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The Development of Furniture Assembly Instruction Based on Augmented-Reality

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***Abstract* -** This research utilized Augmented Reality (AR) technology along with interactive multimedia applications to improve visual guidance and assist non-expert users in assembling furniture. Rather than paper-based or video instructions, AR enhanced learning and manipulative-interactive approach. This research used the Waterfall model for development. It was divided into a couple of stages. It consisted of specifying the problem and requirements, designing the system, implementing and integrating it, and testing the system. Identifying problems and requirements was conducted through an online questionnaire and related works study. The graphics tool used was 3D Studio Max. Unity3d was used to develop the system with the software library from Qualcomm's Vuforia for the AR implementation. The results show the mobile application called ARsembly. It serves as the early stage of concept model as it only assists the simple assembly. Through system testing performed by both researchers and end-users, ARsembly is proven to be useful and helpful in learning and performing furniture assembly.

Keywords: Augmented Reality, furniture assembly instruction

I. INTRODUCTION

Furniture, such as sofas, chairs, tables, cabinets, wardrobe, shelves, or bed frames, is an essential part of completing interior designs. It holds many functions in human's daily life. Most of the time, these products do not come in their final forms. They are set inside a box and unassembled. For example, if a chair is made of eight parts (four legs, two armrests, one backrest, and one seat), inside each of this package, there will be these eight separated parts and tools to help with the assembly. The purpose of this is portability. Because some furniture is heavy and huge, it is easier to deliver a hefty unassembled product such as the sofa in separate parts than moving the whole thing in its final structure.

Despite the convenience of having it packed in separate pieces, the assembly part may have difficulty. It is especially to those who are not used to build furniture or do not have previous experiences from assembling the furniture that they are about to do. Even though the manufacturers facilitate the customers with assembly services performed by the trained operators, some customers choose to save their money and build it themselves. It can be done by following the printed manual instruction that generally comes together with the product. However, these common paper-based manuals are often found to be insufficient.

People commonly face problems such as the complexity of the product's structure and the assembling sequence itself. Seeing through images or reading every word in each step imprinted on a piece of paper is deemed to be ineffective. It is similar to learning by text-reading only. One part can be mixed up or confused with the other part. Not only common customers, even the operators themselves, may be struggling with this task. They are bound to the pressure of completing the assembling within a minimum time but with maximum quality results. If they are not experienced with that particular product, they will perform their task optimally. Thus, a more effective way is needed, such as using multimedia. Multimedia is considered as a powerful tool to convey information to people effectively. It has brought fundamental changes to the way people learn, play, and find information. Between multimedia and learning, there are 12 principles (multimedia principles) that can improve the learning process using multimedia presentations (Mayer, 2014).

To aid the users with the assembling task in a more efficient way, more advanced visual guidance can be engaged. By seeing themselves how the processes happen, it will tremendously help them to learn better how to do the assembly. For this objective, the usage of implementing Augmented Reality (AR) principle is studied. As an emerging technology, AR integrates three-dimensional (3D) images of virtual objects into a real-world workspace. By overlaying computer-generated information on the real world, AR amplifies human perception and cognition in remarkable ways. The insertion of digitalized information into the real workspace using AR can provide workers and customers with the ways to implement correct assembly procedures with improved accuracy and reduce errors (Syberfeldt, Danielsson, Holm, & Wang, 2015).

AR is a technology that has developed very well at this time. It can be used in various fields. AR is initially used for military technology, medicine, and personal entertainment. Its implementations have taken place in assorted fields such as gaming, medical, navigation, education, and tourism (Yesmaya, Dekapaswan, Aspurua, & Prasetyo, 2019). Pokemon Go is one example of AR implementation in the gaming industry. In the medical field, AccuVein is an AR handheld scanner that projects over the skin to show nurses or doctors the location of veins and their valves in patients' bodies. Yelp Monocle is an AR-enabled navigator to find and follow the shortest directions and path to the most regarded public places in the local vicinity.

AR enhances the user's information about their surroundings by creating a modified version of reality. It is enriched with digital information on the screen (Grubert & Grasset, 2013). Van Krevelen and Poelman (2010) defined that every AR system could combine real and virtual objects in a real environment, register (align) real and virtual objects with each other, and run interactively in three dimensions and real-time.

However, within the context of industrial application, there is only a part for AR. It is mainly because the industrial setting is greatly challenging and complex (Tiefenbacher, Lehment, & Rigoll, 2014). To achieve better success, the key factor is user acceptance (Syberfeldt *et al*., 2015). It determines the future of this technology. If users are satisfied with their experience in using the application, they will give positive feedback and constructive critics. Those are valuable to improve the application.

The most popular platform for this virtual AR, especially in the manufacturing field, is the Head-Mounted Display (HMD). For example, there is the Oculus Rift display. The user will not have their hands occupied while doing the assembly. Nonetheless, this advanced technology also has drawbacks. In the early stage, Oculus Rift development, for instance, only has a screen resolution of 640 × 800 pixels. It causes a heavily deteriorated vision for the user. In addition, other mobile AR system devices are not socially accepted as using a smartphone or other hand-carried devices. It also has portability due to its size and weight because there are too many compartments to operate the whole system. Tracking and auto-calibration issues are also concerning (Van Krevelen & Poelman, 2010).

AR technology can overcome the trade-off of Virtual Reality (VR) in the assembly field, as it does not need the entire real world to be modeled. Thus, it reduces the high cost of fully immersive VR environments. AR technology also can enhance the learning process (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014). It improves a person's perception of virtual prototyping with real entities. This gives a better connection between the virtual and real environment, along with maintaining the flexibility of the virtual world.

Smartphone, on the other hand, is much more convenient and familiar to almost everyone. It has advanced computing ability, and this mobile industry is still developing and growing over time. The number of smartphone users has been rapidly increasing for almost a decade since the first Apple's iPhone hit the market in 2007. Until early 2017, almost a third of the world's population has been projected to own a smartphone, which is equal to 2.3 billion people (Holst, 2019b). The globally most used mobile operating system is Android OS with 87,8% domination of the mobile OS market share in the third quarter of 2016 (Holst, 2019a). In Indonesia, Android still topped the list of mobile OS market share with 73,8% in July 2016 (Statista Research Department, 2019).

To face all issues mentioned, the researchers utilize AR technology along with interactive multimedia applications to improve visual guidance and assist non-expert users in assembling furniture. The researchers have developed a mobile application called Arsembly. It is an AR-based assembly guidance application that runs on an Android platform, so it is operable through users' smartphones.

II. METHODS

This research uses the Waterfall method for system development. According to Sommerville (2011), it is an example of a plan-driven process. It requires the teams to plan and schedule all of the process activities before starting work on them. The principal stages of the Waterfall model directly reflect the fundamental development activities. Its process can be seen in Figure 1.

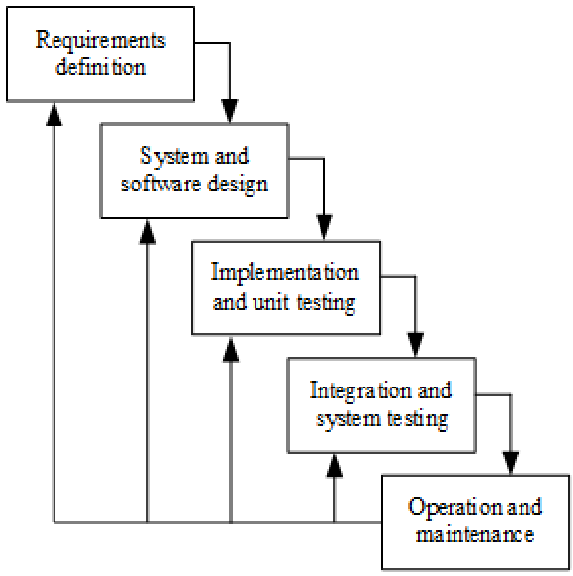

Figure 1 Waterfall Process Model

The existing Waterfall model will be described in Figure 2. There are several stages applied in this system development. First, it is gathering the requirement. This is the step that all possible requirements are gathered and documented in a requirement specification document. User requirements are gathered through questionnaires and study of the previous works from e-journals, international papers, and books. The questionnaire is online, made using Google Form, and distributed online via social media for about two months. The researchers obtain 154 respondents. The questionnaire must have the principal requirement to collect the right information based on related research. Thus, the participant should understand the core of research so they can give useful information (Bird, 2009).

Second, it is requirement analysis. The requirements are documented as preparation for the consecutive system design stage. Each question in the questionnaire represents a certain aspect of the application. Third, there is a system design step. The requirement specifications acquired from the first step are studied to prepare for the system design. In this stage, the researchers with the specified user requirements start to make an overall design of the AR system (how it is going to be built). It includes the architecture, interfaces, the database system, the development tools, the methodology, the hardware, and others. This system also needs some tracking. In AR, there is a term called registration that the virtual information must be positioned correctly to the real environment. It can only be done by tracking the environment. Thus, the synthetic elements can be properly registered with the real scene, which is calculating the relative pose, both location and orientation, of a camera in real-time (Siltanen, Lokki, Tervo, & Savioja, 2012).

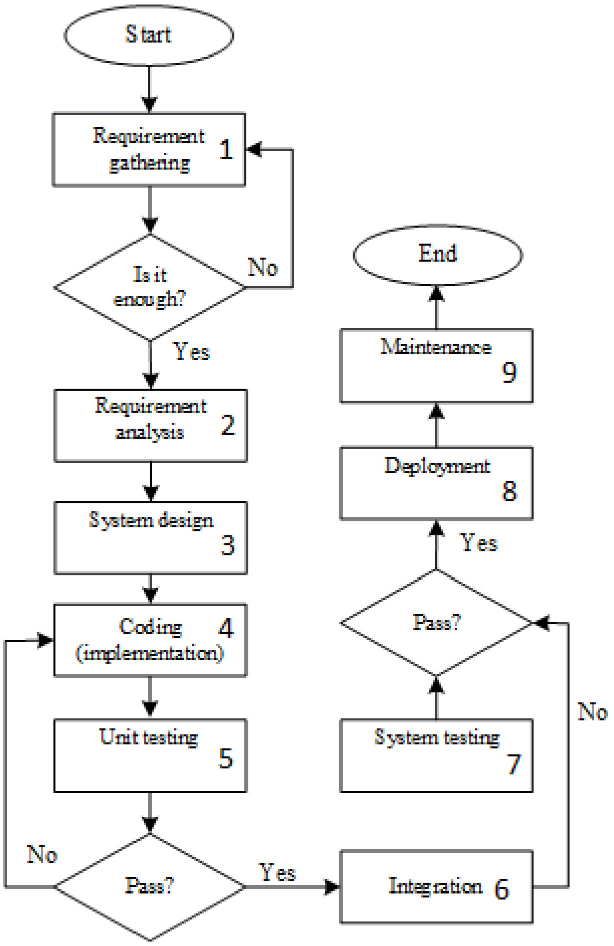

Figure 2 Methodology Flowchart

Fourth, it is implementation. It includes the development of the prototype, starting from small parts called units. The units of the system can be the coding for buttons, for scene's AR camera, and game objects in the project. Those are integrated with the next step. This is the step that the coding takes place. AR system is developed in Unity3d using Vuforia SDK library for the AR implementation and Mono library with C# programming language. Fifth, there is a unit testing step. This step is a part of the implementation stage. Each unit that has been coded is tested for its function. If it works correctly as the researchers design it to be, it is ready to be integrated with the other units. Sixth, it is integration. After unit testing is done, all the units are integrated into a system. System testing during development involves integrating components to create a version of the system and testing the integrated system. Once all the units have passed the testing, they are integrated into a whole system. In ARsembly, the integration is mostly about creating the corresponding relation among the scenes.

Seventh, it is system testing. This stage is highly related to the integration phase. As all the units have been integrated, it is time to conduct a test for the whole system operation. The system is tested to see whether it functions properly, as it should be as a complete system or not. Eighth, it is deployment. The system that has passed the testing phase is ready to be deployed to the market. Last, it is maintenance. As soon as the product is deployed, it enters the maintenance step. The team maintains the quality of the application, so it still functions properly as tested before. Thus, users can experience it well. At this stage, if there are any mistakes or errors, the team can go back to the phase in which the error occurs.

III. RESULTS AND DISCUSSION

This developed application based on mobile runs on a smartphone. The users who use this application need several minimum specifications for the hardware and software so that the system can run well. For the hardware, the specifications are an Android smartphone with a camera, 2GB RAM, and 200MB free storage minimum. Meanwhile, for the software, users should have Android OS with a minimum version of 4.0 Ice Cream Sandwich, and an application file of ARsembly.

The result of this research is an Android application. It consists of many features including the main page on a smartphone that users can access the main feature. The screen shows ARsembly logo and three buttons. The buttons are the scan button to start marker detection, tutorial button to watch the application tutorial video, and exit button to quit the application. The menu screen is in Figure 3.

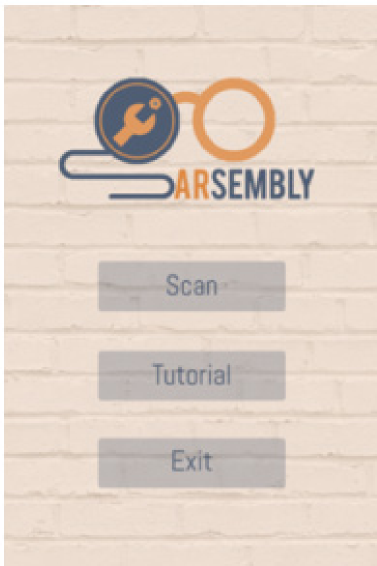

Figure 3 Screen of Start Menu

The users choose the scan button at the screen of the start menu. The system displays the marker scanning screen. It contains instructions regarding how to scan the marker, a home button, and a non-interactable check button. As the name implies, the home button is to get back to the main menu. Then, the checkmark button is to confirm the scanned image target. At this point, the check button cannot be clicked because there is no marker tracked. It will become interactable when a marker is tracked. The example can be seen in Figure 4.

Figure 4 The Marker Scanning Screen

When the camera captures the marker, the system will detect the image target. This screen displays how the application shows the detected and tracked models. This application shows a 3D model of the furniture that appears on top of it. The example can be seen in Figure 5.

Figure 5 The Detected Image Target

Figure 6 displays the assembly steps. It contains an instruction panel at the top of the screen and three buttons. Those are the previous button to go back to the previous step, the next button to go to the next step, and the home button to get back the main menu. At the end of the assembly steps, there is the final step of the assembly process. It has all the components of the regular assembly steps screen. When the next button is pressed, it pops up a message panel that the users have reached the final step. This message panel has a label with the notification and a 'Yes' button. It brings the users back to the main assembly screen so they can press the home button to get back to the main menu.

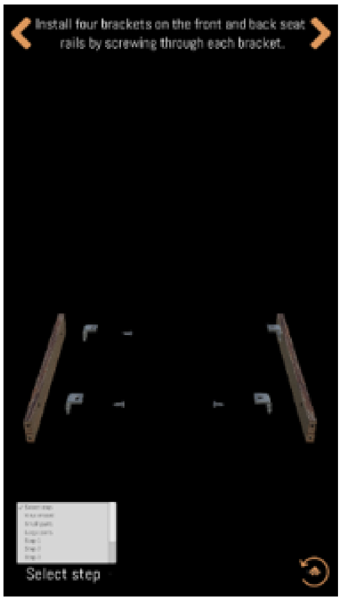

Figure 6 Assembly Step Screen

Figure 7 Final Step Screen

After the final step (Figure 7), the users are given the option to exit from the system. It is when the users press the exit button on the main menu. A confirmation panel pops up to make sure whether users want to exit or accidentally press the exit button. This panel has two buttons. Those are ‘Yes’ to exit the application and ‘No’ to get back to the application. The screen is in Figure 8.

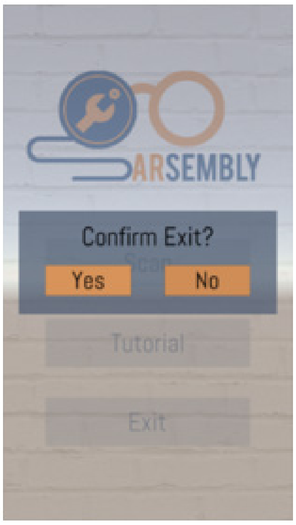

Figure 8 Exit Confirmation Screen

The application is tested for its detection and tracking functions. It concerns many different factors. Those are the distance between the camera and the marker, lighting intensity with a constant distance of 50 cm, and the angle between the camera and the marker with a distance of 50 cm and the indoor environment with the lighting of 15 watts. The result is measured in the time unit (seconds). The results are shown in Table 1. Although it cannot be detected, once it is detected, the marker can track until a certain point. It usually surpasses the detection limit. For the distance factor, the tracking exceeds 80 cm. However, it cannot be tracked anymore at approximately 80 cm. For angle, the marker tracking continues until it reaches an approximate 20 degree.

Table 1 The Results of Detection and Tracking Test

Factor	Test Measurement	Result
Distance	50 cm	0,4 s
	60 cm	0,627 s
	70 cm	0,784 s
	80 cm	Not detected
Lighting	Natural sunlight	0,383 s
	Indoor with 15-watt lighting	0,415 s
	Indoor with 5-watt lighting	0,539 s
Angle	90 degree	0,4 s
	60 degree	0,579 s
	30 degree	0,852 s
	15 degree	Not detected

Next, user requirements are evaluated after the users use the application. Users’ responses are obtained through questionnaires. These questionnaires are distributed to 50 random users. The questionnaires consist of eight questions. The first question is to find out how ARsembly’s interface design is. Then, the second question is whether the ARsembly has functioned well or not. The third question is about the features and touch screen functions. It is to see whether the features and touch screen functions are easy to remember and use. The fourth question is to find out whether the features are enough for users or not. Next, the fifth question is about how the application performance is on users’ smartphones. The sixth question is given to find out whether ARsembly is easy to use and understand for the users. Next, the seventh question is to see whether the ARsembly helps users to perform better at assembling furniture. The last question is the users’ suggestion for the development of this application. The results of each question are in Tables 2-9 respectively.

Table 2 User Satisfaction in ARsembly Interface

Answer	Number of Respondents	Percentage
Good	49	98%
Bad	1	2%
Total	50	100%

Table 3 The Response of Scan Menu

Answer	Number of Respondents	Percentage
Yes	42	84%
No, the scanning process lags a lot and slow	4	8%
No, the ARsembly still has many bugs	2	4%
Other	2	4%
Total	50	100%

Table 4 The Response of Touch Screen Features

Answer	Number of Respondents	Percentage
Agree	49	98%
Disagree	1	2%
Total	50	100%

Table 5 The Response of User Satisfaction in the Features

Answer	Number of Respondents	Percentage
Yes	45	90%
No	5	10%
Total	50	100%

Table 6 The Response of Application Performance

Answer	Number of Respondents	Percentage
Smooth	45	90%
Not smooth	5	10%
Total	50	100%

Table 7 The Response of ARsembly Usefulness

Answer	Number of Respondents	Percentage
Yes	50	100%
No	0	0%
Total	50	100%

Table 8 The Overall Response of ARsembly

Answer	Number of Respondents	Percentage
Yes	48	96%
No	2	4%
Total	50	100%

Table 9 Users' Suggestions

Suggestion	Number of Respondents	Percentage
Add other furnitures	10	20%
Make it compatible with other OS	4	8%
Improve the user interface	3	6%
No suggestions	33	66%
Total	50	100%

The questionnaire results show that users like ARsembly as an assembly simulation application. Most of the respondents (98%) are satisfied with the user interface of the application. The main function of the application, which is the scan function, can work properly. However, 16% of the respondents still have a problem such as unstable figure, and slow and lagged scanning process. The unstable figure can be caused by the level of sensitivity in the marker. It is more stable when the marker is more detailed and colorful because it is easier and faster to track.

In some cases, external factors such as lighting and scanning angle between the camera of the smartphone and marker affect the speed of tracking (as shown in Table 1). The speed of the performance of ARsembly tested on smartphones is quite smooth as the users (90%) are satisfied with it. The application may not run smoothly as it should be because of the inadequate specification of the smartphone. For example, the smartphone has a small RAM. The touch screen features (scaling, moving, and rotating functions) are proven to be useful. The users can easily manipulate 3D models through these features.

Moreover, 90% of the respondents are satisfied with the current features. However, the rest of them expects more features. Out of 50 respondents, 17 respondents have some suggestions. Ten respondents recommend adding other types of furniture in Arsembly. Four respondents suggest ARsembly be compatible with other OS and platform. Then, three respondents suggest improving the user interface. Moreover, all respondents who have tried ARsembly acknowledge that it helps to learn and understand the assembly steps.

Next, a comparison of similar applications is carried out. Table 10 presents the comparison between ARsembly and other assembly mobile applications such as Lego Interactive Building Instruction by Viu More, and CN2's IKEA Augmented Reality Instruction.

IV. CONCLUSIONS

Based on the implementation and evaluation, the main conclusion can be summarized as follows. First, ARsembly helps the users to understand each step of the furniture assembly through more advanced visual guidance.

Table 10 Similar Application Comparison

Application	Viu More's Lego Interactive Building Instruction	CN2's IKEA Augmented Reality Instruction	ARsembly
Platform	Android	iOS, Android, Windows	Android
Graphic	3D	3D	3D
Language	English	English	English
Using Internet Connection	No	No	No
Field	Toy building	Furniture assembly	Furniture assembly
User Control	Next and previous step buttons (touchscreen)	-	Next and previous step buttons; scaling, moving, and rotating 3D models with touchscreen functions
AR Graphic Control	-	-	Navigating, scaling, moving, and rotating
AR Animation	Animated augmented of 3D models of Lego pieces	Still 3D models (not animated)	Step-by-step of furniture assembly in 3D animations
Product piece detection	No	Yes	Yes

It utilizes the AR concept within interactive multimedia. There are augmented 3D animations, graphics, and text elements for each assembly step. Users can control and manipulate the augmented 3D animations to get better information and understand how the assembly process is done. In addition, graphics and texts are complementary to the visual guide. Second, according to user evaluation, ARsembly is easy to operate, and the users can understand the assembly steps. The users (96%) admit that they learn the steps better from ARsembly than the paper-based manual.

This research has revealed a promising future of AR's role in guiding furniture assembly. Based on conclusion, there are several recommendations to improve the existing or future research and for ARsembly. First, the researchers can add more variations for the instruction manuals especially furniture products which have higher complexity. Second, the platform is not limited only for Android smartphones, but it is also for other operation system and devices.

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