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COMPARISON AMONG TYPES OF ASSEMBLY MANUALS BASED ON PAPER, VIDEO AND AUGMENTED REALITY

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Abstract. *Nowadays Augmented Reality (AR) has been utilized in many areas, including assembly tasks. This study was designed to compare and evaluate the performance, perceived usability and user acceptance between the AR-based manual and the other types of manuals, such as the paper-based and the video-based manuals. 30 participants took part in the experiment, and were asked to complete a simple assembly task of LEGO model. Each participant conducted a total of three experiments using one of three types of manuals for the task. Error and completion time during the assembly tasks were measured as the objective performance and at the end of each experiment, the participants were asked to evaluate the perceived usability and the user acceptance. From the statistical analyses, it is concluded that the attitude to use the AR-based manual is relatively positive, even though working through the AR-based manual shows disadvantages, such as the longest completion time, more errors than the other manuals and the high burden of learning. Thus it would be more likely to use the AR-based manual in the near future, although there are now more obstacles to use the AR-based manual than the other types of manuals.*

Keywords: Augmented reality, Assembly manual, Performance, Usability, User acceptance

1. **Introduction.** Recently Augmented Reality (AR) has become closer to our daily lives. AR is not only used to buy furniture or electronic products from the Internet, but also, we can spend time playing AR games like Pokémon Go in the AR café. Some of reasons why AR is getting closer to our daily lives are its advantages, such as reducing errors, and costs in decision-making, providing users with a unique and vivid experience, and providing multimodal information very similar to reality [1]. Nowadays, AR technology has been also extended to the industrial fields, such as manufacturing, product maintenance, and management [2]. In so doing, it was found that the AR-based manuals began to replace the role of paper-based manuals (e.g., a sheet of paper containing how to assemble the LEGO model) and video-based manuals (e.g., video clips containing the assembly processes provided by YouTube). For instance, Gattullo et al. [3] asserted that the AR-based manuals had the advantage of requiring less text than the other existing manuals because they were mainly composed of images. However, it is still doubtful whether these changes from paper or video-based manuals to AR-based manuals can make users satisfied in terms of performance and ease of use. Thus, more attention and efforts are needed to investigate the performance and usability of the AR-based manuals compared to the paper-based or the video-based manuals.

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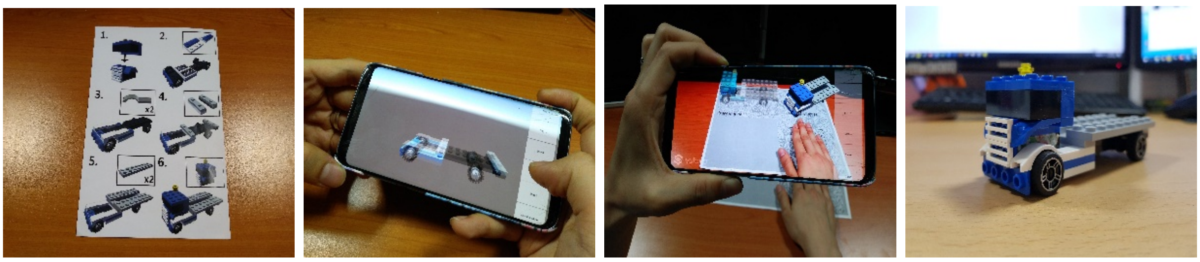
There were a few studies that dealt with AR-based manuals for assembly tasks in terms of performance or effectiveness [4,5]. Baird and Barfield [4] focused on how AR-based manuals contributed to the improvement of performance, in terms of completion time and error frequency, compared to paper-based manuals, when assembly tasks were conducted. Wiedenmaier et al. [5] prepared the tasks of assembling vehicle doors for experiments in a relatively similar state to industrial sites. The focus of the experiments was on investigating which is the most effective manual among AR-based manuals, paper-based manuals and expert tutorials. These studies examined the effectiveness of AR-based manuals for assembly tasks, but did not tackled the aspects of how easily AR-based manuals were used. By the way, there was also a research stream that highlighted the usability of AR [6-8]. Ko et al. [6] tried to establish the usability principles which were related to the use of AR applications for smartphones. They selected a set of usability principles for AR applications and used them for the assessment of AR usability. Lee and Lee [7] proposed the tools for creating user-based design interfaces in mobile augmented reality. In doing so, they developed a basic usability evaluation checklist for AR and used it for assessing interfaces in mobile AR. Also, Wang et al. [8] examined the usability of an instructional application as the AR-based manual when using Google Glass for the phone-disassembly task. However, these studies just focused on collecting usability principles for AR and applied them to the evaluation of AR-based interfaces, but not investigated how AR-based interfaces were different from the others, comprehensively. In order for AR-based interfaces to be more effective, useful, and acceptable to users, it is necessary to develop them based on the characteristics of AR-based interfaces rather than developing them based on general guidelines or usability principles. To this end, it is important to study how AR-based interfaces differ from other interfaces as a first step.

This study aims to identify the status quo of AR-based manuals in terms of performance and usability, and to expect the future use of AR-based manuals through examining user acceptance of it. First, to identify the status quo of AR-based manuals, we compared it with the other existing manuals, such as paper-based and video-based manuals, by measuring their objective performance and perceived usability. Second, to expect the future use of AR-based manuals, we measured user acceptance of all three types of manuals and compared them each other. The AR-based manual and the video-based manual were evaluated in a smartphone-based environment, and a sheet of paper was used for the paper-based manual. This section introduces the motivation of this study, 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.** This study was designed to evaluate the differences in performance, usability and user acceptance between the AR-based manual and the other manuals. Type of manuals, such as paper-based, video-based and AR-based manuals, is the independent variable, and objective performance, perceived usability and user acceptance are the dependent variables. During the experiments, task completion time and errors were recorded as objective performance measures. After the experiments, perceived usability was measured through the questionnaire of System Usability Scale (SUS) [9] (see Table 3). In addition, user acceptance was measured through the modified questions extracted from the Technology Acceptance Model (TAM) related questions in Venkatesh et al. [10] (see Table 4).

2.1. **Preparation of experiment.** Prior to the experiments, a digital camcorder and an action camera called GoPro were prepared to record the whole processes of the experiments. As an experimental task, the participants were asked to assemble a simple LEGO truck (see Figure 1(d)). To guide the assembly task, three types of manuals, namely paper-based, video-based and AR-based manuals, were prepared in the experiments. A sheet of the paper-based manual is configured in 6 steps for assembling the LEGO truck (see Figure 1(a)). As for the video-based manual, the assembly task of LEGO truck is divided in 5 steps, and unlike the paper-based manual, each step of the assembly task can be seen through the video in a smartphone (see Figure 1(b)). In the meantime, the 'image target' is used during the assembly process using the AR-based manual. The image target represents images that AR engine can detect and track. Once the image target is detected, AR engine will track the image as long as it is at least partially in the camera's field of view. A full picture of the image target with a smartphone camera helps participants observe a virtual LEGO model. Unlike the video-based manual, the participants can observe the virtual LEGO model in any direction by properly moving the image target when using the AR-based manual (see Figure 1(c)).

The video clips recorded during experiments were used to measure the objective performance, such as the frequency of errors and completion time of the assembly task. The questionnaire that included SUS questions [9] and user acceptance questions extracted and modified from Venkatesh et al. [10] was prepared for measuring the perceived usability and the user acceptance of three types of manuals (see Tables 3 and 4). The 10 SUS questions were asked using a 5-point interval scale (1: strongly disagree, 2: disagree, 3: undecided, 4: agree, 5: strongly agree), and the user acceptance questions consisted of 12 questions based on a 7-point interval scale (1: extremely disagree, 2: quite disagree, 3: slightly disagree, 4: neither, 5: slightly agree, 6: quite agree, 7: extremely agree).



(a) Paper-based manual (b) Video-based manual (c) AR-based manual (d) LEGO model

FIGURE 1. Three types of manuals and LEGO model

2.2. **Participants.** A total of 30 participants were recruited from college students. Participants were 22.07 years old on average, and the standard deviation was 1.143 years. They were 15 males and 15 females. About 73% of the total participants had AR or Virtual Reality (VR) experience and about 20% of the total participants had AR experience before the experiments.

2.3. **Procedure of experiment.** The experiment was designed with the within-subject design method, and each of participants was asked to use all of three types of manuals, namely paper-based, video-based and AR-based manuals, for the assembly tasks. To minimize the order effect, the order of using three types of manuals was counter-balanced and each of six orders was randomly assigned to five participants equally. 2 or 3 days of the wash-out periods were set between the experiments within each of participants to prevent learning effects. Before conducting the experiments, participants were asked to respond a pre-experiment questionnaire, which included the questions about their experiences in using VR or AR and their consents to voluntary participation of the experiments.

The experiments were conducted in three stages: 1) training, 2) main experiment, and 3) completing a questionnaire (see Figure 2). In the training session, participants listened to how to use manuals, which might be unfamiliar to participants, and were given the same time (i.e., 2 minutes) to freely use the manuals. After the training session, participants conducted the main experiment, where participants were asked to completely assemble

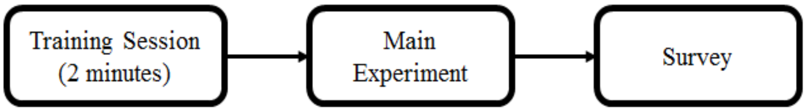


FIGURE 2. Three stages of experiments

the LEGO truck using a given type of manuals. As for the video-based and the AR-based manuals, the smartphone display was used, and the participants could determine whether they would utilize the stand for a smartphone to use both hands freely. The participants then began assembling the LEGO models according to the instruction, and all of the participants' activities were recorded by the camcorder and the action camera. The main experiments were terminated when the participants finished the assembly task. After the main experiments, the participants were asked to answer the questions in the questionnaire, which included 10 SUS questions and 12 user acceptance questions. With this survey, all of procedures for the first experiment were over. Each of participants conducted a total of three experiments with a given type of manuals, and there were 2 or 3 days as a wash-out period between the experiments.

3. Results.

3.1. Objective performance. Errors were detected from the video clips of participants' behaviors that were recorded during the experiments, and were summarized by their sources and frequencies. Some of errors happened during participants assembled the LEGO model (called 'assembly' error), and the other errors included errors that happened during the interaction with the display of a smartphone (called 'display' error) and with the image target of AR (called 'image target' error). Table 1 shows the sources and frequencies of errors according to the types of manuals. As for the paper-based manual, the error happened only during the assembly process because there was no interaction with a display or an image target, whereas the video-based manual included interaction with a display and the AR-based manual did interactions with both of a display and an image target. For example, the assembly errors happened when participants assembled wrong parts of LEGO model, whereas the display errors or the image target errors happened when participants touched wrong buttons of a display or wrong parts of an image target, respectively. As seen in Table 1, the AR-based manual recorded the highest error frequency of 110, which included 73 errors during the assembly process, 26 errors from the interaction with the smartphone display and 11 errors from the interaction with the image target. The paper-based manual produced 66 errors, and the lowest number of errors (i.e., 42 errors) happened in the video-based manual. Table 2 shows the comparison results of error frequency and completion time among the types of manuals. Because error frequency and completion time did not satisfy the assumptions for the parametric statistical analysis, such as Analysis of Variance (ANOVA), the Kruskal-Wallis test as the non-parametric statistical method was used to test whether there was a difference among the types of manuals, and then the Dunn test was applied as the post-hoc analysis method when there was a significant difference among the types of manuals. As a result, the AR-based manual produced significantly more errors and longer completion time than the video-based manual regardless of outliers, and the performance of the paper-based manual was in the middle of the others in terms of error frequency and completion time. Therefore, AR-based manuals should be designed to reduce errors and task completion time, taking into account the need for additional interaction between the user and the image target.

3.2. Perceived usability. Table 3 shows the perceived usability scores and the comparison results of these scores among the types of manuals. 10 individual SUS questions and

Table 1. Sources and frequencies of errors

Types of manuals	Source of error	Error frequency	Total of errors	Percentages
PAPER ($n = 30$)	Assembly	66	66	100%
VIDEO ($n = 29$)[1)]	Assembly	40	42	95%
	Display	2		5%
AR ($n = 30$)	Assembly	73	110	66%
	Display	26		24%
	Image Target	11		10%

Notes : 1) One participant who has not completed all steps was excluded from the analysis.

Table 2. Results of objective performance

Variables		Mean (Standard deviation)			$\chi2$, p-value	Results of Dunn test
		PAPER	VIDEO	AR		
Error Frequency	with Outlier	2.20 (2.212) ($n = 30$)	1.45 (1.476) ($n = 29$)[1)]	3.67 (4.475) ($n = 30$)	$\chi2(2) = 6.076$ $p = 0.048$	AR > VIDEO ($p = 0.021$)
	without[2)] Outlier	1.54 (1.474) ($n = 26$)	0.83 (0.761) ($n = 23$)	2.31 (1.996) ($n = 26$)	$\chi2(2) = 9.273$ $p = 0.010$	AR > VIDEO ($p = 0.004$)
Completion Time (second)	with[3)] Outlier	124.30 (98.947) ($n = 20$)	92.62 (42.118) ($n = 21$)	160.96 (149.3719) ($n = 23$)	$\chi2(2) = 10.334$ $p = 0.006$	AR > VIDEO ($p = 0.003$)
	without[2)] Outlier	87.35 (30.732) ($n = 17$)	81.79 (23.770) ($n = 19$)	120.24 (37.762) ($n = 21$)	$\chi2(2) = 14.721$ $p = 0.001$	AR > PAPER ($p = 0.008$) AR > VIDEO ($p = 0.001$)

Notes : 1) One participant who has not completed all steps was excluded from the analysis.
2) Participants whose data has $|Z| > 3$ were excluded from every analysis.
3) Participants who have finished all steps but not completely were excluded from the analysis.

the sum of these scores were compared using the ANOVA method, and the Tukey test was applied as the post-hoc analysis method when there was a significant difference among the types of manuals. A score of 'sum' from the SUS questionnaire was calculated by converting each score of the 10 SUS questions (i.e., 'scores of positive questions −1' and '5-scores of negative questions'), adding all of 10 converted scores, and then multiplying it by 2.5 to result in a score range of 0 to 100. In terms of the sum of SUS scores, the video-based manual had significantly higher usability score (77.25) than the paper-based manual (66.50), and the usability score of the AR-based manual (70.67) was in the middle of the others. From the comparison of 10 individual SUS questions, it is significantly concluded that the AR-based manual needs more support of a technical person (necessity of support), shows better integrity of functions (integrity of functions) and requires users to learn more things (burden of learning) than the other types of manuals. Therefore, AR-based manuals should be designed to reduce technical support and learning needs.

3.3. **User acceptance.** The user acceptance was measured by 12 selected TAM questions, and four factors extracted from these 12 questions were used for analyses. Before going to the analyses based on the factors of user acceptance, the internal consistency of the questions for the factors was examined. As seen in Table 4, the questions which were supposed to measure 'performance expectancy', 'effort expectancy' and 'attitude toward using manual' showed good internal consistency (i.e., three values of Cronbach's alpha

TABLE 3. Results of perceived usability

Variables	Mean (Standard deviation)			F, p-value	Results of Tukey test
	PAPER ($n = 30$)	VIDEO ($n = 30$)	AR ($n = 30$)		
Use Frequency	3.20 (0.887)	3.27 (0.944)	3.60 (0.932)	$F(2, 87) = 1.62$ $p = 0.2030$	–
Complexity	2.20 (0.847)	1.87 (0.900)	2.10 (0.712)	$F(2, 87) = 1.30$ $p = 0.2790$	–
Ease of Use	3.43 (0.971)	4.30 (0.952)	3.73 (0.944)	$(2, 87) = 6.36$ $p = 0.0027$	VIDEO > PAPER ($p = 0.0021$)
Necessity of Support	1.63 (0.850)	1.53 (0.681)	2.47 (1.106)	$F(2, 87) = 9.81$ $p = 0.0001$	AR > PAPER ($p = 0.0015$) AR > VIDEO ($p = 0.0003$)
Integrity of Functions	2.63 (0.964)	3.13 (1.008)	3.73 (0.785)	$F(2, 87) = 10.65$ $p = 0.0001$	AR > PAPER ($p = 0.0000$) AR > VIDEO ($p = 0.0363$)
Inconsistency	2.20 (0.925)	1.67 (0.479)	1.70 (0.535)	$F(2, 87) = 5.86$ $p = 0.0041$	PAPER > VIDEO ($p = 0.0083$) PAPER > AR ($p = 0.0144$)
Learnability	3.63 (1.098)	4.47 (0.900)	4.13 (0.860)	$F(2, 87) = 5.75$ $p = 0.0045$	VIDEO > PAPER ($p = 0.0032$)
Difficulty	2.37 (1.033)	1.73 (0.640)	2.27 (1.172)	$F(2, 87) = 3.66$ $p = 0.0298$	PAPER > VIDEO ($p = 0.0362$)
Confidence	3.60 (1.003)	3.90 (1.213)	3.70 (1.022)	$F(2, 87) = 0.60$ $p = 0.5530$	–
Burden of Learning	1.50 (0.572)	1.37 (0.556)	2.10 (0.923)	$F(2, 87) = 9.23$ $p = 0.0002$	AR > PAPER ($p = 0.0040$) AR > VIDEO ($p = 0.0003$)
SUM	66.50 (14.660)	77.25 (12.306)	70.67 (14.561)	$F(2, 87) = 4.57$ $p = 0.0130$	VIDEO > PAPER ($p = 0.0098$)

were more than 0.7), and the internal consistency for 'behavioral intention to use manual' was not available because it was measured by a question. The factor scores of user acceptance were compared among the types of manuals using the ANOVA method, and the Tukey test was applied as the post-hoc analysis method when there was a significant difference among the types of manuals. Table 5 shows there are significant differences among the types of manuals in 'effort expectancy' and 'attitude toward using manual'. It is concluded that the video-based manual is expected to need significantly less efforts than the paper-based manual, and that the AR-based manual has significantly better user's attitude toward using the manual than the paper-based manual. Therefore, AR-based manuals should be designed so that users want to keep using them.

4. **Conclusions and Discussion.** Through the experiments, this study investigated comprehensively the performance, perceived usability and user acceptance of the AR-based manual by comparing it with the paper-based manual as a traditional manual and the video-based manual as a popular manual currently. In doing so, we can find the status quo of the AR-based manual, which is that the AR-based manual does not show

Table 4. Factors for user acceptance

Factors	Questions	Cronbach's α
Performance Expectancy	I would find the manual useful in my job.	0.8222
	Using the manual enables me to accomplish tasks more quickly.	
	Using the manual increases my productivity.	
Effort Expectancy	My interaction with the manual would be clear and understandable.	0.8763
	It would be easy for me to become skillful at using the manual.	
	I would find the manual easy to use.	
	Learning to operate the manual is easy for me.	
Attitude Toward Using Manual	Using the system is a good idea.	0.8984
	The manual makes work more interesting.	
	Working with the manual is fun.	
	I like working with the manual.	
Behavioral Intention to Use Manual	I intend to use the manual in the next months.	–

Table 5. Results of user acceptance

Factors	Mean (Standard deviation)			F, p-value	Results of Tukey test
	PAPER ($n = 30$)	VIDEO ($n = 30$)	AR ($n = 30$)		
Performance Expectancy	4.64 (1.161)	5.21 (1.195)	5.03 (1.382)	$F(2, 87) = 1.61$ $p = 0.2050$	–
Effort Expectancy	5.17 (1.270)	5.87 (0.892)	5.63 (1.110)	$F(2, 87) = 4.77$ $p = 0.0108$	VIDEO > PAPER ($p = 0.0101$)
Attitude Toward Using Manual	4.14 (1.322)	4.88 (1.203)	5.45 (1.403)	$F(2, 87) = 7.50$ $p = 0.0010$	AR > PAPER ($p = 0.0006$)
Behavioral Intention to Use Manual	4.39 (1.473)	4.72 (1.551)	4.71 (1.646)	$F(2, 87) = 0.443$ $p = 0.6440$	–

high performance and perceived usability as a whole, but has positive aspects, such as good integrity of functions and good user's attitude to use it. Thus, it can be concluded that even though the AR-based manual now has lots of problems in terms of performance and usability, it has potentials to be well utilized in the near future. Despite these significant empirical results related to the current status of AR-based manuals, this study has the limitation that it used relatively small sample size and too simple assembly task to generalize the conclusions. In addition, although design guidelines were proposed in this study, we could not provide practical suggestions on how to specifically design AR-based manuals. Therefore, for further research, larger sample sizes and actual tasks should be used for the experiments, and for a practical suggestion, it would be needed to investigate what kinds of usability problems the AR-based systems have specifically and how to find them efficiently because the AR-based interfaces are much different from the traditional ones.

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