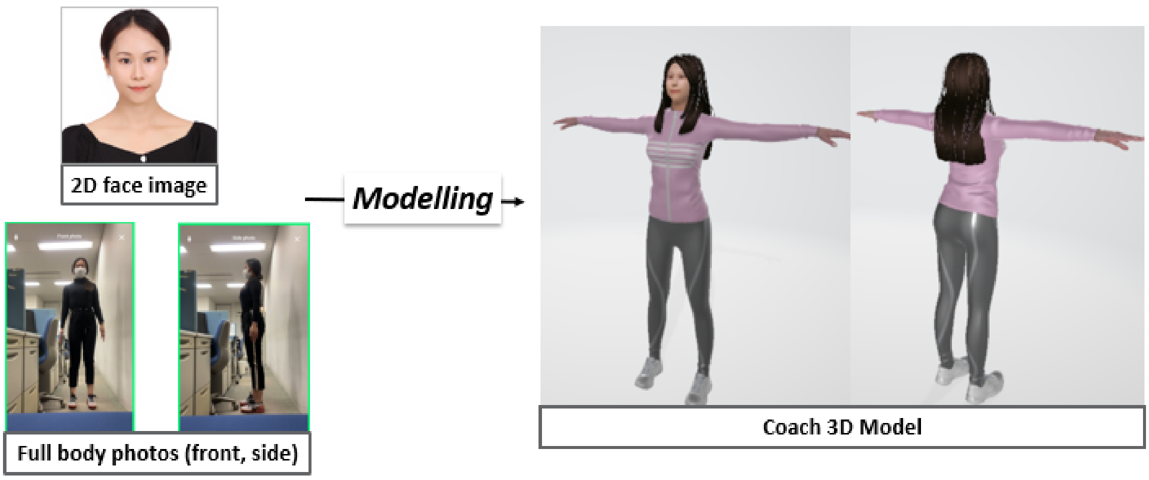


Fig. 5.2 Coach's avatar construction

We generate a 3D face model based on user's face features using the avatar SDK[52] and generated a 3D body model based on user's body shape features by the help of the 3DLook[53] software. And then we combine the 3D face model and 3D body model into a full-body human model to get the personalized coach model.

- **Face model generation:** personalized the face appearance for users. 3D Avatars SDK can combine complex computer vision, deep learning, and computer graphics techniques to turn 2D photos into a realistic virtual avatar. we use a front of the face image of the user as input. As well as, we select a hairstyle that similar to user's daily hairstyle. The output can be the 3D model file of a head that included user hair and neck using the 3D Avatar SDK. Figure 5.3 shows the transforming from the input image to the output 3D model file.

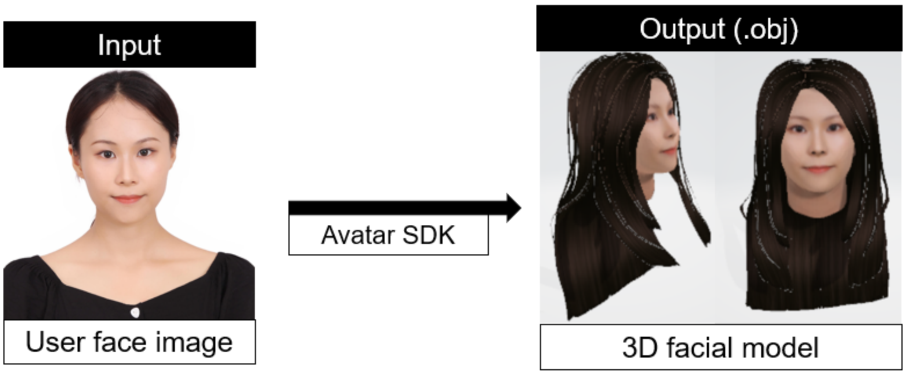


Fig. 5.3 Face model generation

- **Body Model Generation:** Personalized the human body shape for user. 3D LOOK is 3D body model generation software. We need to collect the basic data about user's height and weight and gather user's front and side full-body images as the input of 3DLook software. The software will calculate user's body data automatically based on the basic information and body photos, and then generate the 3D body model (Figure 5.4). The output is the 3D model file, which can allow us to combine the face model and body model together in other model editor software.

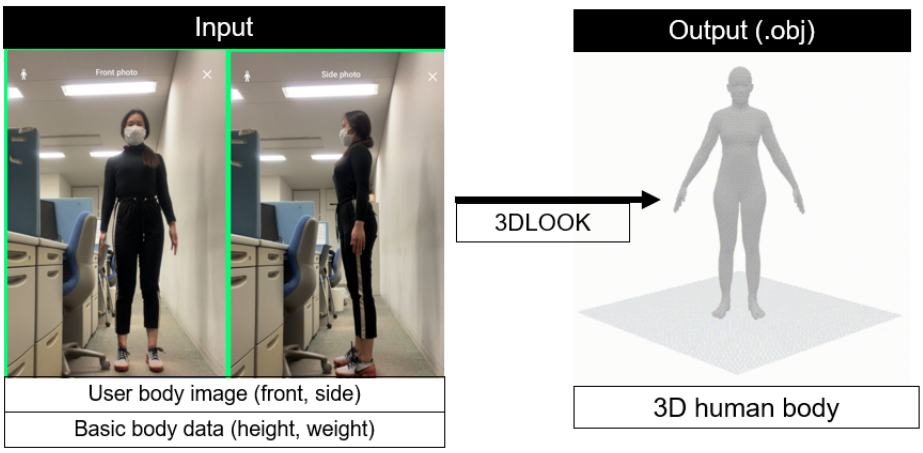


Fig. 5.4 Body model generation

5.2.2 Avatar Animation

The fitness coach in an offline gym are usually professional and friendly. They always perform some certain activities to give exerciser guidance and motivation. To allow user to gain a sense of being accompanied by a real fitness coach in our exercise system, the coach avatar should have some related human-like body movements. To make sure the motion of the coach avatar, the skinning and skeleton rigging should be done in advance.

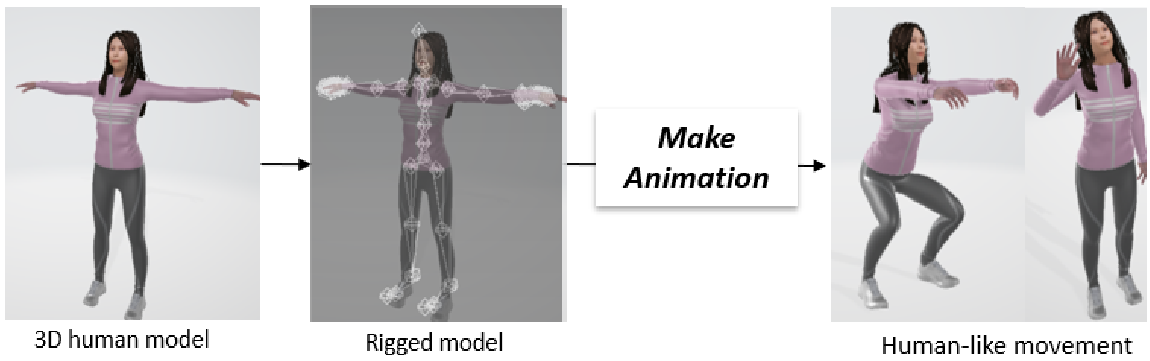


Fig. 5.5 Make animation on avatar

As an exercise system, our animation library mainly contains three kind of animations. These animations will be attached to user's personalized coach's Avatar.

- **Ordinary daily action:** Including the necessary daily movements such as standing, walking, sitting. Or some actions that express human body state, such as feeling hot and fanning with hand, feeling tired and drop head to breathe deeply. There are also greetings action such as beckoning, nodding and bowing. These actions are very close to human daily behaviours, which can make virtual coach's behaviour to be more friendly and natural and more like human-being. Enhance the reality and immersion of fitness coaches in our system.
- **Professional fitness action:** Contains some work out fitness movement that exercisers can serve themselves at home. Some HIIT (High-intensity Interval Training) actions such as burpee, jumping jack and quick step. Some basic fitness actions such as plank, squat, sit up and push up. Also have some simple dumbbell actions. These actions are

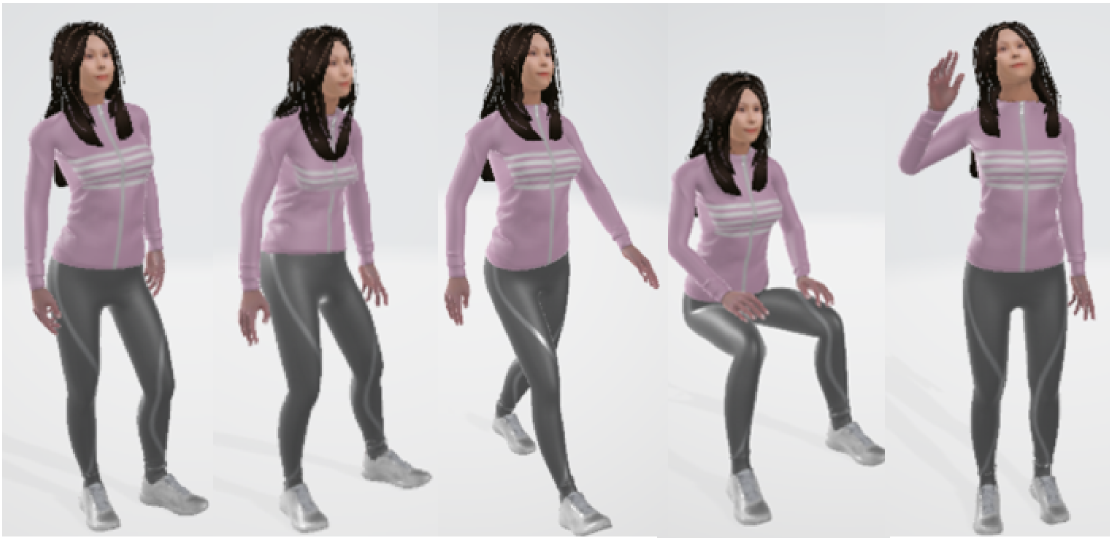


Fig. 5.6 Daily actions in animation library

the core activities for fitness coaches whether in the virtual or real world. This kind of animation can make user's virtual coach more professional and richer in exercising.

Fig. 5.7 Fitness actions in animation library

- **Emotion expression action:** Emotion expression action means that avatar can convey or express some emotion to user by this kind of action. Here include some positive movements such as cheering, thumbs up and clap. Appropriate emotional expression is effective for motivating users to keep exercising. Through these positive body movements, the coach's avatar can convey some positive emotions like belief, praise, or encouragement to user, which can achieve the motivation effect in system.

Fig. 5.8 Emotion expression actions in animation library

5.3 Interactive Exercise Environment

In our system, the fitness coach is virtual, and the user will use this system in a real environment. In order to provide user with an interactive exercise environment, we need the virtual fitness coach to correctly and interact with the user's surrounding world in a natural way. At the same time user can interact with system's virtual contents such as coach or fitness equipment freely. The main idea here is based on Augmented Reality technology, to achieve the combination of physical word and virtual contents, support the natural interactions among user, virtual coach, and physical world.

In this section, we will describe how to obtain the AR-based interactive exercise environment. It will be divided into two part, firstly is the interactions between coach and real world, secondly is the interactions between coach and user.

5.3.1 Interaction Between Coach and Real World

To interact with the real world correctly, the virtual coach must be able to understand user's surrounding physical world. Our system achieves this goal from two key points, one is physical collision detection, another is physical objects detection.

1. Physical collision detection

System can scan and recognize some real-world collision objects such as the floor, walls, tables in user's surrounding environment. Based on these spatial information, the virtual coach can know where the physical collisions are in user's surrounding environment and reacts to these identified collision bodies to simulate the physical collision phenomenon in real world. For example, when the system recognizes the floor in the real world, the virtual coach will stand on the floor instead of above or below it. When the virtual coach is walking and meet a table in real world, coach avatar's walking will be blocked and stopped by the table (Figure5.9). In the same situation, other real-world physical objects such as chairs, cabinets and walls can also block the virtual coach's movements. The virtual coach reacts to them similar to human's physical reaction.

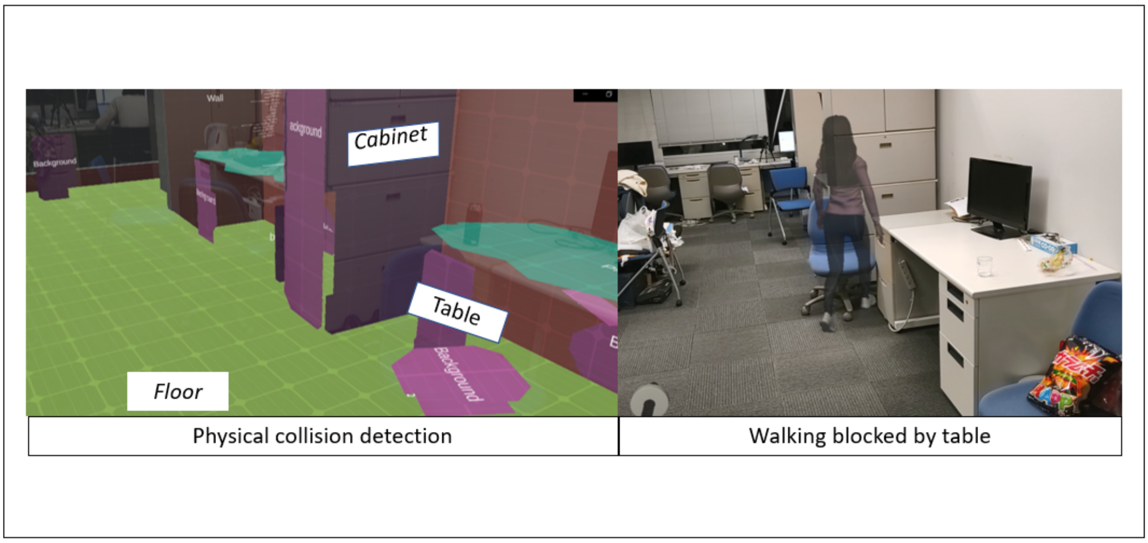


Fig. 5.9 Physical scene understanding

2. Physical object detection

System can identify some target objects in real world such as dumbbells, chairs, yoga mats, etc. The virtual coaches can make use of these objects to perform corresponding actions. In order to recognize the target object, we need to train a sufficient number of object photos in advance and then get the training model for objects detection. When the detect score is more than 90, system recognizes that it's the corresponding object. In the system, when user use point at and click real-world object, recognition will be performed on the target position. Then, the virtual coach will walk to the target position, trigger related behaviours based on the detection result. For example, the user clicks on a target location, when the system recognizes that it is a chair, the virtual coach will walk over and perform sitting down actions on the real chair. When the system detects the stair, the virtual coach can perform the step-jumping fitness motion on the stair steps. In the same situation, when the system recognizes that there is a yoga mat, the virtual coach can lie down on the yoga mat to exercise (Figure5.10). Or when the system recognizes that it is a dumbbell, system will trigger a dumbbell exercise-related menu and virtual coach will guide the user to exercise related to dumbbells.

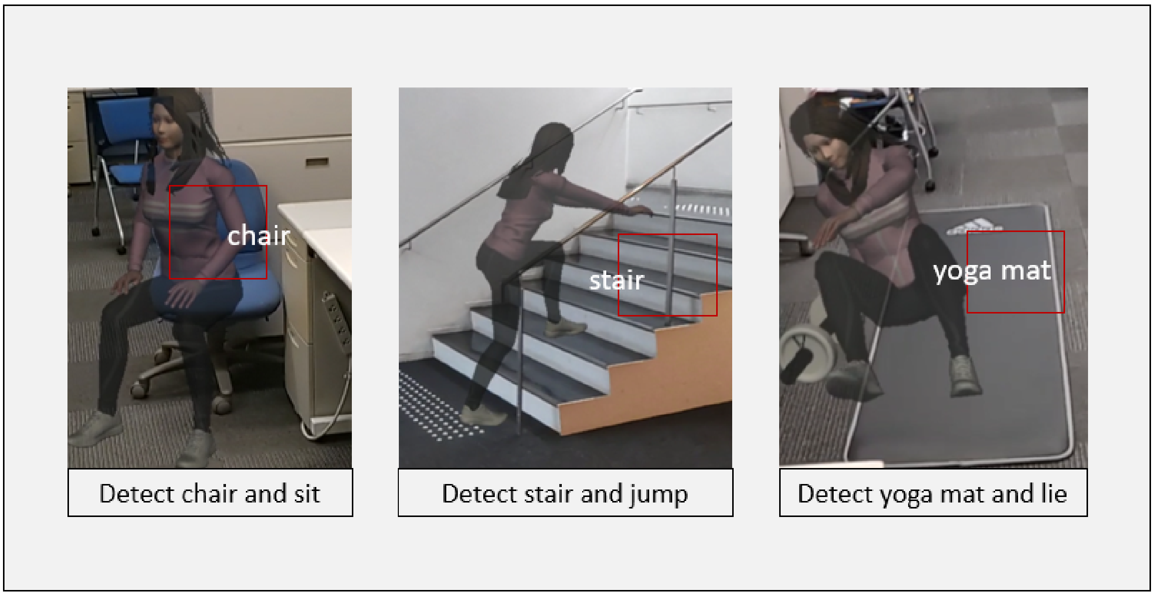


Fig. 5.10 Physical object detection

5.3.2 Interaction Between Coach and User

In the interaction between the user and the virtual coach, information transmission includes from the user to the coach and from the coach to the user. The overview of information transmission is shown in Figure 5.11.

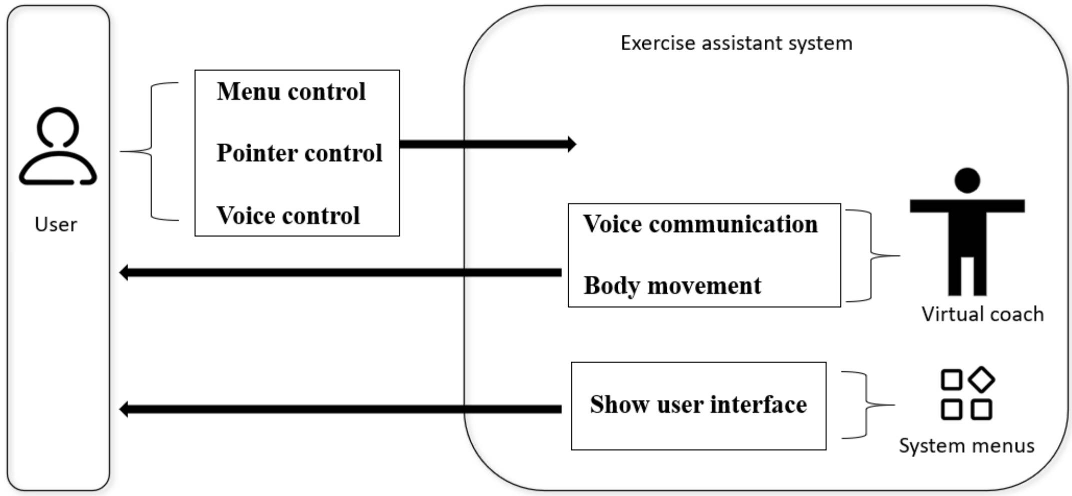


Fig. 5.11 Information transmission overview

Firstly, we discuss the interaction information from the user to virtual coach, it includes menu control, pointer control and voice control. User can control its position by letting the virtual coach walk. When the user clicks on a certain location on the real floor, the virtual coach will walk to that location. Moreover, the user can control the fitness action to be performed by virtual coach through clicking system's menus. When the user use pointer to aim at a certain part of the virtual coach's body, and the coach will trigger the system menu to recommend fitness actions that related to this body part. User also can control the virtual coach through voice input. User can say some instructions by voice to control the virtual coach, such as starting some exercise functions, switching fitness movement on coach avatar, and triggering some guidance function through coach avatar's movements and voice.

Secondly, the interaction methods from the virtual coach to user are the voice communication and body movements. Our system's design goal is to motivate user's training enthusiasm, virtual coach needs to express something to communicate or encourage exerciser. For voice communication, we design some positive sentences for coach speaking. We designed common greetings in daily life for virtual coaches to increase the friendliness of dialogue and communication with users. In addition, during the training, the virtual coach will say some important reminders, exercise guidance and encouraging sentences by voice to user. For coach's body language, use some natural and friendly actions. As same as the description in the section 5.2.2 about avatar animations, we designed ordinary daily actions, professional fitness actions, and emotion expression actions for the virtual coach.

5.4 Training Evaluation and Feedback

As an exercise assistance system, it should effectively help the exercisers improve their training effect. Training evaluation and feedback are very important and necessary for exercisers' progress. Therefore, we will discuss the training evaluation and feedback functions in our system.

Before that, we first introduce the three training modes in our system. Like the Figure 5.12 shown, there are two types of avatars that the system can display, two avatars use the same 3D human model and have the same appearance but different body movements, coach's avatar performs the standard fitness actions provided by system, while the user's avatar performs the physical movements which are from user's body.

- **Learning mode:** The main purpose of this mode is to allow users to learn and familiarize themselves with training actions. The virtual coach perform some standard fitness actions, user tries to watch and learn how to perform this action. The 3D full-body avatar allows user to watch the coach's body movements from 360 degrees freely in the real environment. This teaching form is more intuitive and understandable, which is helpful for users to quickly become familiar with the fitness movements.

- **Recording and reviewing mode:** The main goal of this mode is to allow user to understand the differences between own actions and standard actions through user's

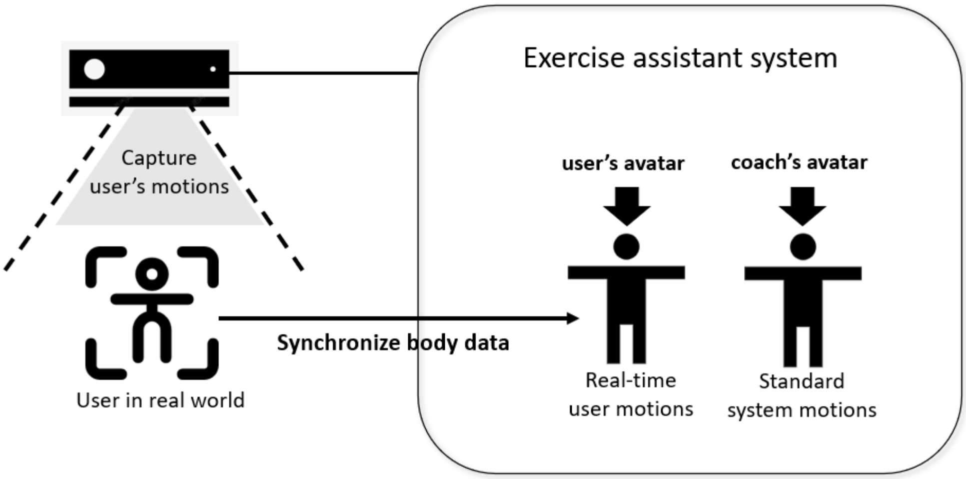


Fig. 5.12 Two types of avatars

own observations and judgments. In this mode, system not only shows the coach's avatar, but also shows the user avatar which is next to coach's. This mode consists of two functions: recording and replaying. When the recording starts, our system starts to record the user's real-time body data with an external capturing device. When the user stops the recording, the system saves the body data into a human-body animation. When the playback starts, the system will play the human-body animation on user's avatar, at the same time, coach's avatar perform the standard fitness actions. Since the user's avatar is next to the coach's and they has the same body structure, the user can intuitively compare his/ her own actions with the coach's standard actions by viewing the playback (Figure 5.13). It provides users with the chance for self-reflection and correction, avoids damage caused by wrong training actions and promotes exercise efficiency.

- **Scoring and feedback mode:** In this mode, the system will automatically evaluate the user's training and give corresponding feedback suggestions. Its purpose is to let users know how to improve their actions in a more convenient and smart way. The purpose is to allow users to know the standard degree of own actions and which part of the body needs to be improved in a more convenient and intelligent way. It is different from the previous mode (recording and reviewing mode) in that the previous

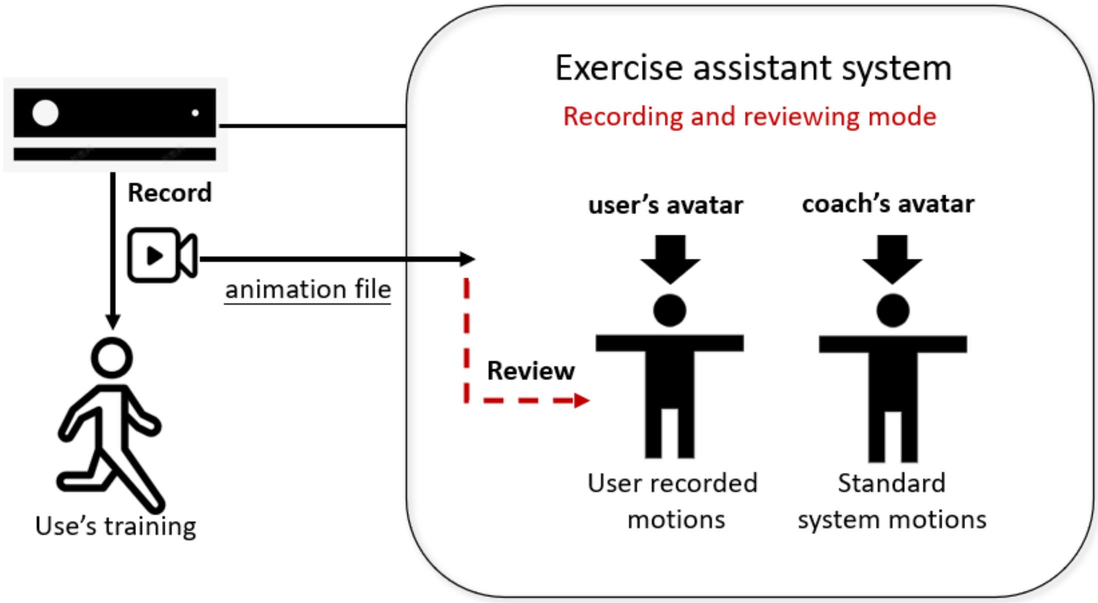


Fig. 5.13 Recording and reviewing mode

mode is evaluated by the user's movement by himself, however, the user's movement in this mode is evaluated by the system automatically. Same as the previous mode, coach's avatar performs the standard fitness actions provided by system, while the user's avatar performs same movement as the user in the real world. Virtual coach performs standard motions and user tries to follow. When the scoring start, system starts to detect the user's real-time movements with the external capturing device. Then the system processes the body movement information, compares and calculates with the coach's movement information at the same time, and finally gives the final score according to the matching degree of the user's movement and displays it on the user interface. At the same time, based on the calculation results of the system, the virtual coach conveys the scoring results to users through voice and actions, and gives some relevant suggestions for improvement (Figure 5.14).

These three training modes are designed based on the general learning process and habits of human beings , covering the user's initial learning stage, practice stage and the stage of testing learning results. It is very similar to the process of a exerciser from unfamiliar to familiar with a new fitness movement, which can better meet the needs of users for continuous learning and improvement.

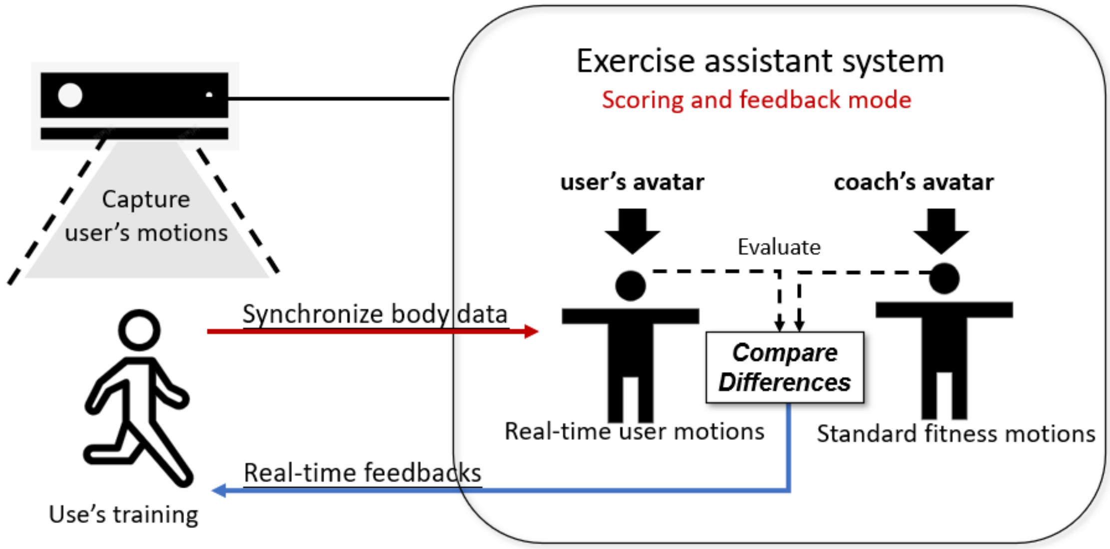


Fig. 5.14 Scoring and feedback mode

Summarizing this chapter, we introduced the overall picture and framework of the system. Firstly, we described the construction of a 3D personalized avatar as the virtual fitness coach for users. Secondly, we explains how to design an interactive fitness environment based on the AR technology. The core idea here is to allow the virtual avatar to combine the spatial information of user's physical environment, so as to display virtual contents to users more realistically and naturally. Finally, we describe the core function in our exercise assistance system: body movement training and guidance. We designed three training modes to describe how users can learn, practice and improve themselves through the system. It also explains how the system evaluates the user's training and gives helpful and instructive feedback. So far, we have completed the system design part from three aspects: character design, interaction design and function design.

Chapter 6

System Implementation

6.1 System Hardware

6.1.1 Mobile Display Device

Our exercise assistance system allows users to have the experience of being accompanied by a virtual fitness trainer and simulates more realistic physical phenomenon. This system is developed on a mobile platform, the purpose is to allow users to move and exercise freely in real space. Therefore, a mobile display device is needed so that user can see virtual 3D objects such as fitness trainers in the real environment. At the same time, our system needs a camera to identify the real environment of the physical environment. To achieve this goal, we choose the Microsoft HoloLens (2st gen) as the mixed reality HMD (Head-Mounted Display) device and build our system on the universal Windows platform.

The Microsoft HoloLens device is equipped with a microphone and an immersive earphone to enable the voice input and audio feedback. The depth camera on it can detect user's gaze point position so as to receive user's gaze and click input. It has various imaging sensors providing data necessary to accomplish the different tasks constituting its mobile indoor augmented reality system such as tracking, re-localization in known environments and capturing the geometric structure of its surroundings by means of depth sensing, which will supports the recognition of the physical environment in our system.

Fig. 6.1 Microsoft HoloLens

6.1.2 MoCap Devices

To capture motion and skeleton information from user to support the training evaluation and feedback functions, we use a Microsoft Kinect Xbox one sensor as a depth sensor (Figure 6.2a) to track the users' body movements. The depth sensor is connected to a computer with the Windows 10 operating system using a USB 3.0 controller and a Kinect adapter for windows(Figure 6.2b).

(a) Kinect Xbox one sensor (b) Kinect adapter

Fig. 6.2 Motion capturing devices

To improve the accuracy of capturing actions from the user, the environment should be open enough to capture the movement without being disturbed by other objects except the user's body. For the suitable position of the device, we place it in the position that facing the front side of user's body to achieve the best effect.

6.1.3 Development Devices

In order to use SDK and software to build the system and process programs, we use a PC with Windows 10 operating system. The configuration of the computer we use is shown in the Table 6.2 shows.

Operation System	Microsoft Windows 10
CPU	Intel® Core™ i7-6500UIntel(R) @2.50GHz 2.59GHz
Graphics Card	Intel® HD Graphics 520
Ram	8 GB

Table 6.1 Information of PC

6.2 Software Environment

6.2.1 Development Tools

We developed our software using the Unity game engine version 2019.4.15f, used C sharp as the development language. We also used 3ds MAX to combine face part and body part to generate the 3D full-body human model.

6.2.2 Technical Support

The other technical supports are shown below:

- Vuforia SDK: Vuforia SDK[54] includes capabilities for putting virtual contents in the real world and ensures that your apps deliver an AR experience on a wide range of devices. We used Vuforia Engine and apply the area target function to get the physical structor of indoor environment for HoloLens to recognize the physical collision in the real world.

- 3D AVATAR SDK: 3D Avatars SDK[52] combines complex computer vision, deep learning, and computer graphics techniques to turn 2D photos into a realistic virtual avatar. Using 3D Avatars SDK, we created the 3D face model from single face image.
- 3DLOOK SDK: 3DLOOK[53] is 3D body model generation software. We used it to generate the human body model.
- Mixamo: Mixamo[55] provides a convenient methods to animate 3D character. After uploading a 3D character model,the platform can help us to achieve the rigging and skeleton of the model, we can create and edit animations for model.

6.3 Avatar Generation

We proposed that fitness coach can be user himself/ herself and the virtual avatar model should include users' own personalized body and appearance. In this section, we discuss in detail the process of personalizing an virtual avatar for the user.

6.3.1 Face Model Generation

we personalize the appearance of the user's face based on the 3D Avatar SDK, it helped to generate 3D models and textures of the user's face. The input is the 2D image of our face with no glasses or hair on the forehead. Figure 6.3 shows the procedure of mapping the texture to the user's 3D face.

1. **Generate 3D face model through 3D avatar:** we upload the image of user's front face to the web sever of 3D avatar, then we can get the 3D face model with its texture, the format of 3D face model is .obj file, the format of texture is .png.

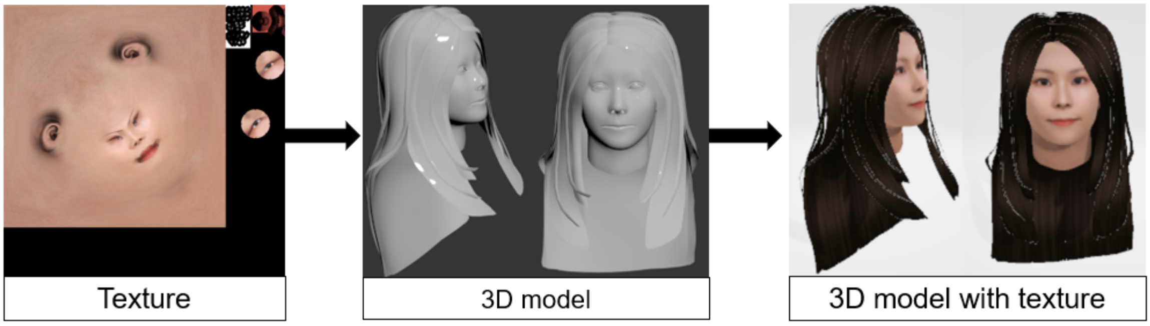


Fig. 6.3 Mapping texture to Face model

2. **Mapping texture of face to the generated 3D face model:** We can mapping the texture of face to its corresponding 3D face model and rending the 3D face model with its texture . As a result, we can generate a realistic 3D face model based on a front face image of the user.

6.3.2 Body Model Generation

1. **Gather basic information:** We generate a 3D body model based on the user's basic information, the height, and the weight of the user.

2. **Capture the body shape of the user:** the front and side image of the user's full body shape are needed. 3D Look can intelligently measures and calculates the body data in detail, and generate a 3D body model based on these data.

6.3.3 Combination of Face and Body Part

Through the above two steps, we can get the OBJ files of human model and face model, we need to combine them together. In order to get the whole avatar, we should input the obj file of face model and body model into the 3ds MAX[56] software. In 3ds MAX, we can move, zoom in/out these 3D models, then combine them together with Boolean operations. The process in 3ds MAX is shown in Figure.6.5.

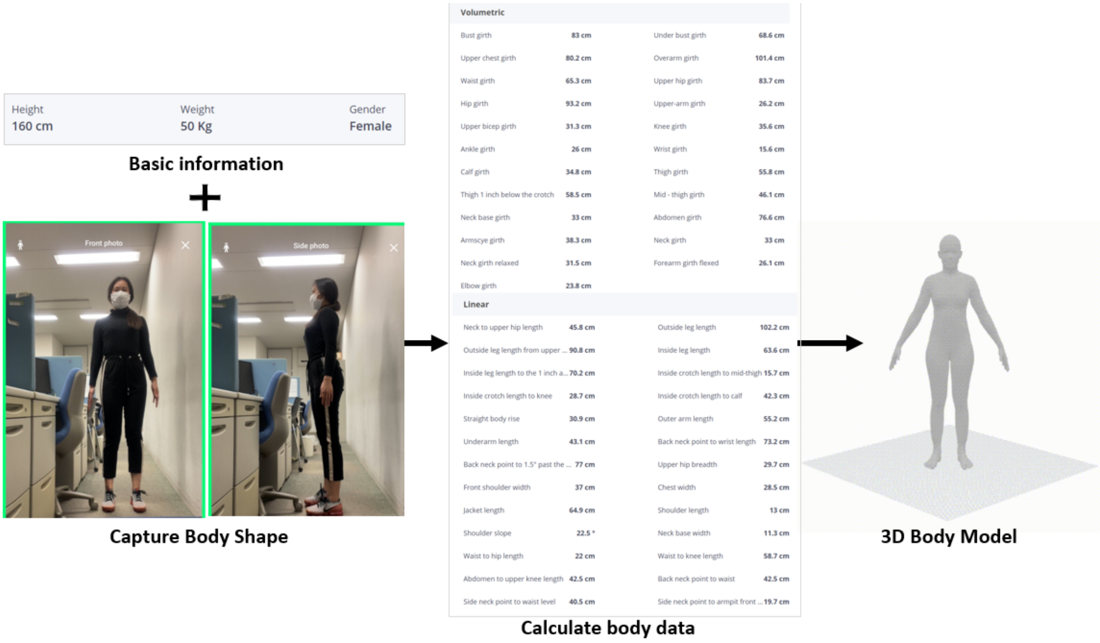


Fig. 6.4 Human model generation

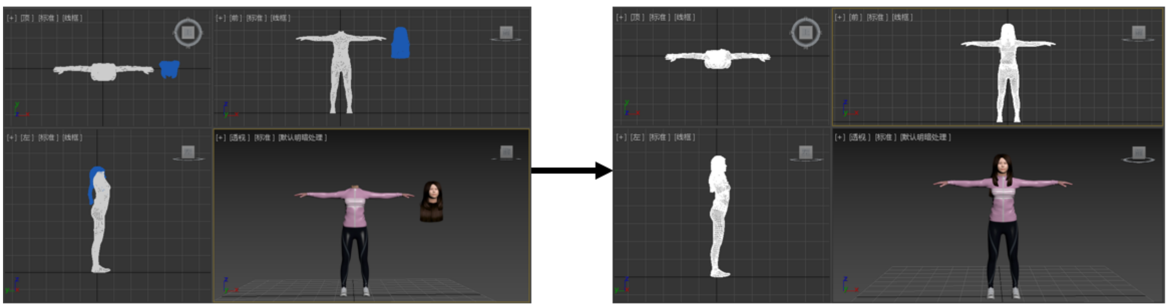


Fig. 6.5 The Combination of face and body model

6.4 Make Avatar Animation

This system need the virtual coach's avatar to perform different human-like animations, and user can dynamically view the fitness movements. We create the animations using Mixamo, which is a web-based service for creating 3D character animations. Mixamo technologies use machine learning methods to automate the steps of the character animation process, including 3D model rigging and animation. After getting the animated avatar, we can import it into our unity project and control the animation transformation of the avatar.

- **Rigging avatar:** To make sure the motion captured data can be controlled by a virtual avatar, we should first bind the skeleton and skin the virtual avatar using Mixamo. We rig as many points as possible key joints of the virtual avatar to achieve the most precise actions.

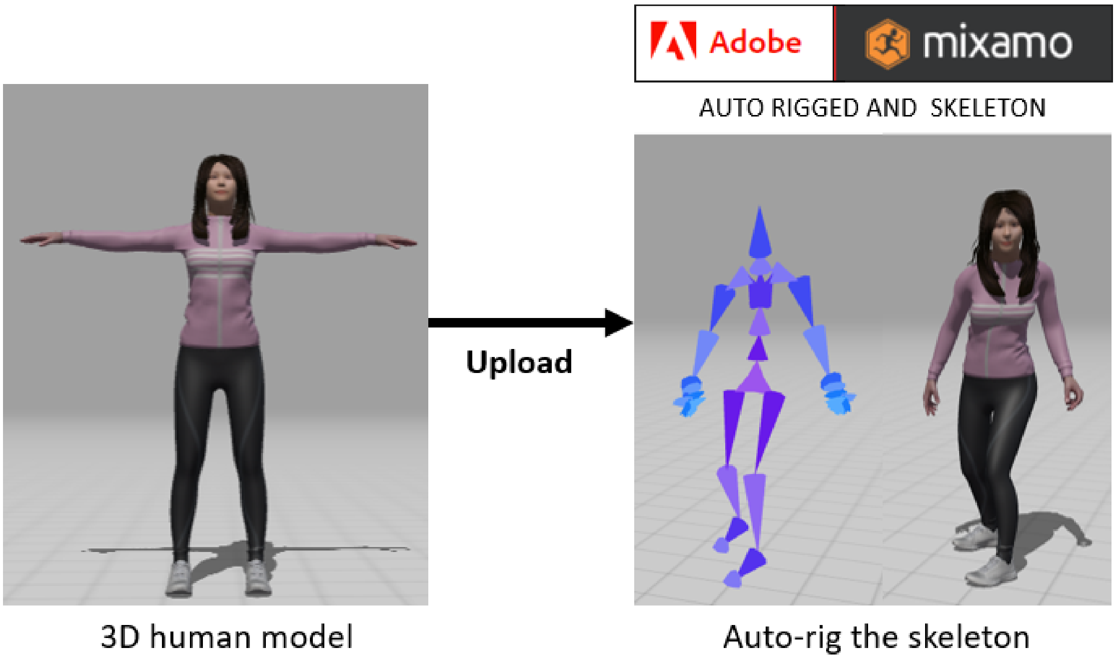


Fig. 6.6 Progress of avatar rigging

- **Making animation:** We can select an animation then view it on our uploaded character. If it's not very suitable and natural , we use the editor panel to control the animation settings such as speed and arm spacing after you've chosen an animation and applied it to your character. The process is as the Figure 6.7 shows. Select the Download button when you're finished editing the animation, we finally got the avatar with animation.

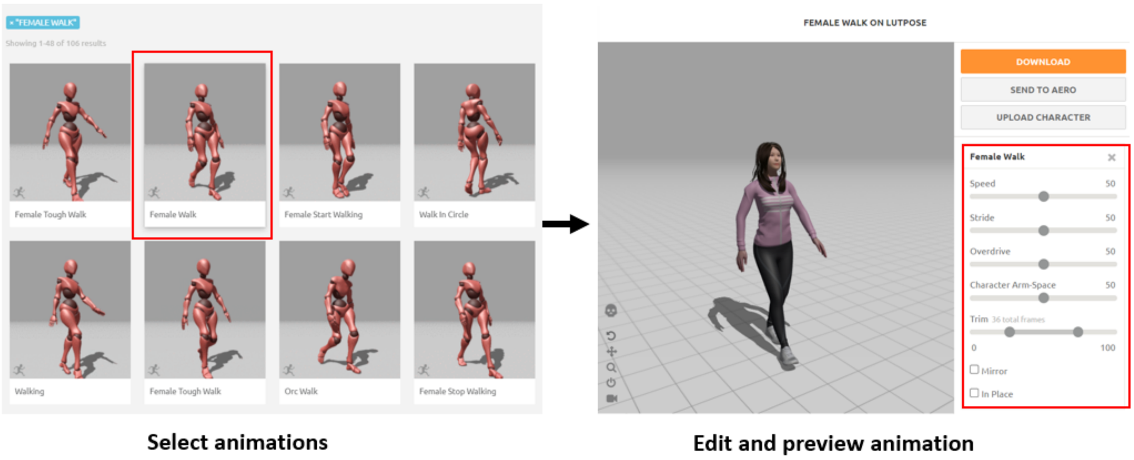
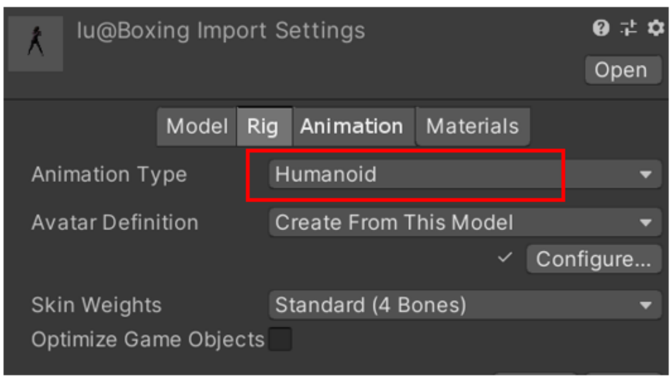
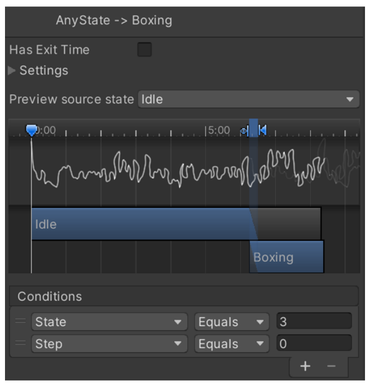


Fig. 6.7 Process of making animation

- **Animation controller:** We import the avatar model with animation into unity and set the Animation type to "Humanoid"(Figure 6.8a), create an Animator controller named "Fitness Controller" (Figure 6.9b) to control the animation play, we need some parameters such as "State" and "Step"(Figure 6.8b) to control these animations by some C# scripts. The controller should add to the "Animator" component on avatar model (Figure 6.9a). Finally, the avatar can do the humanoid motion as the previous chapter described (ordinary daily, professional fitness, emotion expression actions).

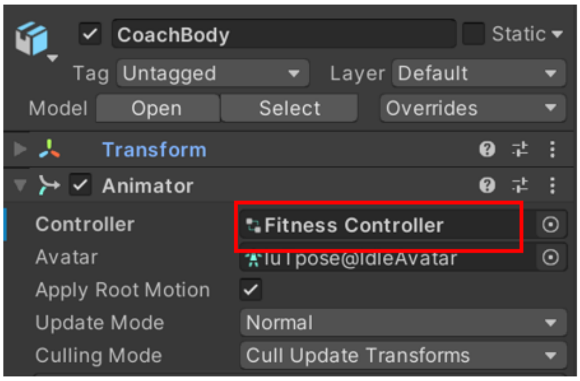


(a) Import setting of avatar

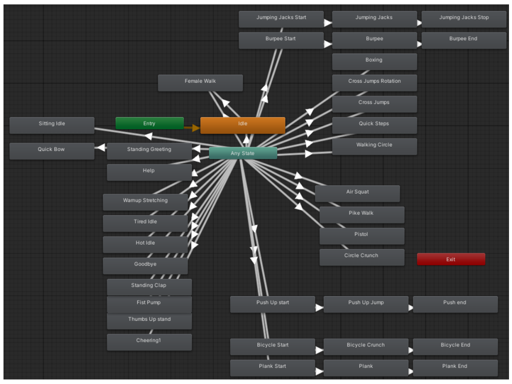


(b) "Boxing" parameters

Fig. 6.8 Animation setting in project



(a) Animator component on coach avatar



(b) Animator controller: Fitness Controller

Fig. 6.9 Animator controller setting in project

6.5 Interactive Exercise Environment

6.5.1 Physical Collision Detection

For the detection of the real environment, we make use of HoloLens2 new feature Scene Understanding in the first attempt. Finally, We adopted the method of the Li-DAR 3D scanning.

1. Scene Understanding SDK

Scene understanding SDK[57] transforms the spatial data that HoloLens captured and converts it into powerful physical mapping in project. It provides mixed reality developers with a high-level environment structure designed for intuitive development of environment-aware applications. Scene Understanding SDK runs on HoloLens2 can recognize SceneObject such as a wall, a floor, a ceiling, etc. We try to run it on HoloLens2 to scan the laboratory room (Figure 6.10). It can classify objects in a spatial map into the following seven categories.

These sceneobjects are geometric, and therefore have functions and properties that represent their location in space. In our project, when HoloLens recognizes these sceneobjects, our program adds “box collisions” component on these objects to simulate the real-world physical properties. However, the real-time detection here isn’t stable. It is affected by the angle and light, the detection results at different times are not exactly the same. As we know,

SceneObjectKind	Description
Background	A label that represents an object that does not belong to any other label.
Wall	Intel® Label representing "wall" in the physical world (reality)
Floor	Label for "floor" in the physical world (reality)
Ceiling	Label for "ceiling" in the physical world (reality)
Platform	Labels is flat surfaces on which holograms can be placed (ex. tables)
World	Label for "unlabeled geometric data" (complex areas)
Unknown	represents its classification label has not yet been created".

Table 6.2 Recognizable objects in scene understanding

the placement of coach avatar is affected by the recognized floor position. If the detection result of the floor's height is not the same every time,the coach avatar's position about height will fluctuate and change .So we continue to explore better solutions.

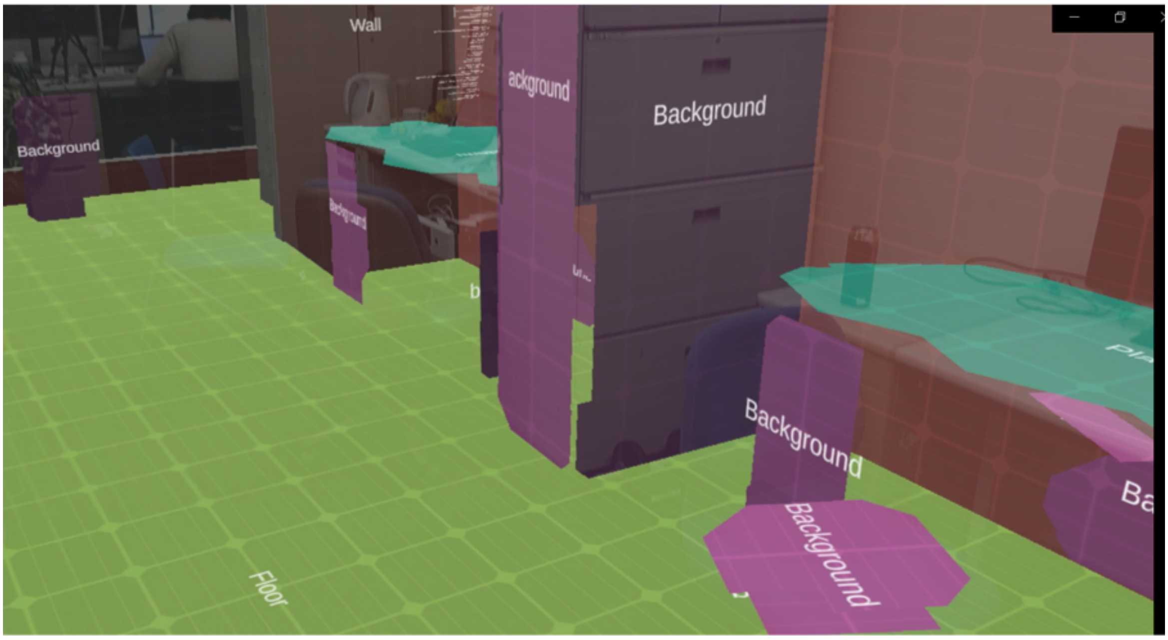


Fig. 6.10 Process result of scene understanding SDK

6.5.2 Li-DAR 3D Scanning

By using a 3D scan by LiDar as an accurate model of the space to create an spatial information database, we can easily deliver augmentations and physical simulation to stationary objects in the scanned environment. This enables creating spatial instructions and functions that are all using the surroundings as interactive elements to be explored. The spatial information database will not be affected by light and angle, so compared with the previous method, this one is more accurate and stable.

Fig. 6.11 Li-DAR 3D scanning

Here we use the Area Target feature of the Vuforia engine[54]. We download the Vuforia Area Target Creator app on a iOS devices with inbuilt LiDAR scanners, here we used iPhone 12 Pro Max. And then we scan surrounding space by the 3D scanning technologies on app and get the digital model, which will generate the Area Target Databases. The output of the scan process is imported into the Area Target Generator which returns a set of dataset files, meshes, and Unity packages. We can import them to our project in Unity. The Area Target Generator creates Area Target databases from the digital 3D models obtained by scanning. Additionally, data structures are created as representation of your space for visual authoring, occlusion, and collision simulation.

6.6 Physical Object Detection

In order to support the richer interaction between the virtual fitness trainer and specific physical objects, we need to realize the function of object recognition. For this part, we adopted the Custom Vision feature of Microsoft Azure. By the help of this platform , we can easily customize our computer vision models that fit perfectly with your unique use case. Just bring a few examples of labeled images and let Custom Vision do the hard work.

Azure Custom Vision is an image recognition service that lets we build, deploy, and improve our own image identifiers. An image identifier applies labels (which represent classes or objects) to images, according to their visual characteristics. Custom Vision allows us to specify the labels and train custom models to detect them.

The Custom Vision service uses a machine learning algorithm to analyze images. Firstly, we submit groups of images, then label these images ourselves at the time of submission. Here we just train three kinds of photo (dumbbell, chair, yoga mat). Then, the algorithm trains to this data and calculates its own accuracy by testing itself on those same images. Once we've trained the algorithm, we can eventually use this trained model in our image recognition application to classify or detect new image that HoloLens takes photo from surrounding scene.

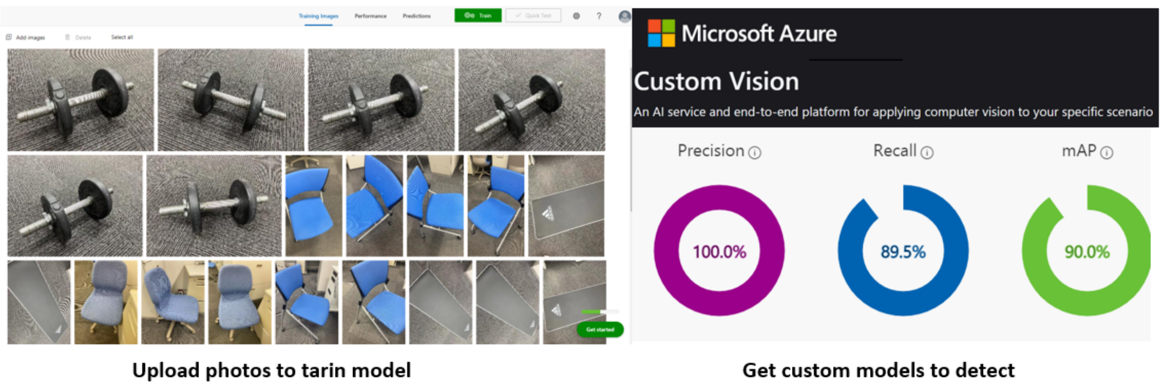


Fig. 6.12 Train custom model for detection

In our project, we use a C# script to make use of the custom model from Custom Vision service and control user's clicking input. When the user wears the HoloLens to point at and click real-world object, the system will start a shot by the HoloLens camera and get a photo in the current view, the custom model we trained before will perform a recognition on this photo. We set in C sharp script that when the detection score is more than 90, we recognize that it's the corresponding object. Then, AR coach avatar will trigger the walking animation to the target position then stop to perform related interactions that based on the recognition result, just like the previous system design section described.

6.7 Kinect-based Features Implementation

For the recording and scoring function in our system, we need to apply Kinect's feature in our project. In this section, we will show the process about how to transmit and make use of Kinect's captured data in our project.

6.7.1 Real-time Data Transmission

Since the system has a real-time feedback function, we need to realize real-time data transmission between Kinect and our project that running on HoloLens. The main problem is that HoloLens does not provide direct access to its embedded Kinect-sensor. To solve this, we deside to transfer body data from Kinect-v2 sensor over the Internet to our scene that is working on HoloLens-2.

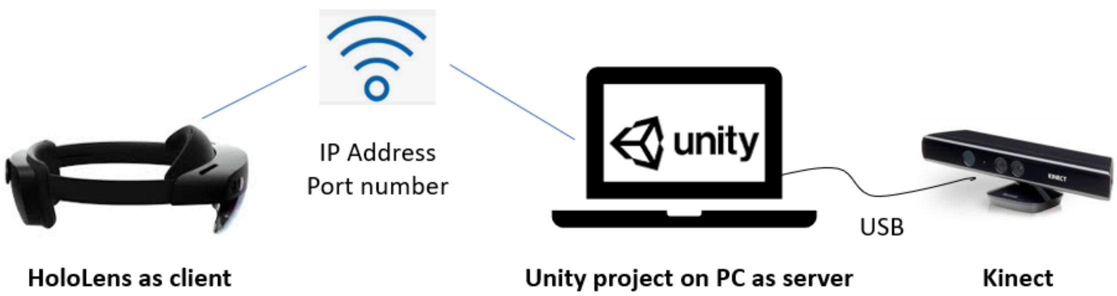
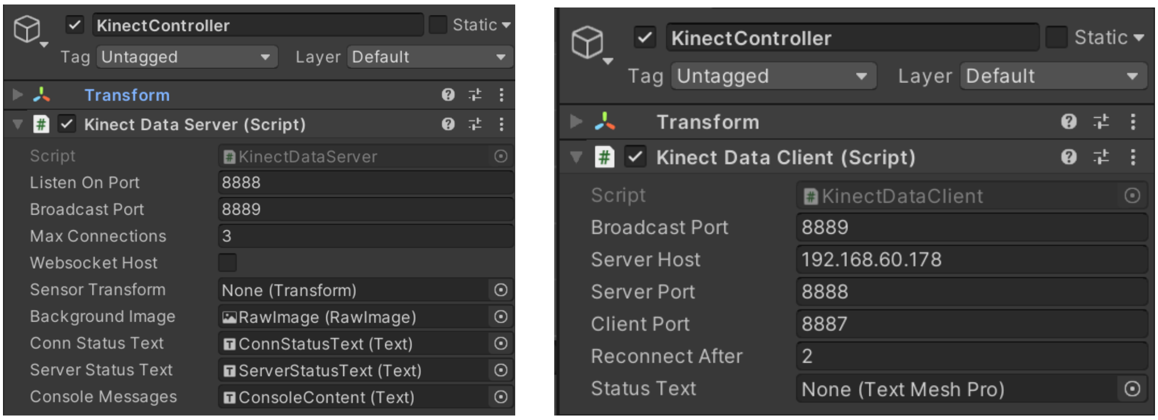


Fig. 6.13 Real-time data transmission from Kinect to HoloLens

We use two C# scripts file to achieve the connection (Figure 6.14). A script named "Kinect Data Server" run on a project in Unity on the PC, another script named "Kinect Data

Client" run on a scene on the HoloLens.



(a) Component setting on server project

(b) Component setting on client project

Fig. 6.14 Kinect connection components in system

For the project in Unity, we ceated a empty object "KinectController" in scene and add compoent "Kinect Data Server" on it. Kinect data server is the component that transmits the Kinect body data to Kinect data clients over the network, which makes the Unity project on our PC as a server (Figure 6.14a). Here we set the "listenOnPort" into 8888, it means the port to be used for incoming connections. The "broadcastPort" is 8889 means that the port used for server broadcast discovery.

In the scene that will be deployed on HoloLens, we also ceated a empty object "Kinect-Controller" and add the compoent "Kinect Data Client" . Kinect Data Client is the component that get the Kinect body data from Kinect data server over the network to make the HoloLens-scene as a client (Figure 6.14b). We set the "broadcastPort" to 8889 means that the port used for server broadcast discovery. The "serverHost" should set to the IP of the computer where Kinect data server is running and the computer is connected by Kinect by the USB. As the sever project shown on PC (Figure 6.15), we should set it into 10.27.85.98. The "serverPort" is 8888 means the port, on which Kinect data server is listening, "clientPort" is 8887 means the port, on which the client is connecting.

When we run the server project on PC and develops scenes on Hololens, and make sure that both the PC and Hololens are connected to the same local area network, they will establish a link and be able to transmit data. The connection status is displayed on the unity project on our PC (Figure 6.15). Since we have connected Kinect to the computer via USB 3.0 controller, the project on our PC acts as a transfer station, it will receive the data from the Kinect and transmit it to the connected client Hololens. Finally, our system running on HoloLens can receive the real-time data from Kinect.

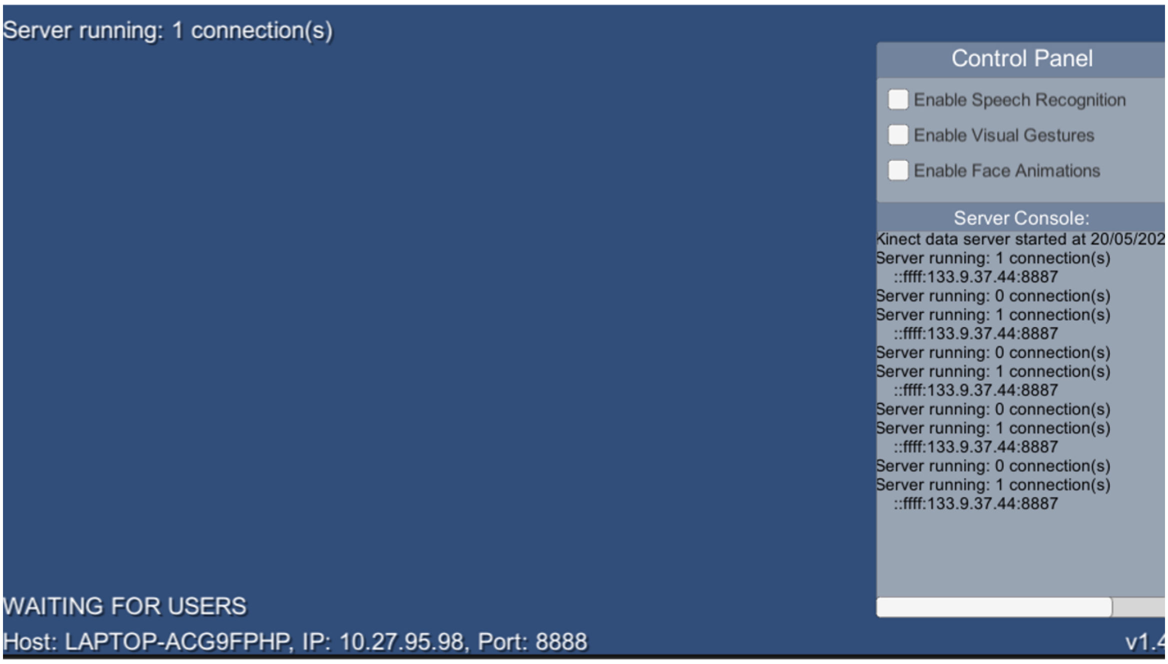


Fig. 6.15 Server project on PC

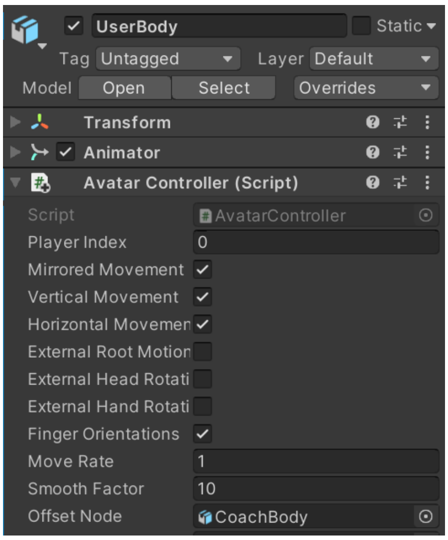
6.7.2 Avateering Humanoid Model

Avateering means that to control a humanoid 3D model using user's body. The models will follow the real-time movements of the user who Kinect is capturing. To achieve the user's avatar controlling, we need to add the "Rigid body" component and the script named "Avatar controller" on the 3D model of user's avatar in scene (Figure 6.16a).

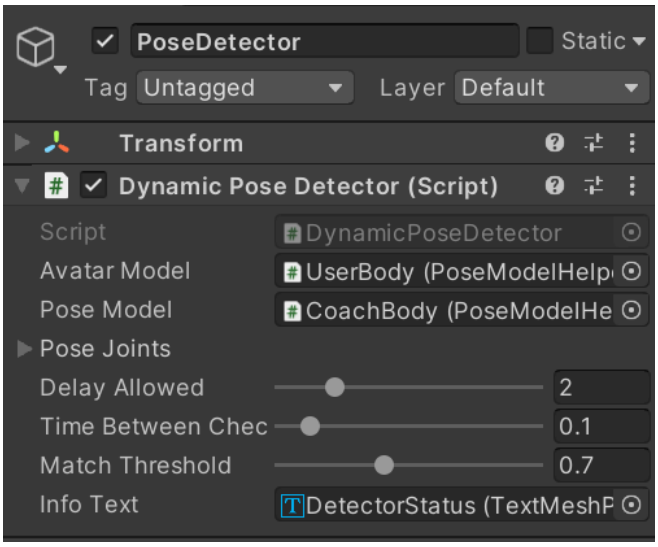
Avatar controller is the component that transfers the Kinect-captured user motion to a humanoid model. Its main function is to map the human-body bones' relative positions captured by Kinect to the transforms of every bone in a List<HumanBodyBones> on avatar. The UpdateAvatar() function updates the avatar each frame to achieve the continuous transformation in real time. We can choose whether to mirror the user's actions on the avatar through the "Mirrored Movement" check box. We want the user's avatar to be displayed next to the coach's, so we set the offset Node as the game object "CoachBody".

6.7.3 Motion Accuracy Factor

This feature estimates the pose matching factor between the user and an animated pose model. The moving-pose detection get the matching score to provide better training feedback to the user. I our project, we need to create an empty object named "PoseDetector" and add DynamicPoseDetector-component on it. What's more, we add the PoseModelHelperClassic-components on the object "CoachBody"(coach's avatar) and the PoseModelHelper-components on the object "UserBody" (user's avatar) . Our scene utilizes the KinectManager-component to manage the sensor and data, DynamicPoseDetector-component to estimate the pose-matching factor between the user and the animated model, PoseModelHelper and PoseModelHelperClassic-components match the sensor-tracked joints to model transforms, they estimate the user's and model's bone orientations.



(a) "Avatar controller" setting



(b) "Dynamic Pose Detector" setting

Fig. 6.16 Kinect feature related components

In the main component "Dynamic Pose Detector", we should finish some setting here. The "Avatar Model means the user avatar model, who needs to reach the target pose in pose model. The "Pose Model" is the coach's avatar whose model in pose that need to be reached by the user. The "Pose Joints" is a list of joints to compare, we can add some key joints and bones into the list."Delay Allowed" means that allowed delay in pose match in seconds, here we use 2 seconds. "Time Between Checks" is the time between pose-match checks, in seconds. "Match Threshold" is the threshold, above which we consider the pose is matched, here we set to 0.7. "Info Text" means the GUI-Text to display information messages on system's user interface (Figure 6.16b).

Next we discuss how to implement the algorithm of action comparison. When the user's action is the same as the coach's action, then their corresponding bones should be parallel, so the angle of the bones is 0. Therefore, from the vector point of view, we think that the smaller the angle, the closer the current action is to the target action, and the more accurate the action. The larger the angle, the less accurate fitness training. Based on this criterion, we implemented this function in the "Dynamic Pose Detector" script.

```
// returns status description
3 个引用
private string GetMatchStatus(float nom, float denom)
{
    float fRes = denom > 0f ? (nom / denom) : 0f;
    if (fRes == 0f)
        return "No motion";
    if (fRes < 0.6f)
        return "Bad";
    else if (fRes < 0.65f)
        return "Good";
    else if (fRes < 0.75f)
        return "Very good";
    else
        return "Excellent";
}
```

Fig. 6.17 Get matching status by motion score

When the avatars of the coach and the user are performing actions, the script obtains the current posture data of the two avatars from that frame at every interval ("Time Between Checks"). Some detection information will be shown in detail by UI text. Firstly, it traverses the list of joint in user avatar. For every two adjacent joints, we calculate a direction vector by subtracting the previous joint's transform from the next joint's transform, which means that the two joint points determine a bone with a direction. Then it stores the direction vector in the BoneDirs[] array for user's avatar. To calculate the motion matching rate, we traverse the list of joint in coach avatar and calculate and stores the direction vector in the BoneDirs[] array for user's avatar. Finally, we compare the difference factor of the vectors in the two BoneDirs[] arrays in the form by calculating the angle between the vectors(Vector3.Angle(userBone, coachBone)). We assume the max diff could be 90 degrees, so we calculate the formula: $fScore = (1f - fAngleDiff/fMaxDiff)$ to get every frame's score, then we accumulate these scores to get the final result such as bad, good, very good, excellent as the Figure 6.17 shown.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

In this thesis, we introduced the AR fitness coach, a holographic AR-based motion training system for exercise assistance to improve use's self-service fitness experience. With augmented reality technology, the virtual character of a fitness coach can be displayed in 3D and be placed in real scene. The innovative design about personalized coach based on user's face and body features is goal to increases the training efficiency and positive effect on fitness training. In such case, user can intuitively learn, compare body motion and get encouragement from the familiar and similar body as himself/ herself, which gives exercisers an attractive fitness experience with a sense of satisfaction and achievement. In order to simulate the sense of being accompanied by a personal coach for user, the virtual coach simulate a real person who have natural interactions with physical world and user and perform human-like activities. In addition, the virtual coach also performs fitness coach's professional duties to give user's exercisers motion teaching, guidance and feedback about training performance. Combine with the Kinect-based motion capture, system gets motion data from user's body. System shows user's self-image for comparing and adjusting, calculates the motion accuracy. Some real-time feedback about current training performance that is based on accuracy will be given by virtual coach to motivate fitness training. System provides three training modes(learn/record/score) to support these core features, they effectively support motion learning, posture adjustment and skill improvement in fitness training.

Our system provides a more attractive and effective self-service fitness experience, and greatly enhances the motivation, willpower and fun of exerciser during self-service fitness. In particular, the sense of companionship and motivation from the personalized coach has a positive impact on fitness training, it enable self-serve fitness excessive to truly feel the company and motivation from the helpful and friendly sports leader, so that exercisers can participate in exercises more easily, calmly and happily. In terms of functionality and usability, our system provides users with effective motion learning and motion skills improvement mechanism. The three suitable training modes in system allows users to experience the motion training's general process from learning, practice to improvement. The AR coach's intuitive guidance, timely feedback and continuous motivation make user to be full of confidence and mental energy to persist in exercising .

7.2 Future Work

In the future, we would improve our works from two main aspects. Firstly, improve the realistic of the personalization. Our previous work only focused on personalized appearance, that is, generating avatars based on the user's facial features and body shape characteristics. Surveys on virtual avatars have shown that embodied avatar can increase the self-identification and self-body ownership in virtual environment and higher level virtual avatar can increase the enfacement illusion and avatar self-identification in social virtual environment[58]. However, current work is no enough for a high level of embodied avatar. First of all, current virtual avatar has no facial expressions, which makes it lack of vividness and human emotion. In the future work, we will add facial expressions to user's personalized avatar, so that it can convey more emotional information to the user. We also hope to explore whether the emotional elements from facial expression can have some influence on the user experience under the augmented reality fitness training environment.In addition, the current virtual avatar's voice lacks similarity with the user's own voice. It is the default human voice and lacks the of the user's own feature, which may make users feel unfamiliar and confused, weakening the similarity and immersion. To enhance the realistic and immersive experience of voice communication and real-time voice feedback in the system, we plan to equip the virtual avatar with personalized voice that has user personal tone features in the future.

Secondly, improve the quality of motion capture. The current motion capture device we use in system is the Microsoft Kinect Xbox one sensor. However, the device's location and facing direction will affect the quality of motion capture. In our previous research, we found that when the Kinect is facing the front of the user body, the captured motion that be synchronized to virtual avatar body is in good quality. However, when the Kinect is face the side of human body, the effect is very poor and it often produces some distorted movements. In the future, we will continue to explore solutions what can better capture the user's body motion. Due to the more advance version Kinect, the Azure Kinect has improve its hardware and technology, it can achieve greater motion capture in comparison to our current device. For the future work, We plan to try Azure Kinect and explore what kind of solution can better support the motion capture of user body, in order to provide users with higher-quality external self-image and more accurate motion accuracy calculation.

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