Assembly of the Virtual Model with Real Hands Using Augmented Reality Technology

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Abstract. In the past few years, studying in the field of Augmented Reality (AR) has been expanded from technical aspect such as tracking system, authoring tools and etc. to applications ranging from the fields of education, entertainment, medicine to manufacturing. In manufacturing, which relies on assembly process, AR is used for assisting staffs in the field of maintenance and assembly. Usually, it has been used as a guidance system, for example using graphical instructions for advising the users with the steps in performing the maintenance or assembly operation. In assembly training, especially for small, expensive or harmful devices, interactive technique using real hands may be suitable than the guiding technique. Using tracking algorithm to track both hands in real time, interaction can occurs by the execution of grasp and release gestures. Bare hand tracking technique, which uses gesture recognition to enable interaction with augmented objects are also possible. In this paper, we attempted to use marker based AR technique to assemble 3D virtual objects using natural hand interaction. By applying the markers to fit on fingertip and assigned the corresponding virtual 3D finger that have physical properties such as surface, volume, density, friction and collision detection properties to them, interaction between fingers and objects could be executed. This setup was designed on a PC based system but could be ported to iOS or Android, so that it would work on tablet or mobile phones as well. Unity 3D game engine was used with Vuforia AR platform. In order to grab and move the virtual object by hand, the shape of the virtual finger (Vulforia's target) has been investigated. Appropriate friction coefficient were applied to both virtual fingers and the object and then at least two virtual fingers were force to press on the 3D virtual object in opposite directions so that frictional force is more than gravitational force. To test this method, virtual model of LEGO's mini-figures which composed of five pieces, was used and the assembly could be done in just a short time. Comparing with other popular technique such as "gestures recognition", we have found that our technique could provide more efficient result in term of cost and natural feeling.

Keywords: Augmented Reality, Manufacturing, Assembly Process, Virtual Object Assembly.

1 Introduction

The goals of Augmented Reality (AR) assisted assembly are to make assembly training more effective in terms of time used, cost and being able to interact naturally.

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In the manufacturing field, AR-based assembly system can be grouped into two categories i.e. AR-based guidance assembly and AR-based assembly training. In AR-based guidance assembly, the assembly is guided by texts or graphics to assemble parts, for example, placing texts, graphics or 3D models on top of real world machines and explaining or creating animations of how to work on the real machine step by step. Some automobile manufacturers are planning to use this technology as a means to assist service staffs in their technical work. Using AR in assisting assembly as a guiding system is proving to be very useful for assembling large and complex equipment. This technique has gained popular acceptance for real time assembly and real time maintenance processes for the last few years. For AR-based assembly training, AR is used to create an environment for assembly training. In this case, the emphasis is based on how to make the assembly process more realistic like performing them in real life. Researches on applying physical properties to the virtual objects to help assembly more naturally had been done and proved to be easy in training, but it still lacks of the "touch" feeling which may be necessary in some experiments. In order to make the training more natural, the users must learn from practicing with their own hands. Bare hand tracking technique, which uses gesture recognition to enable interactions with augmented objects was used by many researchers. By using tracking algorithm to track hands or fingers in real time, interaction may occur by the execution of grasp and release gestures. Even though, this technique seem to be suitable for assembling small devices which are usually assembled by hand but more work needs to be done in terms of easiness to use, precision and response time.

2 Related Work

Researches in the area of Augmented Reality assisting Assembly process have been done for quite some time. Pathomaree N. [1] used graphical instructions and virtual objects for advising the user with the assembly steps and the targeted positions in assembly task. This research also indicated whether the user performed actions correctly or not. Wang Y., et al. [2] had studied several key aspects in AR-based assembly system such as occlusion handling, collision detection and human-computer interaction. A prototype system was implemented to illustrate on how to apply these techniques. An example of AR assisted assembly had been developed by Woll, R., et al. [3], as a serious game for teaching an apprentice mechanic about the components of car's power generator and how these components were assembled. The application has been implemented on smart phone running the Android operation system. With AR technology, users could obtain interactive experiences in the spatial arrangement of components. Tang, A. et al. [4] had evaluated the effectiveness of spatially overlaid instructions using augmented reality (AR) in an assembly task comparing with other traditional media such as user manual and CAI. Results indicated that by overlaying 3D instructions on the workspace, reduction time could be reduced by 10-15% with the error rate of 82%, particularly in cumulative errors. All of these researches gear towards assisted assembly by using AR as guidance in improving speed and quality of assembly processing. For improving skill in assembly, users must be able to perform the assembly process in real environment or at least feel like performing in real one and AR can fit in this situation. Using AR, users can obtain experiences in performing assembly tasks in both real and virtual space. Besides that, users can practice at any time and any place with a minimum cost of performance. Therefore, many users can gain more experiences in assembly process at one time. To make AR assisted assembly more realistic, researchers have used many techniques. Boonbrahm, P. et al. [5] had applied physical properties to the virtual objects to help assembly more natural. This technique had been done and proved to be easy to train users in performing assembly processes, but it still lacks of the "touch" feeling which may be necessary in some experiments.

In order to interact with virtual objects with real hand, either bare hand or with some special equipment, many techniques were introduced by other researchers and our research is related or based on those earlier works. Lee, M., et al. [6] had developed a 3D vision-based natural hand interaction method based on hand direction calculation and collision detection between the user's hand and augmented objects. Results showed that users would have a seamless interaction in AR environments with the tracking accuracy of the hand interaction varied from 3mm to 20 mm depending on the distance between the user's hand and the stereo camera. The drawbacks were that, by using a single finger for interaction, there were some error from calculation and the application was limited. Bare hand tracking technique, which uses gesture recognition to enable interaction with augmented objects are also possible. Wang, Z.B., et al. [7] developed an effective hand segmentation method based on a Restricted Coulomb Energy (RCE) neural network for bare hands interaction in the AR assembly environment. An experiment using two fingertips to control virtual objects to simulate assembly in a 2D space was conducted. The results demonstrated that the proposed bare-hand interaction method was robust and effective. But since the fingertips tracking algorithms were executed in a 2D space, there was no depth information. Li, Y. and Shen, X. [8] studied on how users interacted with virtual objects by hands using the real-time collision detection between virtual and real objects based on 3D tracking of hand. Using a pair of common web cameras to collect images and track the points on hands which were marked by color blocks, then the stereo vision calibration algorithm was achieved. Finally, the accurate collision detection was achieved by calculating the relative positions between real hand and virtual objects real-time. Choi, J [9] proposed an augmented reality interface that provided natural hand-based interaction with virtual objects on mobile phones. The proposed method consisted of three steps: hand detection, palm pose estimation, and finger gesture recognition. A virtual object was rendered on his/her palm and reacted to hand and finger movements. The most popular technique for real hand interaction in AR, is tracking hands in real time. The interaction between hands and virtual objects occurs by the execution of "grasp and release" gestures. Figueiredo, L., et al. [10] proposed and evaluated a solution for direct interaction with augmented objects on tabletop applications through hand tracking and gesture recognition. Kinect device was used for hand tracking and the interaction was performed by a grasp and release gesture recognized by the distance between thumb and forefinger. If there was an augmented object within the region between these fingers points and the evaluated distance was short enough, the object was grabbed. But if the distance increased the object was released.

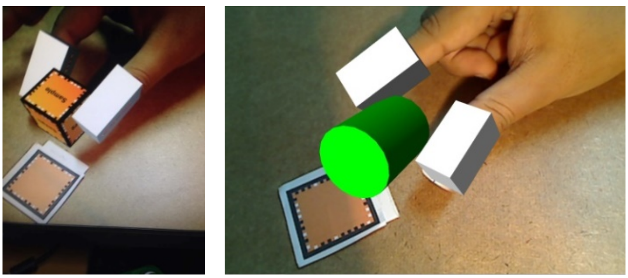
Even though, these techniques seem to be suitable for the assembly of small devices that are usually assembled by hand but some setup still need special equipment or special setup which is too complicate to be done easily. In order to make virtual assembly training more efficient for users, it is still needed more work done in term of easiness of use, precision and response time.

3 System Development

In this paper, we attempted to use marker based AR technique to assemble 3D virtual objects using natural hand interaction. By applying the markers to fit on fingertip and assigned the corresponding virtual 3D finger which had physical properties such as surface, friction, volume, mass and collision detection properties, interaction between fingers and virtual objects could be executed. This technique was similar to "grasp and release" gestures. But instead of using image recognition concept, interaction between objects that had physical properties was used. In this setup, Unity 3D game engine was used on Vuforia platform. Unity is a fully integrated development engine for creating games and other interactive 3D content. Qualcomm's Vuforia platform made it possible to write a single native application that run on almost all smartphones and tablets. In order to grab the virtual object by hand, friction were applied to the surface of both virtual fingers and of the object and then at least two virtual fingers (thumb and index finger) were forced to press on the 3D virtual object in opposite direction. Since there were forces applied to the virtual object and with some appropriate friction between the surfaces of virtual object and virtual fingers, lifting the object could be done easily. Moving the object around was possible by moving the hand to the destination point. Details of the setup could be divided into 3 steps as follows.

3.1 Step 1: Create a Virtual Fingers

In Vulforia, targets that were representatives of real-world objects, which could be detected and tracked, occurred in many types such as image, cylinder, text or user-defined. In this case, we used cylinder target since it would fit in our fingers nicely. Besides that, the look and feelings were more realistic, which made them more natural in action. Rectangular shapes were suitable for grabbing rectangular virtual object since the surface contact between the two objects was large (see Fig.1(a)). Problems with this shape occurred when the surface of virtual object and the surface of the rectangular finger were not in paralleled or the contact surface were not large enough, like when grabbing the cylindrical virtual objects as shown in Fig. 1(b).



a) b)

Fig. 1. Grabbing virtual object with rectangular virtual fingers a) Rectangular shape object b) Cylindrical virtual objects

Using octagon shape of virtual fingers created another problem. Octagon shape had many edges. If one of the edges touched the virtual object, it would push the object away, making it hard to grab as shown in Fig. 2.

Fig. 2. Grabbing virtual object with octagon virtual fingers

Since the shape of the target make big impact on the grabbing situation, trying to make less edges and make the surface in parallel with the object surface as possible, seem to be the good decision. By making the target as a small flat surface attached to the markers, we have found out that it did not improve much in term of grabbing ability. The reason for this is due to the fact that the contact surface is too small to make it possible for grabbing and lifting as shown in fig. 3.

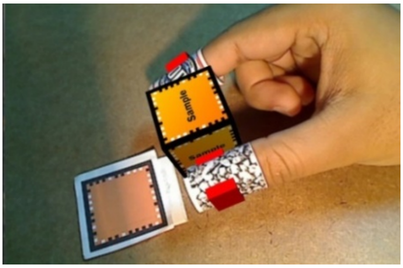


Fig. 3. Grabbing virtual object with cylindrical virtual fingers

For cylindrical shape target (called capsules), the shape look like the real finger, so it should be the perfect solution in term of realistic movement. Since the contact surface didn't improve much in this case, improving the cylindrical virtual finger which have the properties of rigid body, by adding another layer of low mass model on top of cylindrical shape virtual finger, make it easy to grab the virtual objects. This low mass layer performed as an elastic layer just like the real finger, make grabbing more realistic as seen in Fig. 4.

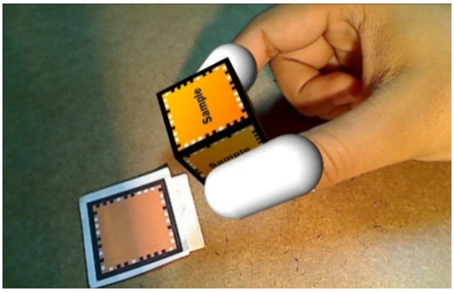


Fig. 4. Grabbing virtual object with 2 layers of cylindrical shape virtual fingers

3.2 Step 2: Apply Physical Properties to the Virtual Objects

Since the setup should give real experience in performing the assembly function such as lifting, dropping, moving the virtual objects, then both fingers and the assembly part should have physical properties. Adding the physical properties to the virtual object could be done on unity 3D platform, but precise calculation of a given values have to be done. For virtual object, in order to perform as a real object, mass, gravity force, frictional coefficient and rigid body properties such as collision detection have to be applied to the virtual object. For virtual fingers to be able to grab the virtual object, some physical properties for rigid body such as mass and collision detection have to be applied also. To make them more realistic, the virtual finger should have rigid body properties inside and elastic skin outside. With this setup, the virtual finger will have collision detection function to detect the object in contact and also have better grab due to the properties of the surface. To understand the situation, the forces applied to the objects are illustrated in Fig. 5.

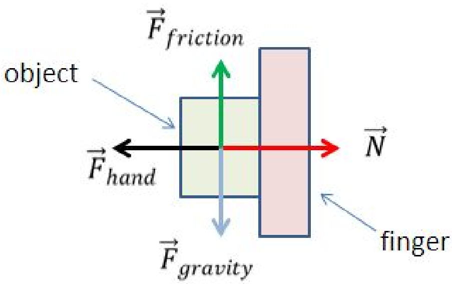


Fig. 5. The forces applied to the objects from finger grabbing

Since the virtual object, that will be grabbed, have weight (mass x gravity), it tends to drop due to the gravitational force. To grab the object and be able to lift it up without dropping it, the frictional force must be equal or higher than the force due to gravity.

$$F_{friction} \geq F_{gravity}$$

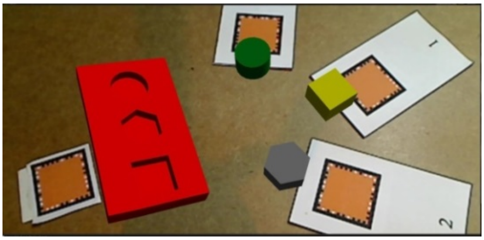
with

$$F_{friction} \leq \mu_s N$$

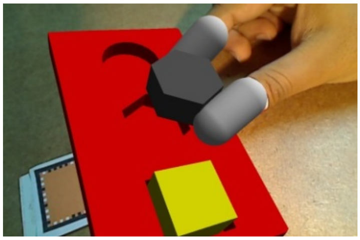
Since N is the force that the object react to the force applied by the virtual finger in opposite direction with equal amount and μ_s is the frictional coefficient that was assigned to the surface of the object, then we can control and make them equal or more than gravitational force. With the value of frictional force more than gravitational force, lifting or assembling the virtual objects by using two fingers can be done easily.

3.3 Step 3: Testing the Concept

Preliminary test of this method on different shape objects was done using "shape sorter" toy concept, in which we had to grab 3D virtual objects in the shape of cube, hexagon and cylinder, and placed them in the right "opening" spots. By placing different shape objects, one by one, in to the base, using two virtual fingers grabbing, we found that this could be done easily with the "touch" feeling.



a)



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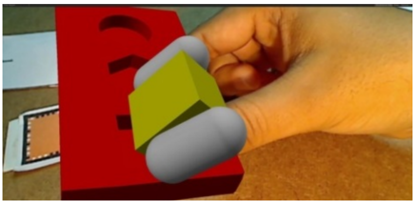
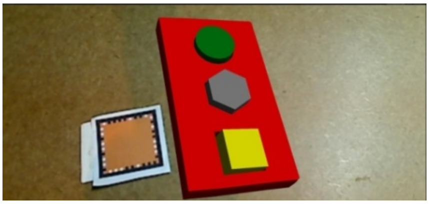


c)

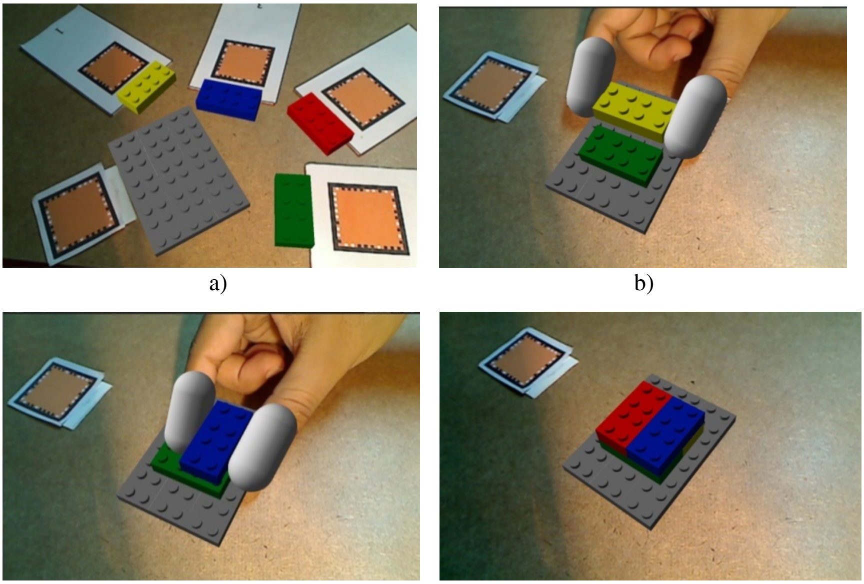


d)

Fig. 6. Testing the concept with "shape sorter" toy (a) "Shape sorter" base with 3 virtual objects (b) Placing hexagon into the base using 2 finger grabbing (c) Placing hexagon into the base (d) Finished process

To assemble a model with many parts, calculations on the direction, distance and matching procedure were made so that the matching parts could be "snapped" together. To test this assembly method, we simply used four virtual LEGO's blocks to form a rectangular block and the result was more than satisfied. These LEGO blocks were used because they had exact positions that can be snapped together when attached at the right position. Details of the assembly is shown in Fig. 7.

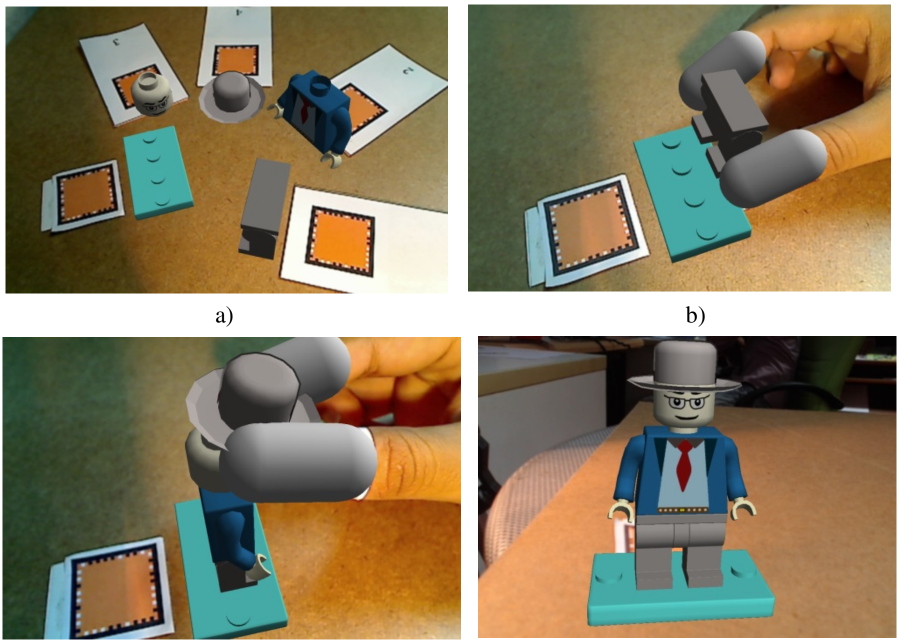
Attempting to try more sophisticated assemblies, virtual model of LEGO's minifigures which composed of five pieces of virtual parts, were used. The parts are base unit, leg unit, body unit, head and hat (as seen in Fig. 8 (a)). With two virtual fingers grabbing and "snap" technique, the assembly could be done in just a short time with the feeling just like assembling by real hand.



a) b)

c) d)

Fig. 7. LEGO's block assemble using "snap" technique (a) LEGO's base with 4 virtual LEGO blocks (b) Placing LEGO block's first layer (c) Placing LEGO block's second layer (d) Finished process



a) b)

c) d)

Fig. 8. LEGO's mini figure assemble (a) LEGO's mini figure parts (b) Placing the leg's part into the base (c) Placing the hat on (d) Finished process

4 Result and Discussion

Comparing the techniques used in this setup and other techniques used by other researchers, we have found that our techniques is more efficient in term of cost, effectiveness and easy to use. For example, in our setup, there is no need for extra equipment except webcam. In term of effectiveness and easy to use, since the virtual fingers is covered on the real fingers, making it felt like user's own fingers, so grabbing virtual object even a small one could be done naturally. In other popular technique such as "gestures recognition", we have found that our technique provided more natural feeling. This may be due to the fact that "grasp and release gestures" are executed in 2D space, so the information used for interaction with 3D virtual object has no depth. But in our experiment, both virtual fingers and virtual object are in 3D world so the interaction could occur in many dimensions. Besides that, there is no precision setup for special equipment such as kinect device or special cameras, setup time can also be reduced. And since this experiment is built on Unity 3D, porting them to other platform like iOS or Androids for running on tablets could be done easily.

5 Conclusion

This virtual fingers technique proved to be useful for assisting hand assembly of small devices because it provides the feeling of real manual assembly without using sophisticated devices, so training can be done many times until the technician understands and gains confidence in assembling real devices. The same concept can be applied for games that need the "natural touch" feeling like chess or other board games. In conclusion, with this technique, human-computer interaction in performing the assembly operation in the AR environment can be improved especially in "touch and feel".

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