Human Interaction and Emerging Technologies (IHIET 2023), Vol. 111, 2023, 305–313
https://doi.org/10.54941/ahfe1004037

Visualization of Additive Manufactured Orthosis via Augmented Reality

Gustavo Melo, Chenyan Feng, Stefan Reich, and Johannes Henrich Schleifenbaum

Chair for Digital Additive Production DAP, Aachen, Campus-Boulevard 73, 52074, Germany

ABSTRACT

Finding an orthosis product that both satisfies the medical requirement and has an appealing design has always been hard for patients with physical inconvenience, especially during corona time. To go to the physical store, the patients must tolerate the time spent on the way, limited choices of design to try on in each store, and the risk of corona infection due to close contact with the others. The Producers also must cover for the wear-out samples and take the risk of the patients not liking the design after production. A virtual try-on application is the best solution to satisfy both sides. This paper describes the process of making an Android AR application on the tablet for the users to try on different types of orthoses virtually, only with the help of a regular camera. It gives a general overview of the development of AR technology and discussed all the tools available to use for this type of app development, a review from the producers is provided, and in the end, some future improvements on this AR application were suggested.

Keywords: Orthosis try-on, AR technology, Android application development, Unity UI design, Vuforia, Marker-based tracking

INTRODUCTION

The concepts of Augmented Reality (AR), Virtual Reality (VR), and metaverse has been mentioned several years ago, but it has not been widely accepted by the public. Things have changed wildly since the breaking out of the coronavirus, people are forced to find remote solutions for their daily needs. These solutions revolutionized the way people view all these technologies, thus more and more applications came to the market and most of them make our life more flexible and more efficient. However, this technology has rarely been used to digitalize the production line of medical device. This paper presents the development steps of an orthosis try-on application, which bridges the communication gap between manufacturers and the consumers, making both the production and the purchase much easier. A design thinking framework from Stanford is implemented in this study, which consists of five steps: Emphasize, Define, Ideate, Prototype, Test (Ashtari et al., 2020).

Fundamentals of AR Technology

Most people would get confused by the term AR, VR, and Augmented Virtuality (AV). VR builds a completely immersive environment for the users, and the real world cannot be seen, while AR brings virtual information or objects into the user's real surroundings, thus enhancing the user's ability to gather information from the environment. AV is something between AR and VR, but is closer to VR, while AR is closer to reality (Carmigniani et al., 2011).

There are three kinds of tracking for an AR system: marker-based tracking (MB), markerless tracking (ML), and hybrid tracking. MB tracking uses the camera to detects the feature of a fiducial marker, and overlay the augmented object on top of it, whereas ML tracking use one or multiple objects themselves as tracking targets and overlay augmented objects on them. Hybrid tracking it the method that combines both MB and ML tracking in a creative way and would not be discussed in detail here.

AR technology has proven itself to be able to increase purchase behaviour, mainly because of three features. First of all, it brings the virtual world to the real world, making the shopping experience more distinguishable, it bridges the Gap between the virtual product and the real user. Second of all, the consumers can interact with the virtual objects in real-time, making the products more attractive and interesting, and the features of the product would also seem more convincing. Third of all, the virtual objects could be attached to a certain position in 3D, allowing the consumers to have the illusion that they are actually trying the product on or interacting with it in other ways, making the consumers feel more present with the product, and making the product seems more personalized, thus more attractive (Smink et al., 2020).

STATE OF THE ART

The first step of design thinking is to emphasize with the users, which means that through observation, researching and questioning, developers learn to look at things from the user's perspective so that the user's needs could be more easily found out (Ashtari et al., 2020).

Traditionally, orthosis making is a long process of try-on and adjustments, which means a lot of travels to the physical store. Therefore, it would be a great relief if the orthosis model could be automatically generated with a 3D scan of the patients' leg, and if the patients can select the design of the orthosis remotely.

The second step of design thinking is to define the problem, so that the developers can know which features of the application they should be focusing on to solve problems from users (Ashtari et al., 2020). In this scenario, the problem of orthosis selection and the long time that it takes for orthosis consumers to get the final product need to be solved.

After the problem is defined, it is time to brainstorm for ideas. Some AR applications in the fashion industry were reviewed for this purpose.

The application developed by Kjærside et al. is based on marker-based tracking technology. After the consumers have selected the clothes, they can place them on the bar in a closet to the left of the mirror and put their phone in the box on the right side. The computer would detect the RFID tag hanging on the clothes and receive data of the consumer's body measurements from the mobile application. The image on the virtual mirror then combined this information together with the real-time data from the camera and gives the illusion to the consumer that he or she is having the augmented clothes. Three fiducial markers are placed on the consumers' upper body for better tracking (Kjærside et al., 2005).

Parth et al. developed an Android AR watch try-on application. The tablet camera can detect the marker placed on the consumer's wrist, and the consumer can go through different models on the user interface, switch to different models, or change the colors of the watches according to their preferences. The augmented watch will be placed on their wrist covering the marker. ML tracking is more challenging to implement than marker-based tracking since more features are required to make the estimation of where the target object is (Yang et al., 2014). Developers such as Philipp Presle uses the Kinect, a depth-recognizing camera to develop a virtual mirror (Presle, 2012). Yang et al. proposed a hybrid tracking also with Kinect, but with three different modes: only MB tracking, only ML tracking, or both of them combined (Yang et al., 2014). The JD online shopping platform has adopted a virtual shoe try-on system for online shoe-selling called ARshoe, which is a complex system that contains an encoder, a decoder, and a processing phase (An et al., 2021).

METHODOLOGY

Analysis and Selection of SDK

After the Ideate phase, a prototype needs to be sketched out. The prototypes should then be tested either through experiment or through interviews and discussions, before an end-product could be generated. To test the orthosis try-on application, meetings with several fellow students were arranged, and valuable suggestions for building this application were gathered from them (see Table 1), such as building platforms or useful software development kits (SDKs).

Table 1. Comparison of popular SDKs (modified) abbreviations: Comm-Commercial, F-Free, P-Paid, O-Open-source, A-Android (Dima Titov 2020; Amin and Govilkar 2015; Sanket Prabhu 2017).

	License type	Supported platform	HMD support	Unity support	Cloud recognition	Edge-based tracking
Vuforia	Comm, F/P	A, iOS	Yes	Yes	Yes	Yes
ARKit	F	iOS	Yes	Yes	No	No
ARCore	F	A	Yes	Yes	No	No
ARToolkit	O	A, iOS	Yes	Yes	No	No
Kudan	Comm, F/P	A, iOS	No	Yes	Yes	Yes
Wikitude	Comm, F/P	A, iOS	Yes	Yes	Yes	Yes
Maxst	Comm, F/P	A, iOS	Yes	Yes	Yes	Yes
Metaio	Comm, F/P	A, iOS	Yes	Yes	No	Yes

Based on the criteria in the table above, Vuforia was selected as the best SDK to use in this case, with Unity as the editor.

Unity Development Engine

Unity 3D as a multi-platform development engine is usually used for game design. It is free to use most of the basic functions, and it is also possible to make upgrades with payments. To save time for the game developers, it has a clean and structured interface, a useful and multi-functional toolset, a play scene to test the game within the development process, and most important of all, Unity 3D provides a library of native plug-ins called Asset Store, which allows the developer to import functionality, 3D models or properties from third-party companies, making the interactions in games more diverse and interesting, at the same time easy to implement. Unity also provides a large community for users to discuss new ideas or problems that come up during the development phase, which helps developers with similar problems (Tetiana A. Vakaliuk and Svitlana I. Pochtoviuk, 2021).

Most of its plug-ins and functions could also be applied for general application development, and it is especially suitable for AR application development because of its on-the-fly play testing and the feature-rich editor which generates the play scenes (Günes et al., 2015). Within the editor, Developers can generate or import objects of various formats, set properties to the objects, change the materials or add sounds to the objects. The orthosis models generated by Ren were imported and modified with these functions of Unity. To make the objects move or interact with the users as the developers want, the developers could use C#, JavaScript, or Boo as the programming language. The orthosis try-on application in this study used C# scripts to create the interactions.

Vuforia Platform

The Vuforia platform is currently one of the most popular Tools for AR application development. It supports all the major platforms like Android and iOS and proposed a powerful plug-in to use its functions in Unity. Most of its features are free to use, and an update of plug-ins costs 99$ per month (Tetiana A. Vakaliuk and Svitlana I. Pochtoviuk, 2021). The platform offers efficient, up-to-date, and reliable algorithms for computer vision problems such as image recognition or 3D object tracking, which saves AR application developers from a lot of technical constraints. It also provides a clearly structured User Interface, which allows the developer to know which tool to use in no time. The SDK also supports 3D tracking, multi-target tracking, cylinder target tracking which tracks objects of cylindric shape, frame marker tracking, etc. (Amin and Govilkar, 2015).

From the design point of view, on the one hand, MB tracking is easier to implement, but the patients might find the markers troublesome. On the other hand, ML tracking requires more effort to develop, but requires fewer actions from the consumers' side. The development of the orthosis try-on application takes therefore both MB tracking and ML tracking into consideration, in the hope that a better end-product could come out.

The development of MB version is planned to have the following steps: Firstly, fiducial markers will be generated and set up in Unity. Secondly, the orthosis models are adjusted and placed on the marker accordingly. Thirdly, a user interface will be designed in Unity, Fourthly, the application will be built through Unity, and last but not least, an interview will be conducted for the validation of this application. Because the consumers of orthosis usually cannot move around as freely as the consumers of regular shoes or clothes, it is important to make the try-on procedure as simple as possible. During the development phase, two different ways of using the marker were designed and were compared during the interview for a version selection.

Vuforia supports model target tracking, which was used for the ML version of this application. This way of tracking imports the 3D model of the object to be tracked into the model target generator from Vuforia, and the 3D model works the same way as the fiducial marker for the camera to keep track of. After the 3D model of the consumer's leg is detected, the Orthosis model would be augmented on the outside of the leg. In this way, no fiducial markers would be used, and it would provide more comfort for orthosis consumers. The development procedure is planned to be the same as the MB version of this application, except that the 3D model of the leg must be generated and used to train the Tracker of Vuforia Engine.

RESULTS

In the design thinking process, the prototype sketching step and the testing step should be repeat in turn multiple times for a better result. After the general development steps were planned and validated by fellow students, the application prototype was developed, and a preference test interview was made with 7 orthosis manufacturers at the Düsseldorf medical trading fair.

Design

After the orthosis model is generated by a parametric design tool with the medical scan of the patient's leg (Pan Ren, 2022), the application helps the user to individualize the model, so that it could be additive manufactured and delivered to the patients. The application program flow is divided into 3 steps. First, the patients can select the model that the doctors recommended, then the design pattern of the lattice that they like, and lastly the colour of the orthosis model that looks the best on their leg.

Development

After the literature review, the MB version was first developed. Since the camera view is limited, it is hard to give a 360° view of the orthosis model for the patients with only one marker. Thus, two markers were used at first, one on the outer side of the patient's leg. And the other marker is placed on the inner side. This version is named the "2 Code Marker-Based" version (2CMB) for this study. Later, it was modified to require only one marker, and this version is referred to as the 1CMB version in this study. After many trials of scanning a human leg and generation of a model target, the end-product of ML tracking was not so promising, thus this version was discarded in the end.

First of all, the marker needs to be generated and imported. An online Marker generator was used for this purpose. For feature tracking with higher accuracy, two 5*5cm black-and-white QR codes were generated and were used as the fiducial markers to be tracked.

After Unity was successfully downloaded and installed, the Vuforia plug-in could be found in its Asset Store and could be added it to Unity. To make this plug-in work, it has to be installed in this project first, and the building settings of Unity need to be changed accordingly. For example, the normal camera of the default Unity setting needs to be replaced with the AR camera. All 12 models with different designs and patterns are then aligned up in the scene.

Until this stage, occlusion of the orthosis models has not been taken care of. The patient would realize that the entire augmented orthosis model is floating on the leg instead of wrapping it around. To fix this, a transparent material was created and attached to a 3D human leg model, which then put inside all 12 models. This step would hide the part of the orthosis model which is not supposed to be seen at certain angles when these parts are covered by the foot or part of the leg (see Figure 1).

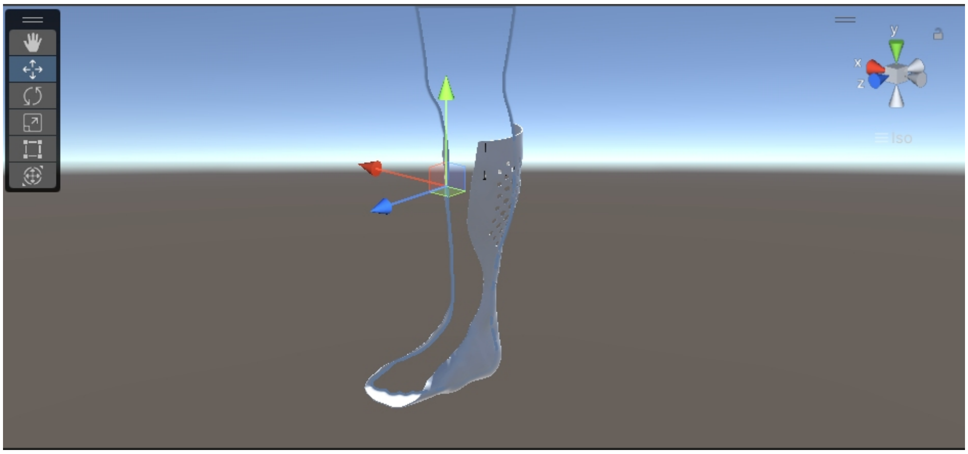

Figure 1: Occlusion adjustment.

After the first orthosis model is placed correctly and adjusted accordingly, when one marker is hidden from the camera and the other is in view of the camera, the orthosis would show up at the same position. For this purpose, the whole setting is then mirrored on the other marker, so that one marker allows the consumer to view the orthosis model from the inside of the lower leg, and the other marker lets them look from the outside when the previous marker is beyond the reach of the camera.

The UI windows are then designed, and each assigned an animation, so that it can slide into and outside the screen, when certain buttons are clicked. Afterwards, a C# script called "OrthosisSelect" was created, so that each time an orthosis is selected on the screen, the corresponding 3D model is chosen to be shown. A colour picker Unity add-in was also added in the project, and this, together with the script called "ColorSelect", enables the colour change of the orthosis models.

1CMB is designed to let the consumer move the marker as well as the tablet, and also interact with the augmented orthosis model on the screen. The most important change for this version is adding the rotation function. To try the orthosis on, the patient first places the marker on the outer side of his or her leg, showing how the orthosis looks like on the outside of their leg, then the orthosis can be rotated 180 degrees by swiping on the screen, so that the patient can move the QR code to the view it on the inner side of his or her leg. The Unity add-in called Lean Touch enables it, as well as scaling the orthosis and moving it around on the screen.

Validation

The last test was taken in the form of an interview to validate the most suitable version of this application. This interview was carried off with seven orthosis manufacturers in a medical device trading fair called medica at Düsseldorf. The seven orthosis manufacturers were asked about their opinions on the 1CMB and 2CMB version of the orthosis try-on application. All of them showed strong interest in this application and the additive-manufactured orthosis models, and they were willing to apply this digitalized production line if the end-product is more reliable and more socially accepted in the future. The 2CMB version was preferred by five out of seven manufacturers, since it is more intuitive and requires less physical movement from the patient.

CONCLUSION

In the end, an AR orthosis try-on application was developed. The 2CMB version needs two markers to be printed out yet is more intuitive and requires less moving of the leg from the consumers. The 1CMB version requires only one marker, but it is less easy to understand, and moving the camera might be burdensome for orthosis consumers. One way to build an ML version of this application was also proposed, but the ML version was not good enough for a final product. Still, it gives some thoughts on future AR application creation.

Some producers from the survey already gave some good suggestions for improving this application. For example, some chatting functions could be integrated into the application, so that doctors could directly talk to consumers and give suggestions on which model to purchase. Also, an elastic band could be used as a cylindric target for Vuforia to track, so that it is easier for consumers to put the marker in the right position.

Some more improvements could be made to this MB version of the application. Because the building platform is Android, and the MB version of the application does not take much storage place, the same design principle could be used for a Hololens application, so that consumers can use an HMD for orthosis try-on in the future, thus they do not have to hold a tablet for visualization anymore.

The Kinect set could be applied in the future for the ML tracking version to be realized, for it provides additional depth data for the developers to get features of the leg more easily. As mentioned in previous chapters, there already exist some shoe try-on applications, which used the Kinect camera for ML tracking of the feet.

Some of the consumers might find downloading a new application and printing out the markers too complicated, to solve this problem, a later version of the AR orthosis try-on application could be integrated onto a website, and the Markers could be made to send to the consumer's smartphone, so that they could use their smartphones to have the augmented orthosis sticking on it, saving more time an effort.

If orthosis production and delivery could be personalized in this way, the same principle of digitalized production line could be applied to other additive manufacturable products, such as necklaces, bracelets, or even costumes. The consumer can try the personalized version of the product within the application and order them for additive manufacturing without any waste of materials or time searching in physical stores.

In digitalizing the production of ankle-foot orthosis models, a more environment-friendly and personalized production line can hopefully be built. AR is still a growing technology. We are hoping that it could bring us a more convenient and simple way of purchasing.

REFERENCES

Amin, Dhiraj., Govilkar, Sharvari. (2015). Comparative Study of Augmented Reality Sdk's. International Journal on Computational Science & Applications 5 (1), 11–26. https://doi.org/10.5121/ijcsa.2015.5102.

An, Shan., Che, Guangfu., Guo, Jinghao., Zhu, Haogang., Ye, Junjie., Zhou, Fangru., Zhaoqi, Zhu., Wei, Dong., Liu, Aishan and Zhang, Wei (2021). ARShoe: Real-Time Augmented Reality Shoe Try-on System on Smartphones.

Ashtari, Narges., Bunt, Andrea., McGrenere, Joanna., Nebeling, Michael., Chilana, Parmit K. (2020). Creating Augmented and Virtual Reality Applications: Current Practices, Challenges, and Opportunities. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. New York, NY, USA, Association for Computing Machinery, 1–13.

Carmigniani, Julie., Furht, Borko., Anisetti, Marco., Ceravolo, Paolo., Damiani, Ernesto., Ivkovic, Misa (2011). Augmented reality technologies, systems and applications. Multimedia Tools and Applications 51 (1), 341–377. https://doi.org/10.1007/s11042-010-0660-6.

Dima Titov (2020). 11 Best Augmented Reality SDKs to Start AR Development in 2021. Available online at https://invisible.toys/best-augmented-reality-sdk/# (accessed 1/23/2023).

Günes, San., Sanli, Okan and Ergün, Övgü Öztürk (2015). Augmented Reality Tool for Markerless Virtual Try-on around Human Arm. In: 2015 IEEE International Symposium on Mixed and Augmented Reality - Media, Art, Social Science, Humanities and Design, 59–60.

Kjærside, Krista., Kortbek, Karen Johanne., Hedegaard, Henrik., Grønbæk, Kaj (2005). ARDressCode: augmented dressing room with tag-based motion tracking and real-time clothes simulation. Proceedings of the Central European Multimedia and Virtual Reality Conference.

Pan, Ren (2022). Design einer additiv gefertigten patientenindividuellen Unterschenkelorthese zur Behandlung von Cerebralparese. Masterarbeit. Aachen, RWTH Aachen.

Presle, Philipp (2012). A Virtual Dressing Room based on Depth Data.

Sanket, Prabhu (2017). Augmented Reality SDK Comparison: Parameters to select the right AR SDK. Available online at https://www.arreverie.com/blogs/augmented-reality-sdk-comparison-parameters/ (accessed 01.2023).

Smink, Anne R., van Reijmersdal, Eva A., van Noort, Guda and Neijens, Peter C. (2020). Shopping in augmented reality: The effects of spatial presence, personalization and intrusiveness on app and brand responses. Journal of Business Research 118, 474–485. https://doi.org/10.1016/j.jbusres.2020.07.018.

Tetiana A. Vakaliuk and Svitlana I. Pochtoviuk (2021). Analysis of tools for the development of augmented reality technologies. In: International Workshop on Augmented Reality in Education.

Yang, Yu-I., Yang, Chih-Kai., Chu, Chih-Hsing (2014). A virtual try-on system in augmented reality using RGB-D cameras for footwear personalization. Journal of Manufacturing Systems 33 (4), 690–698. https://doi.org/10.1016/j.jmsy.2014.05.006.