Context-related Visualization Modes of an AR-based Context-Aware Assembly Support System in Object Assembly

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Abstract - This study proposes and evaluates the effectiveness of visualization modes for an AR based context-aware assembly support system in object assembly. Although many AR-based assembly support systems have been proposed, few keep track of the assembly status in real-time and automatically recognize error and completion states at each step. Naturally, visualization modes and their effectiveness for such context-aware systems remain unexplored. Our test-bed system automatically displays guidance information and error detection information corresponding to the recognized assembly status in the context of building block (LEGO) assembly. In our first evaluation, we compared the performance of the test-bed system in different AR visualization modes with a traditional assembly instruction style-paper manual in assembly tasks. Experimental results show that although subjects took longer to complete the assembly tasks with the test-bed system, accuracy was dramatically improved and subjects also felt that the visualization modes proposed were easier to understand and more useful than the traditional assembly style with a paper manual. Based on these results, we conducted the second evaluation to explore effectiveness of new visualization modes in situations where the best visualization mode proposed in the first evaluation does not function well. We explored two visualization modes: one having guidance information rendered on a virtual model adjacent to the real model, and the other having guidance information and the topmost layer of the virtual model rendered directly overlaying on the real model. Our experimental results suggest that both these modes had the best performance in the contexts considered respectively.

Keywords : augmented reality, assembly support system, context-aware, visualization modes.

1 Introduction

One of the most promising applications of augmented reality (AR) (i.e., systems that blend computer generated virtual objects with the real environment [3]) is in the traditional manufacturing assembly domain. In manufacturing, while some assembly operations are automated, there are still a significant number of assembly operations that require manual human effort. There are several reasons why AR may improve manual assembly. AR technology makes it possible to display digital information in the assembly subject’s field of view, such as step-by-step instructions that are essential for the work. In comparison to conventional systems such as paper based work instructions or multimedia information systems, information in AR applications can be displayed depending on the context (i.e., in reference to particular components or subassemblies). The context-related visualization of information helps to reduce search time in assembly. AR also makes it possible to reduce head and eye movements [6], the cost of attention switching and improve spatial perception, and thus increase productivity [14]. Finally, AR has the potential to resolve spatial ambiguities by displaying spatial indicators (such as arrows or spotlights) properly registered and directly overlaying the actual workpiece, freeing the user from the cognitive burden of relating actual locations on the workpiece to corresponding locations on a separate virtual model [13].

Although a number of assembly support system prototypes and test-bed applications using AR have been proposed, few keep track of the assembly status in real-time and automatically recognize error and completion states at each step. Naturally, identifying what information should be provided, what representation is appropriate for that information, and how the user should interact with the information remain unexplored.

The purpose of this study is to evaluate the effectiveness of a test-bed AR-based context-aware assembly support system in several AR visualization modes in order to understand how best to assist users in the assembly context.
2 Related Work

One of the most well-known applications of AR in the assembly domain is the assembly of cable harnesses at Boeing [3]. Their augmented reality project was designed to display pertinent instructions and diagrams in front of manufacturing workers, who use the information to work on or assemble pieces of the aircraft. The ARVIKA project [1] uses augmented reality technologies to research and implement user-oriented and application driven support solutions for a variety of working procedures. The ARTESAS project [2] aims to provide augmented reality systems to be used in complex industrial service situations. As a follow-up to the ARVIKA project, the main goal is to replace the marker-based tracking system with a marker-less one.

Although many AR-based assembly support systems have been proposed, few keep track of the assembly status in real-time and automatically recognize error and completion states at each step. Such context-aware systems are desirable and expected to meet the needs for good training, improving labor efficiency and accuracy in work.

Recently, there has also been work to track and evaluate the correctness of assembly steps presented to the user. Molineros et al. [12] put encoded markers on each part for tracking it and detecting connections with other parts. Gupta et al. [5] present a real-time system which infers and tracks the assembly process of a building block model. The system is able to detect mistakes made and helps correct them by providing appropriate feedback. However, they require users to put blocks in designated boxes on the table surface to let the system infer a virtual replica of the blocks at every step. This reduces naturalness of assembly operations. Furthermore, in their system, there exists a perception transfer problem that can occur by displaying assembly guidance on a monitor screen. In comparison, our test-bed system makes it possible for users to add or remove parts of a model being assembled naturally, since it automatically recognizes parts added to or removed from the model in real-time in the form of AR.

There has also been a rich body of work on AR visualization methods. AR information needs to be presented to the user in such a way that ambiguities are minimized as to what the information is referring to. Most studies on AR visualization methods cope with two typical sources of such ambiguities; misinterpretation of depth orders and registration errors. For the former problem, it is well known that AR information with solid rendering appears to be from most regardless of its intended depth. To better convey spatial relationships to the real objects, AR information is often rendered with a cut away box or in a semi-transparent manner. A combination of wire-frame and semi-transparent rendering is proven to help discern depth ordering [10]. For the latter problem, in the presence of registration error, expanded boundary regions based on estimated registration errors have been proposed to disambiguate the target object of concern [4]. Robertson et al. report additional visual context can also ameliorate the negative effects of registration error [16].

In our work, we focus on AR visualization modes of assembly guidance as well as evaluating them to explore AR visualization methods to best assist users in assembly tasks. There has also been work to explore the effectiveness of AR as well as AR visualization methods in the assembly, maintenance and repair domains. Henderson et al. [7] report that psychomotor aspects of an assembly task can be completed significantly faster and with significantly greater accuracy with AR than when using 3D graphics-based assistance presented on a stationary LCD. Tang et al. [17] describe an experiment that compared the effectiveness of AR instructions against three other types of instructional media (a printed manual, computer assisted instruction (CAI) using a monitor-based display, and CAI utilizing a head-mounted display. The result of the experiment shows that overlaying 3D instructions (AR instructions) on the actual workpieces reduced the error rate for an assembly task by 82%, particularly diminishing cumulative errors. These studies validated the effectiveness of AR-assisted operations over traditional monitor-based or paper-based operations. In contrast to this prior work, we investigate how AR-assisted operations can gain further benefit from automatic error detection and completion recognition during the assembly process. Also, we explore another visualization technique (in which guidance information is rendered on a virtual model adjacent to the real model) which does function well under poor geometric registration, that is different from the traditional direct overlay.

3 The Test-Bed System

The hardware setup of the test-bed system is shown in Figure 1. The user builds a building block structure from the table up, layer by layer, while the system highlights the next layer to build on the virtual representation of the real model being assembled. The system uses depth in-
formation captured in real-time by a depth sensor, the Microsoft Kinect, for acquiring and tracking. A video see-through head mounted display (Vuzix Wrap 920AR) is used to display assembly guidance information to the user. Due to limitations of the alignment and field-of-view of this hardware display, we chose to present guidance in the form of non-stereo biocular imagery. A depth camera-based system using an algorithm called Lattice-First [11] is used for real-time acquisition and tracking of LEGO blocks. It is fast and effective, providing users with the ability to incrementally construct a block-based physical model using their bare hands while the system updates the model’s virtual representation in real-time. However, the physical model must be rotated around 360° or more for full reconstruction because the tracking system uses only one Kinect. Due to filtering in the tracking system, there is slight but noticeable latency (up to approximately one tenth of a second) such that when the physical model is moving, the virtual model appears to lag behind. The virtual representation of the physical model being assembled is updated and compared with the target model of the same size in a 3D voxel grid space in real-time. Two models are compared to find out parts that should be filled or be marked as error in the physical model (see Figures 2 and 3).

4 Experiments

It is commonly suggested that AR assistance in an assembly task will increase productivity and reduce errors, compared with printed instructions.

Our experiments began with an evaluation, in which we compared printed instructions with two AR visualization modes (see Figure 4a, b).

4.1 Apparatus

All of our experiments were conducted on a desktop computer with an Intel Core 2 Duo E7400 2.80GHz x2 processor, an NVIDIA GeForce GT230 GPU and three gigabytes of memory. A Microsoft Kinect was used as a depth sensor, and a video see-through head mounted display (HMD) - the Vuzix Wrap 920AR - was used for displaying visual feedback (see Figure 5).

4.2 Evaluation I

Two visualization modes for displaying 3D assembly guidance information and detected error information: the Full-wireframe overlay mode and the Side-by-side mode (see Figure 4a, b) are proposed. In the Full-wireframe overlay mode, assembly instructions (next step blocks) are displayed directly onto the real blocks being assembled, by 3D animated color wire frames and dropped down to places where the next step blocks should be added. In the Side-by-side mode, the 3D virtual presentation of the real model is constructed in real-time and displayed next to the real blocks on table.

4.2.1 Hypotheses

The AR test-bed system displays guidance information in the form of visual feedback, such as animation, highlighting, and flashing, which should contribute beneficially to the user’s overall experience. If errors are detected, such as placing parts in an incorrect location.
formation supported by the system will be better in the following aspects: ease of understanding, ease of seeing, satisfaction level, and usefulness.

- **H3**: When compared to traditional media (printed manual), using the current test-bed system will not achieve better completion time of the assembly task.

- **H4**: When compared to traditional media (printed manual), using the current test-bed system will not support better stress level and familiarity.

### 4.2.2 Subjects

Twelve people (12 male) from the author’s laboratory participated in this study. The ages of participants were between 22 and 40 years. None of the participants had used any assembly support system using AR before. Three participants reported that they had previous experience assembling LEGO or Duplo block structures. Ten participants had experience with AR applications; four of these had experience with head mounted displays (HMD) in particular.

### 4.2.3 Experiment Design and Procedure

We used a three-way within-subjects experimental design, where the independent variable was the visualization mode for assembly instructions, and the dependent variables were time taken to complete the task, error rate, ease of use, ease of understanding, ease of seeing, stress level, familiarity, satisfaction, and usefulness. The independent variable ranged over three conditions: the control, a traditional printed instruction manual (see Figure 7), the Full-wireframe overlay mode and the Side-by-side mode, variations of an augmented reality display. Each participant was subjected to all three conditions in a ran-
domized order. For each condition, the participants were asked to assemble five building block (Duplo) models in randomized order (see Figure 6).

Before the experiment, each participant was given a tutorial on each of the conditions. Completion time and number of errors in each assembly task were recorded by the experimenter after the subject indicated they were finished. After completing all fifteen assembly tasks, each participant was asked to fill out a questionnaire asking them for feedback about their experience using the questions shown in Table 1. The questionnaire consisted of 7-point ordinal scale responses, with 1 indicating the most negative response and 7 indicating the most positive response.

Table 1: Questionnaire for evaluating the effectiveness of conditions.

<table>
<thead>
<tr>
<th>No</th>
<th>Question</th>
<th>Response Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Were the assembly instructions information and error notification difficult to understand?</td>
<td>7-point ordinal scale (1: Difficult to understand; 7: Easy to understand)</td>
</tr>
<tr>
<td>2</td>
<td>Were the assembly instructions information and error notification difficult to see?</td>
<td>7-point ordinal scale (1: Difficult to see; 7: Easy to see)</td>
</tr>
<tr>
<td>3</td>
<td>Did you feel stress when using this assembly instructions media?</td>
<td>7-point ordinal scale (1: Feel very stressed; 7: Do not feel the stress)</td>
</tr>
<tr>
<td>4</td>
<td>Did you feel difficult to become familiar with the assembly instructions media?</td>
<td>7-point ordinal scale (1: Difficult to become familiar; 7: Easy to become familiar)</td>
</tr>
<tr>
<td>5</td>
<td>Did you feel satisfied with the assembly instructions media after using it?</td>
<td>7-point ordinal scale (1: Not satisfied at all; 7: Very satisfied)</td>
</tr>
<tr>
<td>6</td>
<td>Did you feel the assembly instructions media useful for the assembly tasks?</td>
<td>7-point ordinal scale (1: Not useful at all; 7: Very useful)</td>
</tr>
</tbody>
</table>

4.2.4 Analysis of quantitative data

Figures 8 and 9 indicate the overall completion time and average number of errors, respectively. Stars indicate significance levels as follows: * p<0.05, ** p<0.01, *** p<0.001. In this experiment, AR instructions did not appear to have an advantage in completion time compared with the traditional instruction media; the printed manual condition had the shortest completion time while the Full-wireframe overlay mode had the longest. However, subjects in the printed manual condition occasionally made assembly errors without noticing, whereas in the AR conditions the errors were pointed out by the system and the subjects corrected them before finishing the assembly.

We conducted a repeated measures Analysis of Variance (ANOVA) test and found significant differences among the three conditions in both completion time ($F_{2,9} = 24.116, p < 0.0001$) and mean number of errors ($F_{2,9} = 25.000, p < 0.0001$). We conducted a post-hoc analysis using pairwise t-tests with the Holm’s Bonferroni adjustment [8], and found that mean completion time was significantly shorter with a printed manual than with the Side-by-side mode ($t_{11} = -3.577, p < 0.025$), yet shorter with the Side-by-side mode than the Full-wireframe overlay mode ($t_{11} = -3.645, p < 0.05$). We also found that the error rate using the printed manual was significantly greater than in the other conditions ($t_{11} = 5.000, p < 0.025$) when compared with the Full-wireframe overlay mode and ($t_{11} = 5.000, p < 0.05$) when compared with the Side-by-side mode.

4.2.5 Analysis of questionnaire data

Figure 10 shows that the Side-by-side mode performed better than the printed manual specifically in the following aspects: ease of understanding, ease of seeing, satisfaction level and usefulness.

We used a non-parametric Friedman test to check for significant differences in qualitative metrics reported by participants for each condition. We found significant differences among effect of conditions in the aspect of
ease of understanding ($X^2 = 18.681$, $p < 0.0001$). Using Wilcoxon signed rank tests with the Holm’s Boneferroni correction, we found significant differences between the Side-by-side mode and the paper manual ($z = -3.063$, $p < 0.0167$) and between the Side-by-side mode and the Full-wireframe overlay mode ($z = -2.937$, $p < 0.025$) but there was no significant difference between the Full-wireframe overlay mode and the printed manual ($z = -1.533$, $p = 0.125$). The participants reported that they were easy to understand and easy to figure out what to do next when using the support of the system. We also found significant differences among effect of the conditions on the ease of seeing aspect ($X^2 = 11.783$, $p < 0.01$). Using Wilcoxon signed rank tests with the Holm’s Boneferroni correction, we found significant differences between the Side-by-side mode and the Full-wireframe overlay mode ($z = -2.941$, $p < 0.0167$) and between the Side-by-side mode and the printed manual ($z = -2.672$, $p < 0.025$) but no significant differences between the Full-wireframe overlay mode and the printed manual ($z = -0.534$, $p = 0.593$). Statistical data also showed that effect of conditions in the aspect of stress level ($X^2 = 6.617$, $p = 0.046$), familiarity ($X^2 = 4.638$, $p = 0.098$), satisfaction level ($X^2 = 3.957$, $p = 0.138$) and usefulness ($X^2 = 4.667$, $p = 0.097$) were not found to be significant. However, the small $p$-value suggests that this difference may be significant with more participants.

4.2.6 Discussion

In the first evaluation, the test-bed system was hypothesized to significantly improve accuracy and reduce errors of assembly tasks when compared to traditional media (printed manual) (H1). The result of the experiment supported this hypothesis. With the traditional instruction media (printed manual), mistakes made by the subjects were realized when the subjects had passed several assembly steps and almost at or after the timing of completion assembly of the model. With automatic detecting the models status in real-time supported by the system, the subjects made almost no mistakes. Although there were still some mistakes which occurred by placing parts in a wrong location or incorrect orienting parts during assembly process, they were detected and notified by the system in real-time right at each assembly step and the subjects easily corrected them by following the appropriate guidance instructions of the system corresponding to the recognized states at that time.

In the aspects of ease of understanding, ease of seeing, satisfaction level and usefulness, our hypothesis stated that the guidance information modes (the Full-wireframe overlay mode and the Side-by-side mode) supported by the system are significantly better when compared with the traditional media (printed manual) (H2). We believed that displaying guidance information and notifying the user by visual feedback, such as animation, highlighting and flashing using AR display techniques help the subjects to see and understand guidance information. Visualization modes of the system display guidance information step-by-step visually. The result of the experiment supported this hypothesis.

For completion time of the assembly tasks, the experiment’s result also supported our hypothesis (H3) that using support of the test-bed system, subjects may not achieve better completion time of assembly tasks when compared with traditional media (printed manual). This result could be explained because the current test-bed system uses only one Kinect device, the subjects have to rotate the physical model to let the system construct the 3D virtual model of the model being assembled as well as recognize completion and error states on the physical model and this requires time. The system guides the user
step-by-step instructions, therefore, with simple models, the subjects seem to spend more time to complete assembly tasks than using printed manual. As another reason for this result, the test-bed system uses a video see-through head mounted display (HMD) to display guidance instructions. Since the real world is digitized, and due to the lack of binocular and accommodation depth cues, the sense of distance to the model is not as good as sense of distance to the model in case of using traditional media with naked eye. This partially slowed down the subjects’ assembly operations.

In the aspects of stress level and familiarity, we predicted that using the test-bed system may not support better stress level and familiarity (H4) because of disadvantages of video see-through displays include a low resolution of reality, a limited field-of-view, fixed focus distance and biocular display may cause user discomfort, eye strain and fatigue. The result of the experiment supported our prediction with the printed manual have stress level lower than the Full-wireframe overlay mode but there was no statistically significant effect between the printed manual and the Side-by-side mode.

4.3 Evaluation II

In this evaluation, we explore effectiveness of visualization modes of Overlay in situations where the Side-by-side mode proposed in the first evaluation does not function well.

In the first evaluation, the Side-by-side mode had the better performance than the Full-wireframe overlay mode in task completion time as well as users’ subjective evaluation. However, side-by-side visualization is not always available as we need an empty space next to the target object. For example, in a situation that size of models being assembled is too big, virtual representation rendered adjacent to the real models in the Side-by-side mode cannot be displayed due to limited, small size of HMD screens. Obviously, the Side-by-side mode cannot be used in this situation and the Overlay mode is a better choice.

However, the Overlay mode is easy to be affected by registration errors. In the first evaluation, participants reported the Full-wireframe overlay mode made it easier to figure out the position of the next guided blocks in situations of poor alignment between guidance information and the real models. The participants also reported that the display of full virtual presentation of real models being assembled in the Full-wireframe overlay mode made them hard to see parts of the real models, so they spent more time to determine the right position of the next guided blocks on the real models. Also in the first evaluation, some participants reported that they may prefer a mode where the real model is displayed without overlay, and only the next guided blocks is rendered with augmented imagery. It may help them to see the real blocks more easily specifically when rotating the models. However, they also agreed that they may have to pay more attention to determine the right position blocks being added because there will be no reference in poor alignment situations.

Based on the feedback from the first evaluation, we propose two new variations for the overlay mode beside the Full-wireframe overlay mode. Then we compare them in an assembly task experiment to determine the best visualization mode among the three variations of the overlay mode.

4.3.1 Proposed Variations of Overlay Mode

To keep the advantage of the Full-wireframe overlay mode as well as reducing the problems with it, we developed: the Partial-wireframe mode (see Figure 4c). The idea of this visualization mode is that instead of displaying the full virtual representation of real models being assembled, only a portion of the virtual representation immediately below the block being guided is displayed. This visualization mode helps users to see real models easier while it also helps them to figure out the position of the next blocks. This visualization is expected to have a better performance than the current Full-wireframe overlay mode. We also proposed another visualization mode that we call the Phantom overlay mode (see Figure 4d) based on feedback from study participants who felt that only the next guided block should be superimposed onto the real model.

4.3.2 Subjects

Six people (3 males, 3 females) from different faculties of a co-author’s university participated in this evaluation. The ages of participants were between 22 and 35 years. None of the participants had used any assembly support system using AR before. Five participants have no experience with AR and they reported that this was the first time they assembled LEGO, Duplo block structures. This evaluation was conducted on a test-bed with the same hardware setup with the first evaluation (see Figure 5).

4.3.3 Experiment Design and Procedure

We used a three-way within-subjects experimental design, where the independent variable was the visualization mode for presenting assembly instructions, and the
dependent variables were time taken to complete the task, ease of use, ease of understanding, ease of seeing, stress level, familiarity, satisfaction, and usefulness. The independent variable ranged over three conditions: the overlay mode from the first evaluation (the Full-wireframe overlay mode), and two proposed variations, the Partial-wireframe overlay mode and the Phantom overlay mode. Each participant was subjected to all three conditions in a randomized order. For each condition, the participants were asked to assemble two building block (Duplo) models in randomized order (see Figure 11).

Before the experiment, each participant was given a tutorial on each of the conditions. The completion time in each assembly task was recorded by the observer. After completing all six assembly tasks, each participant was asked to fill out the same questionnaire from evaluation I (see Table 1), allowing them to give feedback about their experience with each condition.

4.3.4 Analysis of quantitative data

Figure 12 illustrates the mean time of completion for each condition in the pilot study. The Partial-wireframe overlay condition had the shortest completion time, while the Phantom overlay mode had the longest. We conducted a repeated measure ANOVA test and found differences in completion among the conditions ($F_{2,3} = 7.737, p < 0.009$). Using post-hoc pairwise t-tests, we found differences between the Partial-wireframe overlay mode and the Phantom overlay mode ($t_5 = -2.992, p = 0.03$) and between the Full-wireframe overlay mode and the Phantom overlay mode ($t_5 = -2.710, p = 0.042$). However, due to the Holm’s Bonferroni adjustment, these differences were not statistically significant.

In this evaluation, mean number of errors per assembly task found on models after completing the assembly task were not considered because the automatic error detection function of the test-bed system helped users to find and fix all errors occurred during assembly process.

4.3.5 Analysis of questionnaire data

Figure 13 shows that the Partial-wireframe overlay mode had a better performance than the Phantom overlay mode specifically in aspects: ease of understanding and usefulness.

We used a non-parametric Friedman test to check for significant differences in qualitative metrics reported by participants for each condition. We found significant differences among conditions in the aspect of ease of understanding ($X^2 = 9.238, p < 0.01$) and in the aspect of usefulness ($X^2 = 9.238, p < 0.01$) but no significant differences on ease of seeing, stress level, familiarity and satisfaction level. We performed a post-hoc analysis with Wilcoxon signed rank tests with the Holm’s Boneferronni correction on ease of understanding and usefulness aspects to uncover interesting patterns. For ease of understanding, we found differences between the Partial-wireframe overlay mode and the Phantom overlay mode ($X^2 = 2.214, p = 0.027$) and between the Full-wireframe overlay mode and the Phantom overlay mode ($X^2 = 2.032, p = 0.042$). For usefulness, we found differences between the Partial-wireframe overlay mode and the Phantom overlay mode ($X^2 = 2.207, p = 0.027$) and between the Full-wireframe overlay mode and the Phantom overlay mode ($X^2 = 2.041, p = 0.041$). Due to
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the Holm’s Bonferroni adjustment, these differences were not found to be significant. However, small p-value suggests that these differences may be significant with more participants.

4.3.6 Discussion

In the evaluation II, we expected the Partial-wireframe overlay mode to have the best performance because it combines the merits of the Full-wireframe overlay mode and Phantom overlay mode.

Although the statistical analysis of this evaluation did not show significantly better performance of the Partial-wireframe overlay mode, (due to small sample size), five of the six participants preferred this mode over the other two. They reported that the Partial-wireframe overlay mode makes it easier for them to see and determine the position of guided blocks on real models while still helping them to figure out the spatial correspondence between the guided blocks and the real models being assembled. The Phantom overlay mode was reported to be relatively easy to see, but made it difficult to determine the correct location to place the next piece. The Full-wireframe overlay mode got the lowest evaluation among three modes. The participants reported that because of misalignment and the potential to mistake between some parts of the real model and parts of virtual representation due to the same color, they spent more time to try to determine the position of next blocks in this mode.

5 Conclusion

In this study, we proposed and evaluated the effectiveness of visualization modes for an AR based context-aware assembly support system in object assembly. Our experiments showed that although subjects took longer to complete the assembly tasks using the proposed AR systems, the accuracy was dramatically improved when compared with the traditional instructions method (print manual). Context-related visualization modes proposed was also significantly preferred to traditional media (print manual) in the following aspects: ease of understanding, ease of seeing, satisfaction level and usefulness.

In the evaluation I, we confirmed that the side-by-side mode is a promising visualization method that is comparable to, or even better than, a traditional overlay visualization method. However, side-by-side visualization is not always available as we need an empty space next to the target object. In the evaluation II, we therefore explored a better overlay visualization method for situations where side-by-side visualization is not available, and found the Partial-wireframe overlay method was the best among three Overlay visualization modes proposed. We believe that two visualization modes found in this study (the Side-by-side mode and the Partial-wireframe overlay mode) as well as our experimental results provide useful insight into the design of AR visualization techniques for assembly support systems as well as establish a basis for follow-up studies. As a follow-up study, we conducted a comparative experiment between the Side-by-side and the Partial wireframe modes [9]. We plan to conduct a series of studies, such as those with an optical see-through HMD, and with a more robust object tracking algorithm.

Although visual guidance based on geometric models has been solely investigated in this study, other forms of visual assistance [18][15] are also an interesting area to explore.

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[Authors' Introduction]

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