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CHARACTERISTICS OF USABILITY PROBLEMS FROM AUGMENTED REALITY-BASED USER INTERFACE FOR ASSEMBLY TASK

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Abstract. *Augmented Reality (AR) is one of the cutting-edge technologies that are rapidly developing, and it is used in many areas, such as manufacturing, game and automobile industries. The purpose of this study is to get characteristics of the AR interfaces by comparing the usability problems of the AR-based manual with those of the paper-based and the video-based manuals when the assembly tasks are conducted. The task was to assemble the blocks of the LEGO. The paper-based manual was developed based on the original manual of LEGO, the video-based manual was developed as video clips of showing all steps of assembling virtual LEGO blocks, and the AR-based manual was developed as the AR application implemented on the smartphone, showing the process of assembling virtual LEGO blocks on the image target. Usability problems obtained through the experiments, which 30 participants took part in, were analyzed and the characteristics of the AR interfaces were derived from the usability problems.*
Keywords: Usability problems, Augmented reality, Usability evaluation, Assembly task

1. **Introduction.** Augmented Reality (AR) is a technology that synthesizes virtual information or objects using computer graphics technology in a real environment. This is the lowest level of 'mixed reality' at the continuum of 'real environment – AR – augmented virtuality – virtual environment (or Virtual Reality (VR))', according to the proportion of virtual objects to the real environment in the display [1]. As interest in AR has grown, a number of AR applications have been released, and smartphone games based on AR like Pokémon Go were also released. Recently, various industries such as maintenance and assembly operations, began using the AR interfaces or getting help from the AR. During the maintenance and assembly operations, the AR can serve to reduce the error rate, which often requires a mental effort [2,3] and the completion time [4]. Due to these effects as well as user's positive attitude and satisfaction, the AR is expected to be used in more areas in the near future [5]. Therefore, research on the characteristics of the AR interface and how to improve its usability is needed. The usability is defined in ISO 9241-11 as the extent to which a product can be used by users to achieve their goals with effectiveness, efficiency and satisfaction in a context of use. A lot of researches have been conducted in the area of usability evaluation. In 1994, Nielsen [6] introduced heuristic evaluation and cognitive walkthrough methods as the usability inspection methods, through which the experts collected usability problems from the evaluated interfaces. Hartson et al. [7] presented principles and issues related to the usability evaluation, and proposed the criteria for comparing the Usability Evaluation Methods (UEM). By the way, Livingston [8] insisted that the usability should be considered to verify the effectiveness of AR systems. Even though he emphasized the importance of usable interfaces in AR systems, he did

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not show empirical research results regarding the characteristics of AR interfaces and how to evaluate the usability of AR interfaces. Lee and Lee [9] proposed an evaluation tool that could assess the usability of AR interfaces based on the design elements of the AR, focusing on the mobile media AR interfaces. Ko et al. [10] developed the usability principles for smartphone AR applications based on the existing usability guidelines, which were collected from the prior research, and conducted the experiments to validate the proposed usability principles. This research is meaningful in that it attempts to evaluate the AR interface based on usability rather than performance measures, such as task completion time and errors. However, these usability checklist and principles proposed from the previous studies [9,10] do not fully reflect unique characteristics of the AR interface or main features of the AR systems, but include general usability principles and guidelines mostly that can be used for various types of interfaces.

This study aims to investigate the characteristics of the AR interface, which is specifically the interface of the AR-based manual, by comparing it with the existing other interfaces, such as those of the paper-based manual and the video-based manual. Knowing the characteristics of the AR interface compared to other common interfaces, it is possible to create development and evaluation guidelines specific to the usability of AR interface, which will lead to the development of AR interfaces that users can easily use and be satisfied with. The assembly task is considered by users as an appropriate task using the AR interface, and the AR-based manual is a common AR interface for the assembly task. The paper-based manual is a traditional one that is still in wide use, and the video-based manual is currently a popular manual due to the development of video media such as YouTube. We focus on the usability problems of these three types of manuals to extract the unique characteristics of the AR interface in the aspect of usability. This paper is organized as follows. This section gave the motivation of this study and an overview of related works, and is followed by a description of research methods in Section 2. Sections 3 and 4 provide the results of the experiments and discussion on the results with conclusions, respectively.

2. **Method.**

The tasks in the experiments were to assemble a LEGO truck (see Figure 1), which consisted of blocks from LEGO models, with the guidance from each of three types of manuals, such as the AR-based, the paper-based and the video-based manuals. In order to extract the characteristics of AR interfaces, three types of manuals were developed and their usability problems were collected during the experiments.

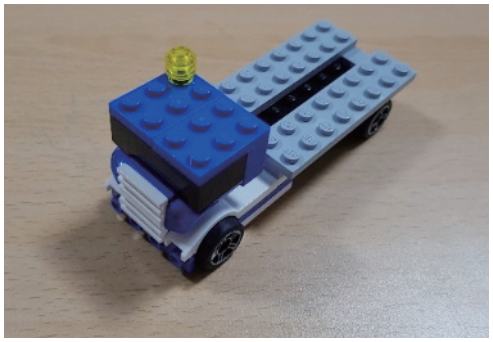
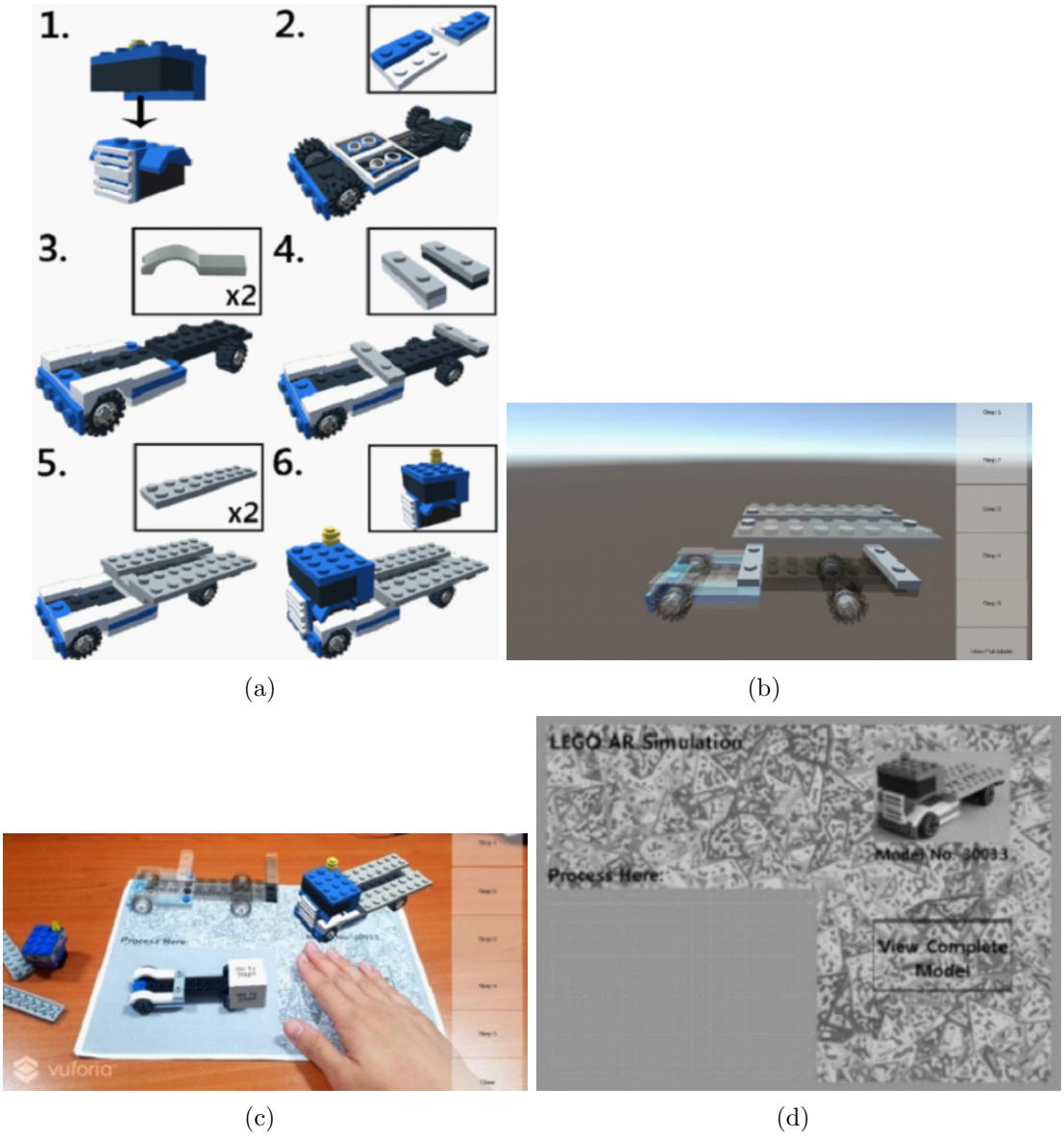


FIGURE 1. A complete LEGO truck for assembly task

2.1. **Preparation of experiment.**

The paper-based manual that was developed based on a manual of the LEGO company has 6 steps in total, and it focuses on reflecting the assembling instructions including required parts and directions of assembling (see Figure 2(a)). The video-based manual was developed as video clips shown in a smartphone application and is interactive in that users can freely choose the step they want to see



(a) (b)

(c) (d)

FIGURE 2. Three types of manuals ((a) Paper-based manual, (b) Video-based manual, (c) AR-based manual, (d) Image target of AR-based manual)

out of 6 steps. Both the background and the LEGO object were simulated as a virtual object, and the assembling instructions were made by showing the repeated movements of two or more parts (i.e., LEGO objects). On the display, there are buttons for users to choose the steps of assembling parts. LEGO objects are rendered transparent so that the assembly cross-section can be seen (see Figure 2(b)).

The AR-based manual was developed with a smartphone application using Vuforia engine with Unity. The display shows the real environment through the camera, and when the image target is viewed on the screen, AR LEGO objects are rendered on it (See Figures 2(c) and 2(d)). The image target is the image that AR engine can detect and track as long as it is at least partially in the camera's field of view. The assembling instructions were made by showing the repeated movements of two or more parts, similar to the video-based manual. On the display, there are buttons for each step, and when the button is pressed, AR LEGO objects in the step appear. Also, there is a 'Clear' button so that all LEGO objects on the image target disappear. The rectangle with the words of 'View Full Model' in the image target is the virtual button, which makes users see the complete model on the display when it is covered with user's hands. In addition, a small

cube appears next to LEGO parts, which is being assembled. This cube shows the phrase of assembly tasks, for example, 'Go to STEP 2' to indicate the next step. LEGO objects are rendered transparent so that the assembly cross-section can be seen.

A question sheet with the sentence, 'please write down and specify something inconvenient, difficult to use or unsatisfied as many as possible when you interact with this manual', was prepared so that participants could fill out it after the experiments.

2.2. **Participants.** A total of 30 university students participated in the experiment. Of the participants, 15 were males and 15 were females. The average age of the participants was 22.07 and the standard deviation was 1.143. They are expected to represent assembly workers in terms of age and gender. Among the 30 participants, 16 participants (53.34%) have experience of using VR devices, and 6 participants (20%) have both of VR and AR devices.

2.3. **Procedure of experiment.** The experiments were conducted according to the within-subject design, in which each of participants experienced all of three types of manuals, such as the paper-based, the video-based and the AR-based manuals. The within-subject design has the advantage of avoiding the subject effects that may adversely affect the results. Six possible orders of using three types of manuals were randomly and evenly assigned to all of 30 participants, and thus each of orders was counter-balanced. There was also a washout period of 2-3 days between the experiments. Before conducting the assembly tasks, participants learned how to use each of manuals in the training session. For example, as for the AR-based manual, participants had a training session of 1 minute and 30 seconds after hearing a detailed explanation of each function, and freely determined whether they used the smartphone tripod in the experiment. Participants were asked to assemble a LEGO model following the given type of manual after the training session. After the experiment, participants were asked to fill out the question sheet. Participants were given enough time to find out usability problems, and encouraged to write down them as many as possible in the question sheet (see Figure 3).

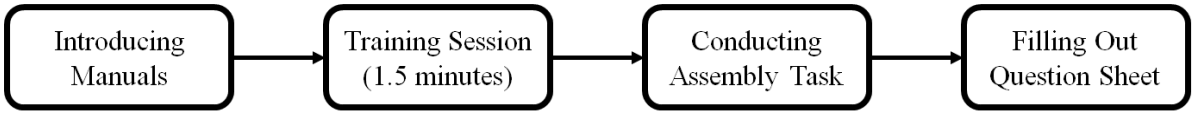


FIGURE 3. Stages of experiment

3. Results.

3.1. **Usability problems of three types of manuals.** Tables 1 through 3 show the summarized lists of usability problems collected according to the types of manuals. Usability problems that were mentioned more than once are listed in the tables, and otherwise the frequencies are summed up in the category of 'others'. As for the paper-based manual, a total of 116 usability problems were collected (see Table 1). The common usability problems with more than 10 participants include 'I need sufficient instructions or explanations for the parts that are being assembled (28 participants)', 'I wish we could see them from different directions depending on the situation (20 participants)', and 'some step components are vaguely expressed (18 participants)'.

As for the video-based manual, a total of 168 usability problems were collected (see Table 2). The common usability problems with more than 10 participants include 'the distinction between components is ambiguous (28 participants)', 'the viewing angle in the video is fixed (27 participants)', 'the difference in transparency between components that need to be assembled and assembled parts are ambiguous (21 participants)', 'the motion of the components is too fast (19 participants)', 'I wish there was a description of the

Table 1. Usability problems of paper-based manual

Description	Frequency	Common Features
I need sufficient instructions or explanations for the parts that are being assembled.	**28**	Video, AR
I wish we could see them from different directions depending on the situation.	**20**	Video
Some step components are vaguely expressed.	**18**	Video
In STEP 2, I did not realize that the block was inverted and assembled incorrectly.	7	
It would be nice if it could show me in advance what the finished shape looks like.	5	
For each step, I would like it to give warnings to any errors or mistakes that may occur.	5	Video
I wish I could see the finished picture at each stage.	4	
It is boring and monotonous.	3	
Others	26	
Total	116	

Table 2. Usability problems of video-based manual

Description	Frequency	Common Features
The distinction between components is ambiguous.	**28**	Paper
The viewing angle in the video is fixed.	**27**	Paper
The difference in transparency between components that need to be assembled and assembled parts is ambiguous.	**21**	AR
The motion of the components is too fast.	**19**	AR
I wish there was a description of the parts and precautions required by each step.	**13**	Paper, AR
I am not sure what stage I am in.	**10**	AR
I do not think I will have to use the video manual.	7	
I wish STEP 2 would be separated by two.	6	AR
The shape and size of the buttons are inconsistent.	6	AR
The letters on the button are small.	5	AR
Interface distributes attention.	4	
It was cumbersome to click the STEP button alternately.	3	AR
Others	19	
Total	168	

parts and precautions required by each step (13 participants)', and 'I am not sure what stage I am in (10 participants)'.

As for the AR-based manual, a total of 183 usability problems were collected (see Table 3). The common usability problems with more than 10 participants include 'if the whole paper is not on the screen, LEGO model disappears (16 participants)', 'I think it would be inconvenient to use without a tripod (13 participants)', 'I hope it can distinguish parts that need to be assembled from their locations through transparency and dynamics (13 participants)', and 'I hope there is a button on the display that allows me to see the complete picture (12 participants)'. Therefore, it can be inferred that the majority of

TABLE 3. Usability problems of AR-based manual

Description	Frequency	Common Features
If the whole paper is not on the screen, LEGO model disappears.	**16**	
I think it would be inconvenient to use without a tripod.	**13**	
I hope it can distinguish parts that need to be assembled from their locations through transparency and dynamics.	**13**	Video
I hope there is a button on the display that allows me to see the complete picture.	**12**	
The shape of AR LEGO was transparent and so it sometimes was not visible.	9	
The position of the AR image is biased at the corners.	7	
The AR components which are moving on display are too fast.	7	Video
It is inconvenient to use image targets when checking several sides of a block.	7	
I think that the LEGO assembly area is narrow and paper is inefficient.	7	
I am not sure I need to use this manual.	6	
I hope that each STEP button has more visibility.	5	Video
I hope the size of the image target is smaller.	5	
It was uncomfortable to have manual operation while assembling.	5	Video
I want it to let me know which step I am currently in.	5	Video
Interface button problems (space distribution, border blur, button visibility)	5	Video
I would like to be able to rotate the AR object directly from the interface.	4	
Instructions are needed to operate.	4	
I wish I could fix AR components that are moving continuously.	4	
It is inconvenient to watch it on the screen of a mobile phone.	3	
I would like to see the blocks I need to use first.	2	Video
I would like to separate STEP 2 into two steps.	2	Video
In STEP 4, I would like it if it emphasizes the two blocks apart.	2	Paper, Video
Others	40	
Total	183	

usability problems come from the characteristics of manual interfaces, such as simple figures from the paper-based manual, ambiguous components and their motions from the video-based manual, and unfamiliar interfaces (i.e., image target) from the AR-based manual.

3.2. **Common features.** The usability problems which were common in all three types of manuals belong to the fact that users want more instructions or explanations for the

parts being assembled in general. By the way, the usability problems that the video-based and the AR-based manuals have in common include 'the distinction between components is ambiguous', 'the motion of the components is too fast', 'the letters on the button are small', 'the shape and size of the buttons are inconsistent', 'I am not sure what stage I am in', 'I would like to see the blocks I need to use first', 'I would like to separate STEP 2 into two steps', and 'it was uncomfortable to have manual operation while assembling'. These common usability problems appear because the common points between the video-based and the AR-based manuals are the display of the hand-held device, virtual (and AR) LEGO objects and additional interactions through buttons on the display. The usability problems that the video-based and the paper-based manuals have in common include 'I wish we could see them from different directions depending on the situation' and 'some step components are vaguely expressed'. These common usability problems appear because the common point between the video-based and the paper-based manuals is the fixed viewing direction, in which the LEGO objects are viewed. There was nothing common in the usability problems of the paper-based and the AR-based manuals. Therefore, the AR-based manual should basically be designed taking into account device characteristics (e.g., handheld type) as well as general needs for additional information about the task.

3.3. **Different features.** Typical usability problems in the AR-based manual are 'if the whole paper is not on the screen, LEGO object disappears', 'I think it would be inconvenient to use without a tripod', and 'I hope there is a button on the display that allows me to see the complete picture'. These are due to the use of an additional interface called the image target in the AR-based manual, and the need to manipulate the manual while viewing the image target with the hand-held device. A typical usability problem in the video-based manual is 'I do not think I will have to use the video manual'. This usability problem appears due to the monotony of users interacting with the display mainly. Typical usability problems in the paper-based manual are 'when assembling STEP 2, I did not realize that the block was inverted and assembled incorrectly', and 'it would be nice if it could show me in advance what the finished shape looks like'. These usability problems appear due to the lack of interaction with the interface and the inability to notice when the LEGO object representation changes (LEGO object is turned over in STEP 2). Therefore, the AR-based manual should be designed considering that users are not familiar with new features like the image target.

4. **Conclusions and Discussion.** This study investigated the characteristics of the AR interfaces by comparing the usability problems of the AR-based manual with those of the paper-based and the video-based manuals. First, the usability problem that all of three types of manuals have in common is related to the task. However, this problem was mentioned by 28 participants in the paper-based manual, 13 participants in the video-based manual, but only 2 participants in the AR-based manual. Thus, it is concluded that the AR-based manual gives users enough information compared to the paper-based and the video-based manuals. Second, the usability problems that the AR-based manual has in common with the video-based manual are caused by buttons of the display, components of the virtual (and AR) LEGO objects and needs for the additional interaction. It is because the common parts of the video-based and the AR-based manuals are mainly buttons of the display and the LEGO objects, whose problems include movement of objects, transparency of assembly cross-section, and non-discrimination between some components.

Third, the usability problems that are not shown in other types of manuals but are only shown in the AR-based manual are due to the use of an additional interface called the image target, the interaction with the image target using the hand-held device, and the unfamiliarity with the AR interface. Specifically the AR-based manual requires recognition of the image target to show a LEGO object, which leads the usability problems,

including inconvenience to check the size of the image target, the location of the AR image above the image target and the location and manipulation of the virtual button. In addition, there is inconvenience with the small screen of the hand-held device, whose problems get worse without using a tripod. There are also usability problems for AR objects as follows: the LEGO objects are not easily seen depending on the environment; the repeated movement of the LEGO objects cannot be stopped; and the LEGO objects cannot be enlarged or rotated directly on the display. In this study, the usability problems of the AR-based manual are analyzed to reveal the characteristics of the AR interfaces. These characteristics need to be considered to improve the usability of the AR interfaces. For further study, the usability principles for designing the AR interfaces need to be developed specifically, not just the general usability principles for all types of interfaces.

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