AN INTERACTIVE VIRTUAL MANUAL IN AUGMENTED REALITY

BY

QIUHUA DING

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Computer Science
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2017

Urbana, Illinois

Adviser:

Professor David Forsyth

ABSTRACT

We present a novel virtual manual system for users to author and view virtual manuals on augmented reality devices. Augmented reality virtual manuals offer multiple advantages over traditional paper manuals. We explore the design space of building a virtual manual system on a variety of augmented reality devices with different features. Multiple sample virtual manuals are developed to demonstrate key usages and functionalities of a virtual manual system.

To my family, for their love and support.

ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. David Forsyth, for his guidance and assistance throughout my thesis project. He was helpful and supportive during the entire project, and I am very grateful. He provided many insightful suggestions and ideas, and this project would not have been possible without his support.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

With the recent advent of more augmented reality devices on the market, exploring new usages of these devices becomes an interesting topic. One possible use we believe is valuable for people's daily life is the virtual manual system. We present a novel interface for authoring and viewing an interactive virtual manual on augmented reality devices, such as Project Tango and HoloLens. 3D models and animations are superimposed into real-world environments along with virtual notes to provide the instructions from a manual. We believe this approach will be more visually appealing to users as well as much easier to understand compared to traditional paper manuals.

We also introduce an advanced feature for virtual manuals that can verify users' actions against the instructions to provide real-time feedback. We explore the design space of building virtual manuals with this kind of system on a variety of augmented reality devices. Multiple sample virtual manuals are presented to demonstrate the key features and advantages of a virtual manual system.

CHAPTER 2

ADVANTAGES OF VIRTUAL MANUALS

2.1 Intuition

One significant advantage of using a virtual manual is that it can present manuals in a visually intuitive way compared to a traditional paper manual. Each step in a virtual manual can contain multiple 3D models and animations that directly demonstrate the entire process and actions needed to be performed by the user. Furthermore, since 3D models and animations are in persistent positions and rotations with respect to the actual physical objects the manual is built for, users can view animations and 3D models from different angles, which enables users to better understand the structure and process. These features are achievable with virtual manuals on augmented reality devices, but are extremely difficult to achieve with traditional paper manuals.

2.2 Interactions

A virtual manual system also makes interactions possible between users and manuals, which is impossible using traditional paper manuals. A useful interactive feature is to include a verification mechanism within virtual manuals to provide real-time feedback to users while they are performing actions directed by the manual. Users would know if they are following correctly in real-time through these feedback, and then make adjustments as necessary.

2.3 Video Log

A forward-facing camera is necessary for the function of a virtual manual system. This camera can also be used to perform simultaneous video recording while the user is interacting with the virtual manual. A video log file can be saved as a proof of process and later viewed as a reference. This feature is easy to implement and would be useful for industries where logging and monitoring are essential.

CHAPTER 3

BACKGROUND

3.1 Augmented Reality Devices

Augmented reality devices allow users to see real-world environments along with superimposed virtual objects [1, 2]. There are different types of augmented reality devices. Two of the most common forms seen in today's marketplace are hand-held devices and head-mounted devices. Hand-held devices can provide augmentations with video see-through, while head-mounted devices can provide augmentations with either video see-through or optical see-through [2, 3].

The augmented reality devices used in this research project are Google's Project Tango and Microsoft's HoloLens. Project Tango is a hand-held tablet device, and HoloLens is an all-in-one head-mounted optical see-through device. They provide very different user experiences, so it is valuable to explore the design spaces for these two device types.

3.2 Depth Perception and Tracking

Depth perception and tracking are important for building augmented reality applications. With depth perception, users can visualize superimposed virtual objects into real-world environments. Izadi et al. introduced an approach of physics-based interactions in augmented reality using depth data from a moving depth camera [4] based on structured light technique [5]. Tracking is required for persistent annotations in augmented reality. Multiple reviews have been made regarding tracking technology for virtual environments [6, 7].

In terms of building a virtual manual system, we need to add virtual annotations, such as 3D models and animations, and have them maintain persistent positions and rotations with respect to the physical target objects throughout and across each viewing session. Both

Project Tango and HoloLens use inside-out tracking, and structured light depth camera for depth perception. These approaches provide both portability and sufficient functionalities for building a virtual manual system.

3.3 Virtual Manuals

Multiple attempts have been made to build a virtual manual system in augmented reality. Caudell and Mizell introduced a prototype of using augmented reality technology in manufacturing process [8]. Kancherla et al. proposed an application of using augmented reality for teaching anatomy [9]. Boud et al. investigated the use of context-free augmented reality for the training of assembly tasks [10]. Aiteanu et al. developed an augmented reality helmet for manual welding process [11]. Many of the attempts showed promising results of using augmented reality. However, most of them were built for some specific tasks and required prototype equipment. The virtual manual system proposed in this research project aims to provide a general virtual manual system that is accessible to ordinary users for various purposes, and that could be built on commodity devices such as Project Tango or HoloLens.

CHAPTER 4

AUTHORING A VIRTUAL MANUAL

4.1 Overview

We first present a novel interface for authoring a virtual manual on the hand-held device Project Tango. This interface is developed with Unity game engine[1]. Each virtual manual consists of multiple steps that users can see, or users can create new steps through the interface. The steps consist of multiple augmented reality virtual annotations that represent the instructions of the manual. A list of available virtual annotations is presented at the bottom of the screen when authoring the steps, including (1) attach a different 3D model, such as a box or arrow, (2) attach 3D animations, such as a button-press animation, and (3) add virtual notes with custom text. This list may be customized to suit different needs when building the interface in Unity game engine.

Two primary steps are required when building a virtual manual. First, users need to localize the device with respect to the physical object that the manual is designed for, so that the virtual annotations can have persistent positions and rotations with respect to the object. Next, users can create virtual manuals by adding virtual annotations.

We choose Project Tango as our implementation device because it provides all the functionalities we need, and its familiar tablet interface allows users to perform actions easily. Users can select different options on the interface by simply tapping on the buttons on the screen. Attaching virtual annotations is similarly as easy as taping on the screen. The system will determine the actual 3D positions and rotations within the augmented reality using ray casting and real-time point cloud data.

[1] `https://unity3d.com/`

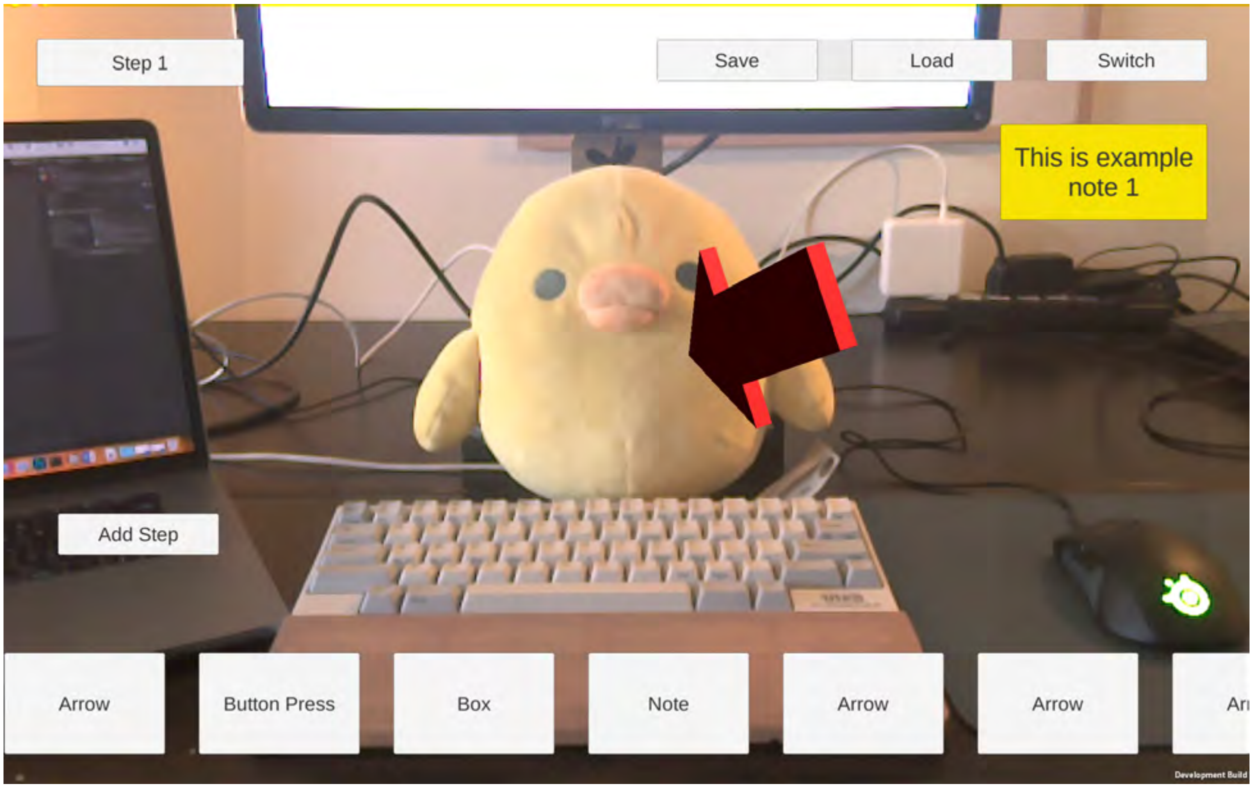

Figure 4.1: Preview of the authoring interface.

4.2 Localization

To have persistent positions and rotations for 3D models and animations that are used as instructions in virtual manuals, we need to localize the augmented reality devices before placing the virtual annotations. To build a virtual manual, it is natural to choose localizing our devices with respect to the real-world objects for which we want to build the manual.

The point cloud data of the target object is first collected using Project Tango, which are then cleaned and used to generate mesh data using MeshLab[2]. This mesh data is then built into our virtual manual system for registration of the real-world object and localization of the device. To accomplish this registration, we perform the iterative closest points (ICP) algorithm [12] on the real-time point cloud data and the mesh data.

Figure 4.2 demonstrates the process of registering the mesh of a puff toy to the real-world object. The mesh data of the puff toy is collected beforehand and loaded into the application

[2]http://www.meshlab.net/

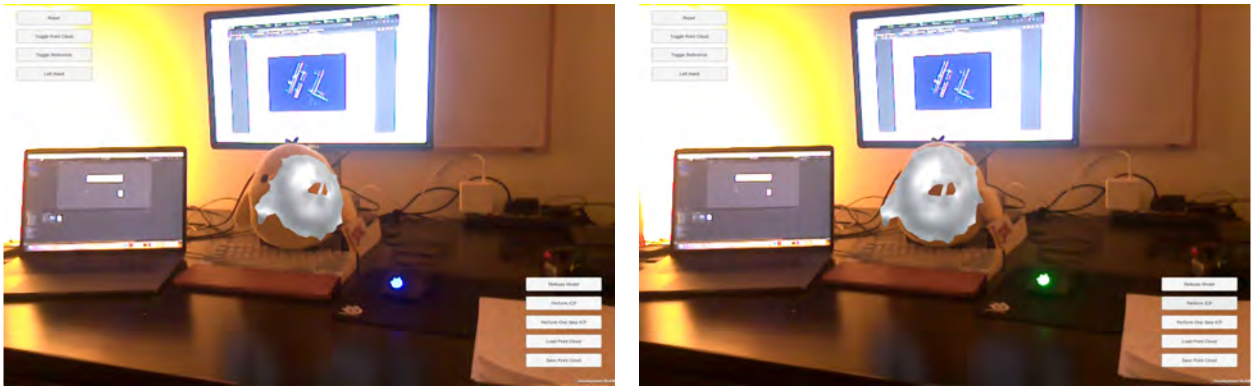

Figure 4.2: Mesh of a puff toy before registration (left). The same mesh after registration using the ICP algorithm (right).

at launch. As shown in the left picture, the mesh is fixed at the center of the screen before registration so that users can roughly align the mesh to the real-world target. This rough alignment of the mesh and real-world target is needed to obtain good results from the ICP algorithm. Next, users can press the button at the bottom right corner to start the ICP process. The mesh will be aligned as closely as possible during the process. The picture on the right in the figure shows the final result of the registration. At this point, the device is localized with respect to the target object. All virtual annotations, including 3D models and animations, that we add after localization will have persistent positions and rotations with respect to the target object.

4.3 Main Interface

After the device successfully localizes itself with respect to the target object, the authoring of the virtual manual may begin. We develop an interface on Project Tango that covers the elements that could be obtained from a traditional paper manual but more intuitively.

Figure 4.3 overviews the primary interface for authoring the manual. There are four major regions of the interface:

1. *Steps Panel*. Located at the left of the screen, each step consists of multiple virtual annotations to guide users through the virtual manual. Users can create a new step by pressing the Add Step button located at the bottom of this panel. A new step

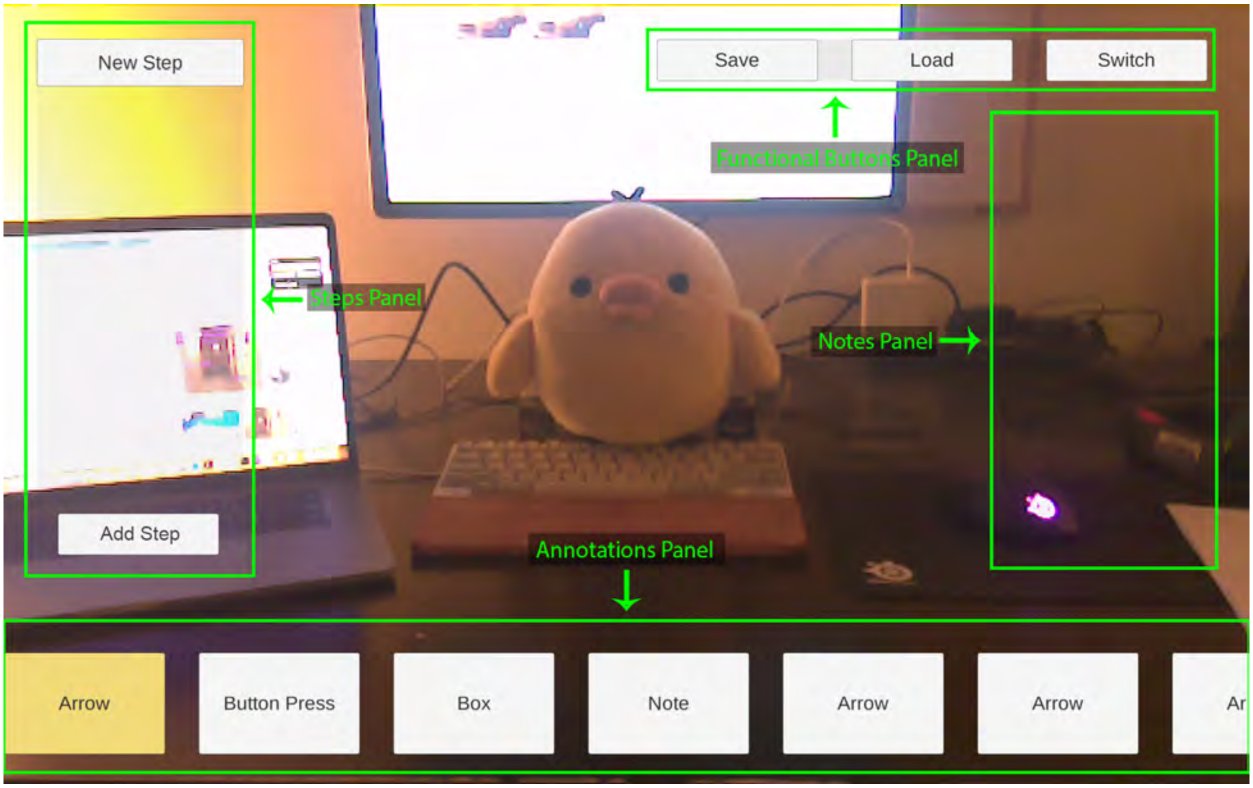

Figure 4.3: The main interface for authoring a virtual manual.

button will be created with the default name New Step,' and be added to the steps list starting from the top of the Steps Panel. Users can navigate existing steps by pressing these step buttons. Users can also press and hold a step button to change its text.

2. *Annotations Panel*. Located at the bottom of the screen, the pre-defined virtual annotations are listed. Users can select what virtual annotations they want to add to the current step. Examples of virtual annotations include 3D arrows, boxes, button-press animations and virtual notes.

3. *Notes Panel*. Located at the right of the screen, the notes that are added from the Annotations Panel are displayed. When users tap on the note button in the Annotations Panel, they are offered the opportunity to choose from some preset texts. After the note is added to the note panel, users can press and hold on a note to change its text.

4. *Functional Buttons Panel*. Located at the top right corner of the screen, this panel

includes buttons for saving and loading virtual manuals. Users can also press the switch button to toggle on or off all other buttons and panels to see only the virtual annotations.

4.4 Workflow

A typical workflow of authoring a virtual manual would be as follows:

- The user creates a new step using the Steps Panel; then the step name is changed by pressing and holding the step button.
- The user selects a 3D model or animation from the Annotations Panel, which is added by tapping on the screen location where they want it placed. The actual 3D positions and rotations of the 3D model or animation in augmented reality will be determined by ray casting to the real-time point cloud data provided by Project Tango.
- The user modifies a 3D model or animation, such as changing its color or removing it, by tapping on the model.
- The user adds a virtual note by pressing the Note button in the Annotations Panel and selecting from the preset text content.
- The user modifies the note's content by pressing and holding on the note in the Notes Panel.
- The user adds more models, animations, and notes to create a comprehensive virtual instruction for this step. The user creates more steps with virtual instructions to create a complete virtual manual.

4.5 Limitations

This interface does not currently support advanced modification to the 3D models and animations. All models and animations are developed beforehand and built into the ap-

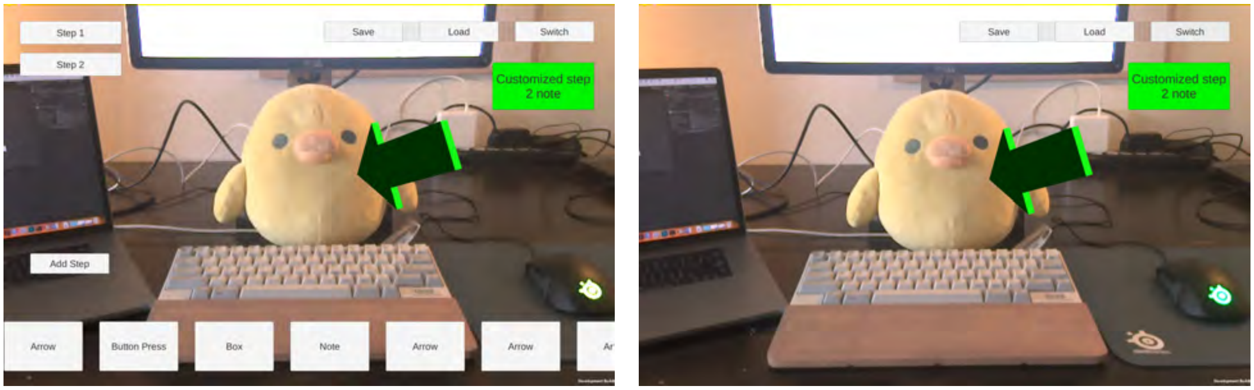

Figure 4.4: A 3D arrow is added and modified to a green color along with a customized green virtual note (left). The panels are hidden by pressing the switch button to obtain a clearer view of the virtual annotations (right).

plication as defaults. Authoring with advanced modification functions will require a more sophisticated 3D editing interface, which is neither feasible nor desired for a mobile tablet device because of both hardware and software limitations. On the other hand, users can always place complicated 3D models and animations directly into the Unity game engine with respect to the target mesh data and build these into the application.

CHAPTER 5

A VIRTUAL MANUAL FOR PRINTER

5.1 Overview

We create a sample virtual manual using the Unity game engine to demonstrate the process of using such a virtual manual and how it presents it in a more visually intuitive way compared to a traditional paper manual. The mesh data is collected beforehand, and 3D models and animations used as instructions are placed with respect to the printer mesh model. For the simplicity of demonstration, most of the instructions are simple cubes, arrows, or arrows with simple animations. Figure 5.1 shows the mesh model used in this virtual manual along with virtual annotations in the Unity Editor.

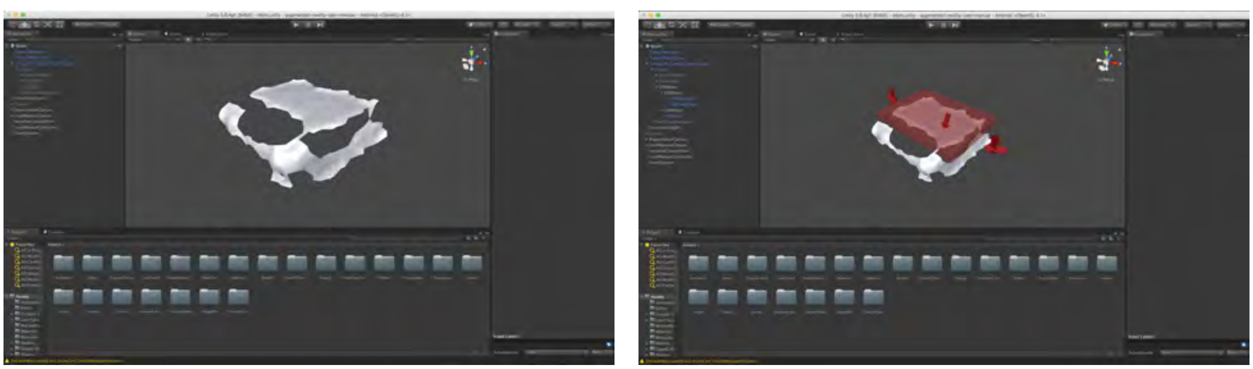

Figure 5.1: The mesh model collected beforehand and used for registration (left). Virtual annotations overlaid on the mesh model (right).

5.2 Registration

As mentioned in Section 4.2, users need to localize the device by registering the mesh data to the real-world target object to obtain the correct persistent positions and rotations for the 3D models and animations with respect to the target object.

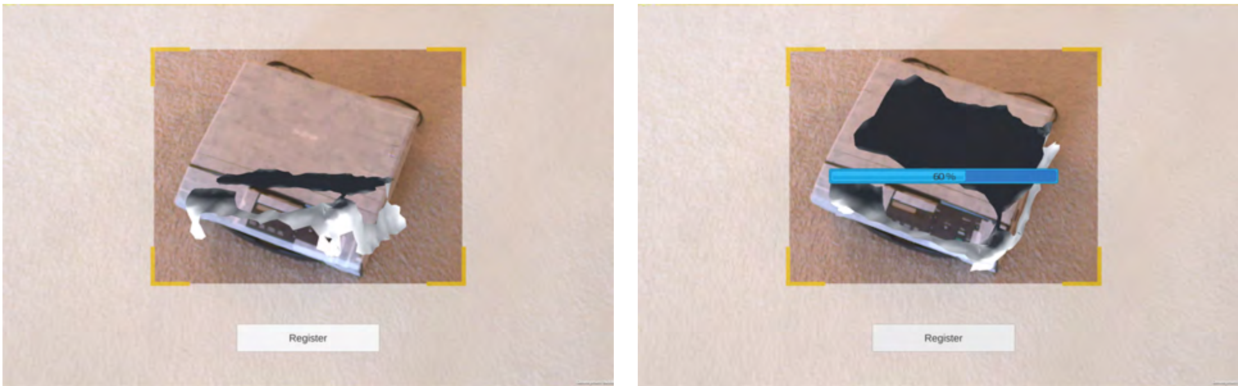

Figure 5.2: The initiation of registration (left). The registration process in progress (right).

Figure 5.2 shows the process of registering mesh data of a printer to the real-world target. Notice the printer surface is covered by white paper tape to reduce surface reflection, which is necessary to obtain better point cloud data from the infrared sensor, resulting in a better alignment and registration result from the ICP algorithm.

A framed rectangular area along with the mesh model of the printer is presented on the interface to guide users to roughly align the mesh to the real-world target at the beginning of the registration process. Users press the register button on the bottom of the screen to start the ICP process, and a progress bar will appear representing the progress of ICP algorithm.

5.3 Virtual Manual

After registration, virtual annotations are presented as instructions for each step in the virtual manual to guide the user. Figure 5.3 shows multiple steps in this virtual manual guiding users to find the USB port in the printer. The picture on the top left shows two arrows pointing to positions users should locate for the following step. After users press the Next Step button, they will see a simple animation instructing them to hold the positions they locate previously to lift the lid (top right picture). The bottom left picture shows the result after lifting the lid. Another arrow pointing to the USB port will be shown after users press the Next Step button again (bottom right picture).

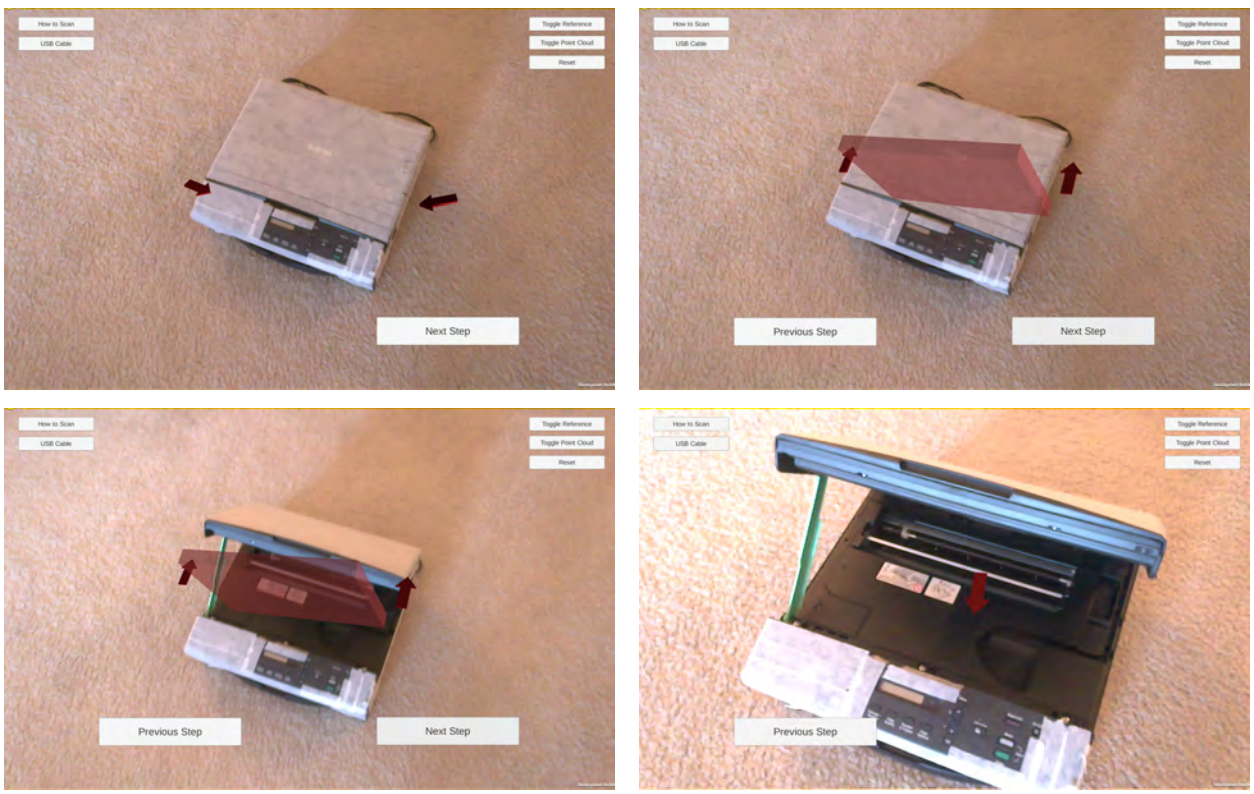

Figure 5.3: Multiple steps with virtual annotations guiding users to find the USB port on the printer.

5.4 Limitations

As we can see from Figure 5.3, virtual annotations are not perfectly aligned to the physical object, which is caused by small errors when the system registers the printer mesh data. We will not be able to perfectly register the mesh data to the real-time point cloud data because the real-time point cloud data from Project Tango is relatively sparse and always changing. So, there will always be some small errors in positions and rotations. There may also be small errors when the virtual annotations are placed with respect to the printer mesh within the Unity Editor. Therefore, at this time, precise instructions can be difficult to make in virtual manuals.

CHAPTER 6

TOWARDS MORE COMPLEX MANUALS

6.1 Verification Mechanism

In Chapters 4 and 5, we presented a novel interface for authoring and viewing virtual manuals. We demonstrated the use of such a virtual manual and how it can provide a more visually intuitive approach to read a manual compared to a traditional paper manual.

An additional advantage mentioned in Chapter 3 not included in the sample virtual manuals is the verification mechanism. This feature would be valuable for more complex manuals that involve complicated user actions. An example would be manuals for assembling flat packed furniture. The complex nature of this type of manual often makes it unavoidably confusing at some point in the instructions. This complex type of manual would be a perfect candidate to be translated into a virtual manual. Along with providing a more visually intuitive instruction process using 3D models and animations, a virtual manual could offer a verification mechanism to check if the user followed the instructions correctly, and provide feedback in real-time. This feature would be helpful and significantly increase the success rate of performing this type of task that requires accurately following the manual's instructional steps.

6.2 Registration

Building such a virtual manual requires recognition and registration of all flat wood pieces used for assembling the furniture. However, most of these parts share a similar simple cuboid shape, which makes it impossible to distinguish and register using the ICP algorithm with sparse point cloud data available from Project Tango. We solve this problem by attaching 2D square barcode markers [13, 14] onto the surface of the target object.

6.3 Disadvantages of Hand-held Devices

Hand-held devices, such as Project Tango, can provide sufficient functionality for a virtual manual providing marker recognition. However, this means that, while assembling the furniture, users need to hold the tablet to view and follow the instructions and allow the tablet to perform the marker recognition through its camera. Certainly, this will become inconvenient for users as both hands are typically required during furniture assembly.

We explored the option of setting up the tablet in a fixed position with the camera facing the working area, so it could recognize the markers. An external display was connected to the tablet for users to view instructions. However, users lose the advantage of being able to hold the tablet and view 3D models and animations from different angles. Also, Project Tango has difficulty in recognizing the markers at far distances and small angles because its camera's resolution is relative low and it needs to be far away enough so that its camera can cover the entire working area.

6.4 Explore More Design Spaces

A head-mounted device, such as the HoloLens, could provide a natural solution to this issue. Unlike hand-held tablet devices, users wear the device on their head making it much easier in this case as users are free to use both hands for assembling the furniture while still being able to see the virtual manual in the display.

In addition, since the device is not in a fixed position, the advantage of viewing 3D models and animations from different angles is again available. Since the device is worn and the camera on the HoloLens moves with the user's head, the markers should be easier to identify because the users would be close enough while following along with the virtual manual.

CHAPTER 7

A VIRTUAL MANUAL FOR ASSEMBLING FURNITURE

7.1 Overview

We create a sample virtual manual using the Unity game engine for assembling flat packed furniture. This virtual manual is built for the HoloLens as a proof-of-concept to demonstrate the abilities to perform marker-based registrations and verification in virtual manuals with head-mounted devices. We explore the design space of using markers in virtual manuals and build such a virtual manual for head-mounted devices.

7.2 HoloLens User Experience

The user experience on the HoloLens is very different from the user experience on Project Tango, which shares the same user interface as smartphones and tablets to which users should be easily accustomed. On the other hand, the HoloLens features a different user interface as it does not include a touchscreen, and users select items through an augmented reality by looking in the appropriate direction along with a combination of gestures.

7.3 Models and Animations

Multiple models and animations are created for each assembling step using 3ds Max modeling software[3]. These 3D models and animations are created to mimic the physical objects and assembling process. When they overlay on the target objects, users should have an intuitive understanding of the assembling step. Users can navigate the manual with gaze and gesture inputs on the HoloLens.

[3] `https://www.autodesk.com/products/3ds-max/overview`

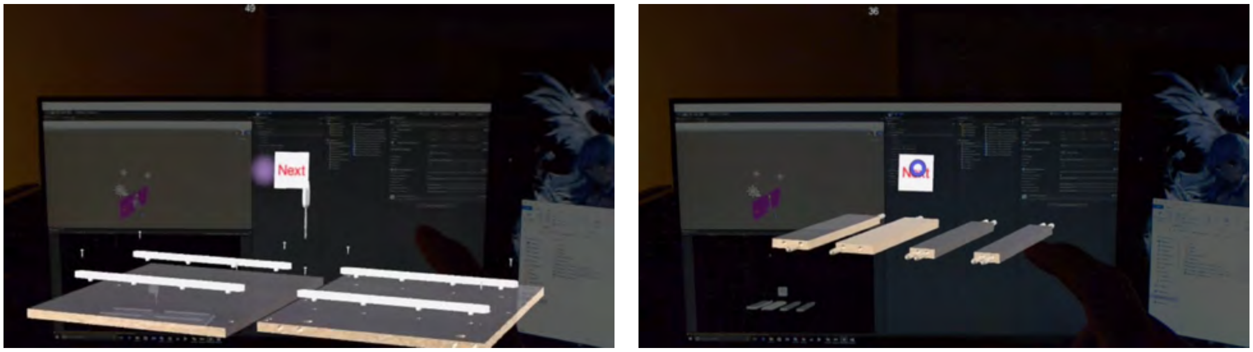

Figure 7.1: 3D models with animations showing the assembling instructions (left). A second step in the virtual manual (right).

Figure 7.1 shows two assembling steps in the virtual manual. 3D models and animations are created to demonstrate the process of adding plastic pieces and screws into the wood piece. The user was looking in the direction slightly left to the next bottom as indicated by the pink dot in the left picture. The picture on the right shows a subsequent next step in the virtual manual after the user moved his gaze onto the next button, as indicated by the blue circle, and clicked the button using a gesture.

7.4 Marker-based Registration

As described in Section 6.2, it is difficult to register flat wood parts in a furniture assembly without the use of extra tools, such as 2D barcode markers. We choose the open source library, ARToolKit[4], for the marker recognition, and the specific version used in this research project is `https://github.com/qian256/HoloLensARToolKit`, which is a modified version of ARToolKit built for the HoloLens. A cube is added on the top of each marker in the virtual manual to demonstrate the registration results.

Figure 7.3 shows the result of attaching a marker to a wood piece to register it in our virtual manual. The exact position of the 3D furniture models and animations relative to the marker is adjusted when the virtual manual is created in the Unity game engine to mimic their relative position in relation to the real world.

[4] `https://artoolkit.org/`

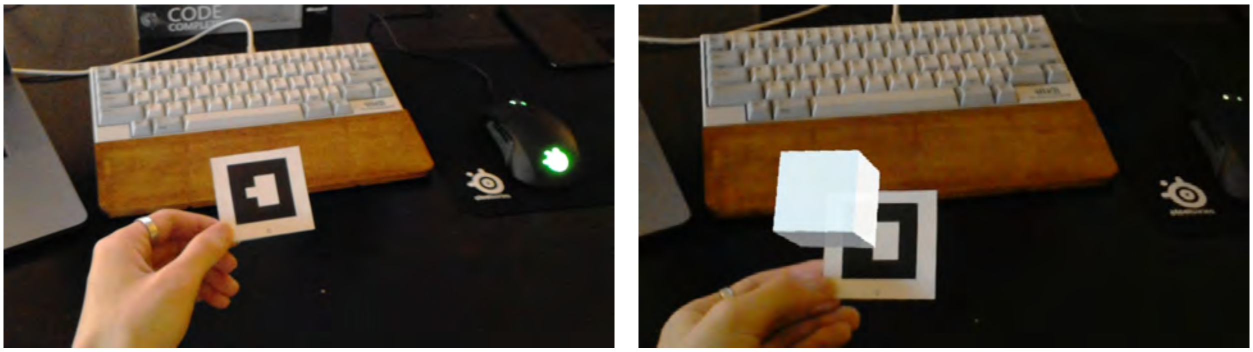

Figure 7.2: The type of markers used in this project (left). The registration result represented by a cube overlay on the top of the marker (right).

Figure 7.3: 3D models with animation registered to the physical objects with a marker.

7.5 Verification Mechanism

7.5.1 Markers

The verification mechanism is made possible by the use of multiple markers. We use the cube created for each marker to verify if users followed the virtual manual correctly and assembled the correct pieces as expected. When two cubes overlap, the verification system checks if this overlap is found in the preset data in the application, and then presents the corresponding correct or incorrect sign to the user on top of the marker. This type of checking can be added to each step in the virtual manual to ensure users correctly perform each step when assembling the furniture.

Figure 7.4 shows the process and results of verification between markers where two combinations of markers are presented in the figure. On the top row, a collision, or overlap, of the cubes caused by the combination is correct according to our preset data in the application. A correct sign (the green sphere) is shown to the user to communicate they are performing correctly. The collision in the bottom row is not correct according to our preset data, so an incorrect sign (the red sphere) is presented to the user.

7.5.2 An Example

Figure 7.5 shows the verification results when the markers are attached to the furniture pieces. Notice the difference between the two images. Two different markers are attached to the two different sides of the vertical furniture piece in the images. In both images, cubes are created on top of the markers. The collision in the left image is correct according to our preset data in the application, and a correct sign is shown to the user, which indicates the user is inserting the furniture piece in the correct direction. An incorrect sign is shown in the image on the right according to the preset collision data, which indicates the user is inserting the furniture piece in the wrong direction.

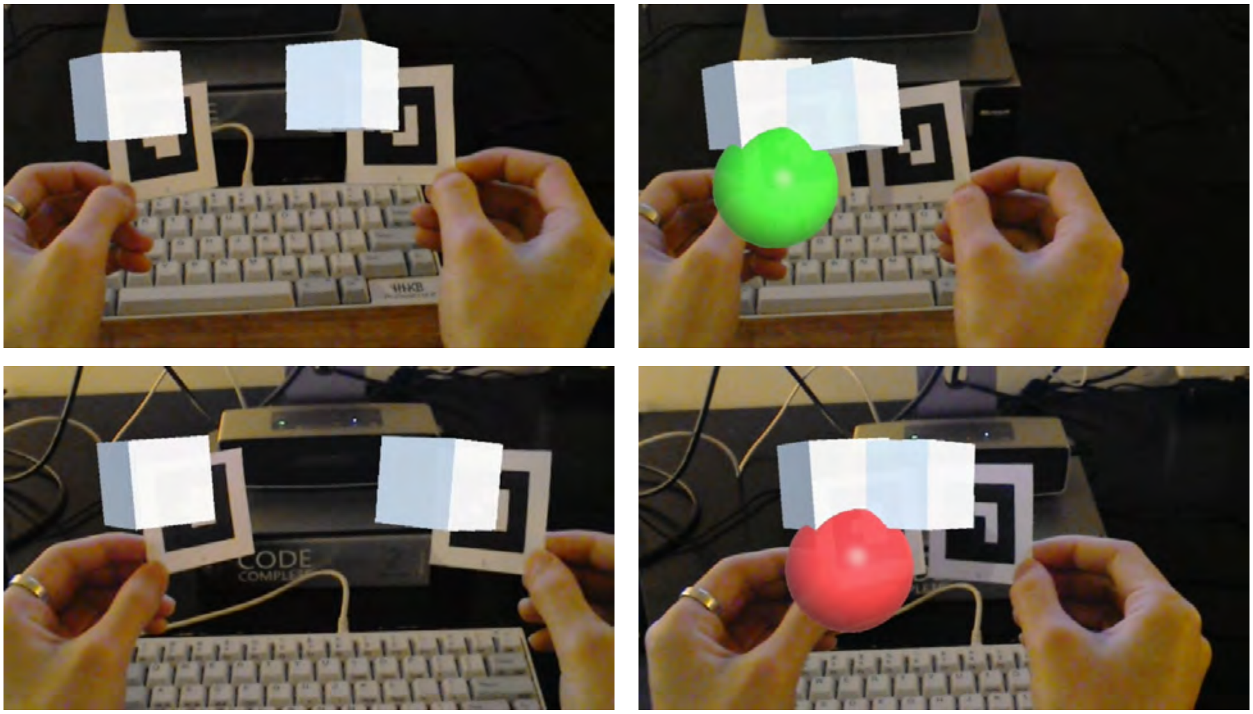

Figure 7.4: Two markers with cubes overlapping (top left). The correct sign (green sphere) is shown on top of the maker (top right). Using a different combination of makers (bottom left), the incorrect sign (red sphere) is shown on top of the marker (bottom right).

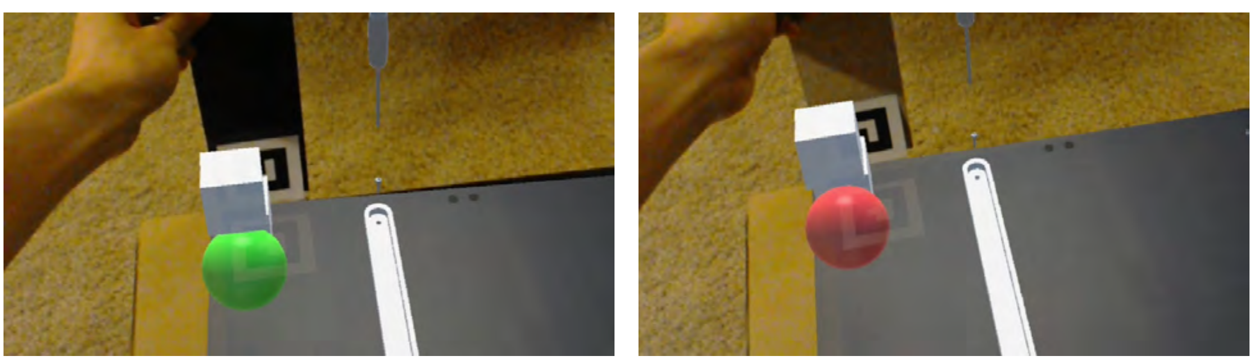

Figure 7.5: Markers attached to the furniture pieces for detecting the assembly. (1) The correct combination of markers (left), and (2) incorrect combination of markers (right).

7.5.3 An Advanced Example

Cubes created for the markers do not have to be located on the top of the markers. A constant offset of the positions of the cubes can be configured with respect to the positions of the markers to allow for more complicated verifications that cannot be achieved by simply detecting collisions of cubes on top of markers.

Figure 7.6 shows an example where a furniture piece should be at some distance above the bottom piece, and we want to detect if users are placing the correct piece in the correct direction. The picture on the left shows the top furniture piece with a marker on it. A cube is created for this marker positioned at some distance below the marker to match the distance that this piece should be above the bottom piece. The picture on the right shows two cubes created by the markers colliding, which then results in a correct sign appearing on the top marker based on our preset data.

Figure 7.6: A cube is created below the marker (left). Two cubes collide with each other, and a correct sign is shown.

7.6 Limitations

Because of the nature of assembling furniture pieces in 3D space, users will often be at positions where markers are occluded by other furniture pieces, or at very small angles to the camera, even if we carefully design where to attach the markers. This geometric issue makes the system very difficult to provide accurate and stable recognition of markers. The problem could be minimized by using larger markers. However, this defeats the idea of building a verification system in the virtual manual because users could tell the difference between different markers if markers are so much larger.

Moreover, the fact that markers must be used for recognition is not ideal. Some small objects, such as assembly screws, are not possible to have markers attached, which makes these parts impossible to track in the system. Also, additional setup is required to attach the markers to the physical objects along with the configuration of preset data related to the verification between different combinations of markers, which complicates the authoring process.

CHAPTER 8

FUTURE WORK

8.1 More General Use

Although Project Tango and HoloLens are available in the marketplace today, they are still considered devices built specifically for augmented reality. Also, HoloLens is relatively expensive compared to mainstream consumer electronics. Many consumer platforms, like iOS and Android, have recently released their augmented reality development toolkits to provide functionalities needed for simple augmented reality tasks. Because of these advancements, it would be beneficial if a virtual manual system is made available on these platforms.

CHAPTER 9

CONCLUSION

In this paper, we proposed a virtual manual system for users to author and view a virtual manual. We explored the design spaces for building such a system on multiple augmented reality devices.

Multiple advantages of a virtual manual compared to a traditional paper manual were discussed throughout the paper along with limitations. A novel interface was presented to show how users can author a virtual manual on Project Tango. A sample virtual manual for a printer was developed to demonstrate how users can view a virtual manual with virtual annotations. An advanced feature for verifying users' actions was demonstrated and discussed with a sample virtual manual for assembling flat packed furniture.

We conclude that although having such a virtual manual system with advanced features could benefit users on many aspects, certain limitations and engineering obstacles, which both head-mounted devices and hand-held devices cannot overcome presently, prevent us from fully utilizing the potential of this kind of system.

REFERENCES

[1] R. T. Azuma, "A survey of augmented reality," *Presence: Teleoperators and virtual environments*, vol. 6, no. 4, pp. 355–385, 1997.

[2] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, "Recent advances in augmented reality," *IEEE computer graphics and applications*, vol. 21, no. 6, pp. 34–47, 2001.

[3] J. Carmigniani, B. Furht, M. Anisetti, P. Ceravolo, E. Damiani, and M. Ivkovic, "Augmented reality technologies, systems and applications," *Multimedia Tools and Applications*, vol. 51, no. 1, pp. 341–377, 2011.

[4] S. Izadi, D. Kim, O. Hilliges, D. Molyneaux, R. Newcombe, P. Kohli, J. Shotton, S. Hodges, D. Freeman, A. Davison, and A. Fitzgibbon, "Kinectfusion: Real-time 3d reconstruction and interaction using a moving depth camera," in *Proceedings of the 24th Annual ACM Symposium on User Interface Software and Technology*, ser. UIST '11. New York, NY, USA: ACM, 2011. [Online]. Available: http://doi.acm.org/10.1145/2047196.2047270 pp. 559–568.

[5] B. Freedman, A. Shpunt, M. Machline, and Y. Arieli, "Depth mapping using projected patterns, oct 2008," *WO Patent WO/2008/120217*, 2008.

[6] Y. Baillot, L. Davis, and J. Rolland, "A survey of tracking technology for virtual environments," *Fundamentals of wearable computers and augumented reality*, p. 67, 2001.

[7] L. Yi-bo, K. Shao-peng, Q. Zhi-hua, and Z. Qiong, "Development actuality and application of registration technology in augmented reality," in *Computational Intelligence and Design, 2008. ISCID'08. International Symposium on*, vol. 2. IEEE, 2008, pp. 69–74.

[8] T. P. Caudell and D. W. Mizell, "Augmented reality: An application of heads-up display technology to manual manufacturing processes," in *System Sciences, 1992. Proceedings of the Twenty-Fifth Hawaii International Conference on*, vol. 2. IEEE, 1992, pp. 659–669.

[9] A. R. Kancherla, J. P. Rolland, D. L. Wright, and G. Burdea, "A novel virtual reality tool for teaching dynamic 3d anatomy," in *computer vision, virtual reality and robotics in medicine*. Springer, 1995, pp. 163–169.

[10] A. Boud, D. J. Haniff, C. Baber, and S. Steiner, "Virtual reality and augmented reality as a training tool for assembly tasks," in *Information Visualization, 1999. Proceedings. 1999 IEEE International Conference on*. IEEE, 1999, pp. 32–36.

[11] D. Aiteanu, B. Hillers, and A. Graser, "A step forward in manual welding: demonstration of augmented reality helmet," in *Mixed and Augmented Reality, 2003. Proceedings. The Second IEEE and ACM International Symposium on*. IEEE, 2003, pp. 309–310.

[12] P. J. Besl, N. D. McKay et al., "A method for registration of 3-d shapes," *IEEE Transactions on pattern analysis and machine intelligence*, vol. 14, no. 2, pp. 239–256, 1992.

[13] J. Rekimoto, "Matrix: A realtime object identification and registration method for augmented reality," in *Computer Human Interaction, 1998. Proceedings. 3rd Asia Pacific*. IEEE, 1998, pp. 63–68.

[14] M. Fiala, "Artag revision 1, a fiducial marker system using digital techniques," *National Research Council Publication*, vol. 47419, pp. 1–47, 2004.