EXPERIMENTAL FRAMEWORK FOR EVALUATING COGNITIVE WORKLOAD OF USING AR SYSTEM IN GENERAL ASSEMBLY TASK

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ABSTRACT: Assembly task is an activity of collecting parts/components and bringing them together through assembly operations to perform one or more of several primary functions. As an emerging and powerful technology, Augmented Reality (AR) integrates images of virtual objects into a real world. Due to its self-characteristic features, AR is envisaged to provide great potentials in guiding assembly task. In this paper, it reviews some AR applications in the area of assembly and elaborates the great potentials of integrating animated agent with current AR technique in guiding product assembly. Besides, in view that different assembly operations share certain common features and functions in essence, the authors formulate the experimental framework for evaluating cognitive workload of using animated AR system in general assembly task and make the framework general to be applied in evaluating diverse classes of AR systems for different assembly operations.

***Keywords**: Augmented Reality, Cognitive Workload, Experimental Framework*

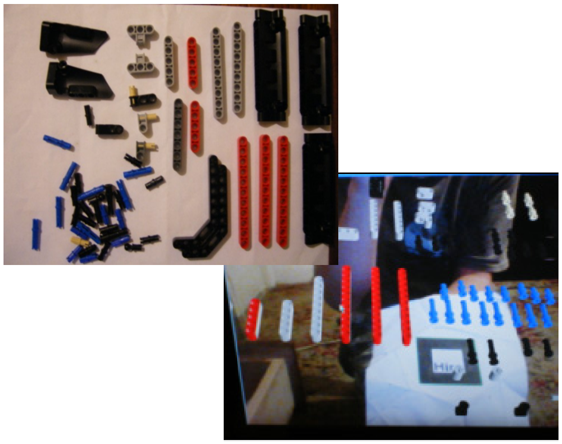
1. STATE-OF-THE-ART REVIEW OF AUGMENTED REALITY FOR PRODUCT ASSEMBLY

As an emerging and cutting-edge technology, Augmented Reality (AR) technology integrates images of virtual objects into a real world. By inserting the virtually simulated prototypes into the real environment and creating an augmented scene, AR technology could meet the goal of enhancing a person's perception of a virtual prototyping with real entities. This gives a virtual world a better connection to the real world, while maintains the flexibility of the virtual world. Through AR, an assembler can directly manipulate the virtual components while identify the potential interferences between the to-be-assembled objects and the existing objects inside the real environment. Therefore, in AR environment, an assembler cannot only interact with real environments, but also interact with Augmented Environments (AEs).

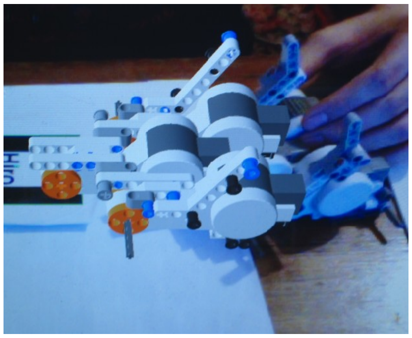
There are some critical AR applications in assembly area: In order to obtain the optimized assembly sequence, Raghavan et al. (1999) adopted AR as an interactive technique for assembly sequence evaluation and formulated the assembly planner and liaison graph. In their work, they have addressed the issue of automatically generating the most optimized product assembly sequence in AEs. Besides, Salonen and his colleagues (2007) used AR technology to conduct their research in the area of industrial product assembly and developed a multi-modality system based on the commonly used AR facility, a head-mounted display (HMD), a marker-based software toolkit (ARToolKit), image tracking cameras, web cameras and a microphone. Additionally, considering the utilization of AR in product assembly design was based on the marker registration technology, Xu and others (2008) realized a markerless-based registration technology, for the purpose of overcoming the inconveniences of applying markers as the carrier in assembly design process. Nowadays, the utilization of AR assembly has extended to a wide range of products, e.g., furniture assembly design (Zauner et al., 2003), toy assembly design (Tang et al., 2003), and so on. Notwithstanding, these research works have achieved fruitful results, there are still some issues far from being well solved in the assembly area. For instance, previous works have not completely eliminated the assemblers' cognitive workload when using AR as an alternative of manuals. To most previous applications, the virtual images of to-be-assembled objects are typically registered for merely reflecting the bilateral or multilateral position relations of to-be-assembled objects, but the assembly process is dynamic and it should include the dynamic context like displacement path, spatial interference and so on. Accordingly, to acquire the sequent information context such as assembly path and fixation forms of part/component, the assemblers still need a positive cognitive retrieval after they retrieve these static AR clews in mind.

2. COGNITIVE FACILITATIONS OF INTEGRATING THE ANIMATED AGENT WITH AR IN ASSEMBLY TASK

The dynamic requirement of adopting AR in assembly has raised a promising trade-off: integrate the dynamic animation with the existing AR facility and make them as a dynamic augmented agent to guide the assembly task. This way, collaboration between information retrieval and task operation could possibly be realized. The following snapshots briefly present our related work, where we developed the animated AR system to guide LEGO toy assembly. In this work, the virtual counterparts of physical LEGO components (Model No.8263) and the animated process of assembly are formulated as AR assembly guidance (Fig. 1).



(a)



(b)

Fig. 1 (a) Snapshots of 65 LEGO components (physical view and AR views) (b) Using animated AR system in guiding LEGO assembly.

2.1 Enhancement of information retrieval capacity

In animated AR system, it provides a dynamic demonstration of consistent information context via animation segments displayed in each assembly step. Assemblers could detect the existing dimensions from already positioned components as well as the registered ones attached to the virtually to-be-assembled components from see-through HMD. At the same time, animation dynamically demonstrates the assembly process in HMD by approaching the virtually to-be-assembled objects to the already-assembled ones installed in the ideal positions (Fig. 2). This enables assemblers to mimic each assembly step and complete real assembly operation with great ease. Through demonstrating a series of virtual animation segments registered in real environment, AR compensates for the mental and cognitive gaps between individual differences of information retrieval capacity and lowers the influences that task difficulty imposes on individuals. Consequently, it eases the information retrieval.

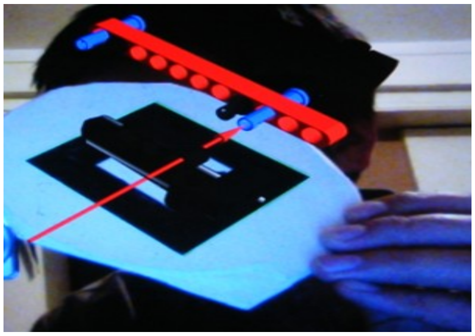


Fig. 2 Virtual arrow hints pin-hold assembly.

2.2 Collaborative assembly guidance

Collaborative guiding is another characteristic feature of animated AR system. To each step, augmented animation dynamically and sequentially ushers the position changes of spatial components by means of the activation of each animation segment triggered by the assemblers themselves. When completing each animation segment, the system turns into a visual tool for presenting the statically augmented component images, as well as the attached information. In parallel, the system is temporarily suspended for the next trigger by assemblers. During each suspended interval after last bout of guiding animation, the assemblers have plenty of time to pick up the components from the rest, and position them properly. This way, implementing assembly and retrieving augmented guidance could be proceeded collaboratively (Fig. 3).

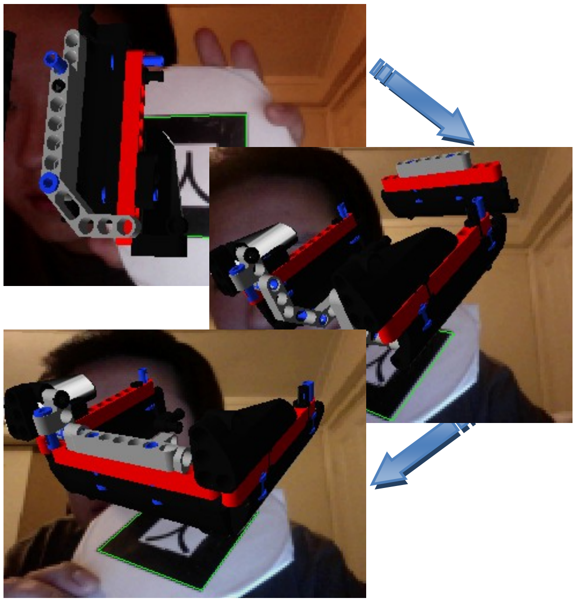


Fig. 3 Step-by-step guidance with completion sequence: left, right and front (dumper).

2.3 Stimulation of motivation

The fun of interactive experience in animated AR system might stimulate the task motivation. As Chignell et al., (1997) stated that multimedia could produce a rich sensory experience that not only conveyed information but also increased motivation and interest to its operator or viewer and improvement of interactivity is contributive to the enhancement of assembly motivation, it is believed that animated AR is a good multimedia to increase motivation by offering lifelike assembly guidance environment and enabling interactive operation to assemblers.

3. EXPERIMENTAL FRAMEWORK FOR EVALUATING AR SYSTEM IN GENERAL ASSEMBLY

This section discusses an experimental framework of how to evaluate cognitive workload when using AR system for general assembly task (Fig. 4). The authors make the framework general to be applied in evaluating diverse classes of AR systems for different assembly operations, considering that different assembly operations share certain common features and functions in essence. The framework can be applied in evaluating the AR system presented in this paper as well as the other types of AR systems for other assembly operations.

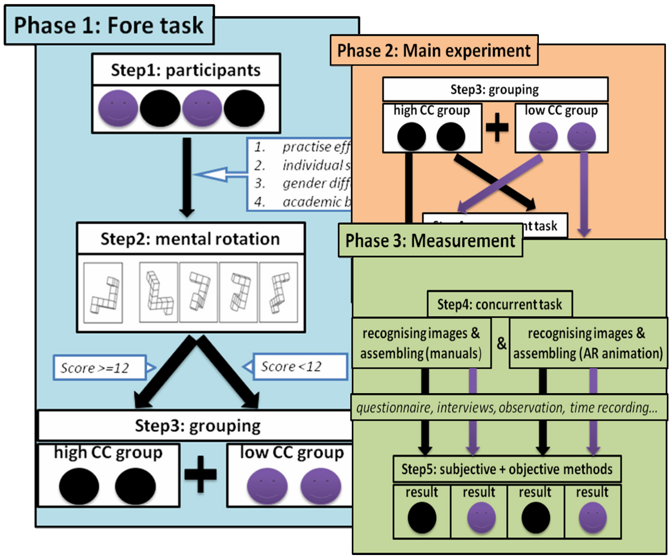


Fig. 4 Evaluation framework for AR systems for general assembly.

3.1 Fore-task (Phase 1)

The intent of designing a fore-task is to distinguish the human subjects according to their different levels of inherent cognitive capacity. This is prior to the main experiment and the results can be used to help analyze the findings in the main experiment. The notion of cognitive capacity is related to a person's ability to mentally move into a spatial space, navigate in this environment and manipulate the visuo-spatial imagery. To date, mental rotation is regarded as a direct and convenient measurement for human capacity of spatial object cognition. The principle of mental rotation refers to a mental processing of objects transformation, rather than physically rotating the objects. Testers are required to recognize those objects as mental images and rotate them mentally, and then they should decide whether one version of the object image is a reflected version of the other. As Kosslyn (1994) pointed out, objects in images first moved along continuous trajectories as they were transformed and then came the mechanism used in visual cognition and mental imagery. In view that the task processing refers to the visuo-spatial input, mental manipulation and visuo-spatial output, (needs considerable spatial capacity and cognitive workload), it is secure and reliable to use mental rotation to roughly divide different levels of cognition. The fore-task uses the 24 items testing based on testing sheet. For each item, there is an original layout of a given spatial object and its four rotated versions (Fig. 5). However, only two of them are the same spatial layout of the given one while the other two play a role in confusion to the testers. For the testers, they have to try to figure out which two of the four are the true reflections of the given object. During the mental rotation task, there are some variables to identify, e.g., practice effect, individual strategies, gender difference, academic background and so on. Based on the performance of mental rotation task, the human subjects should be divided into different groups (high cognitive capacity or low cognitive capacity).

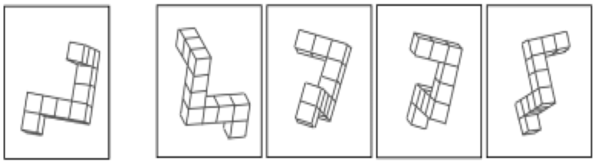


Fig. 5 An item in mental rotation test sheet.

3.2 Main experiment and measurement (Phase 2 &3)

The aim of the main experiment is to study the human subjects' performance of merging the digital virtual information (e.g., animated AR guidance) into the real assembly workspace on the nature of a person's cognition as compared with merging the physical information (e.g., manuals) into the real assembly workspace. The concurrent task strategy (also known as secondary task strategy) is supposed to be applied. It reflects the level of cognitive load imposed by a primary task. The secondary task entails simple activities that require sustained attention, such as detecting a visual or auditory signal, and the typical performance variables are reaction time, accuracy, error rate and so on. Specifically, the measurement should contain mental load (which originates from the interaction between task and subject characteristics. It provides an indication of the expected cognitive capacity demands and can be considered as a priori estimate of the cognitive load), mental effort (which refers to the cognitive capacity that is actually allocated to accommodate the demands imposed by the task, thus it can be considered to reflect the actual cognitive load) and recorded performance (which is in terms of learner's achievements, such as the number of correct test items, number of errors, time consumption, etc). According to adding concurrent cognitive task, the susceptibility of human mental and motor performances could be examined. This is based on the tentative that to those who suffer less cognitive load, they may free up their cognitive capacity to deal with interfering tasks.

The next issue is to address what is considered to be the appropriate and plausible measurement for human cognitive workload in assembly task, a criterion for measuring cognitive load should be constituted. The measurement of cognitive workload was proved to be diverse for researchers. The mainstream of measurements for cognitive workload includes subjective analytical methods and empirical methods e.g., subjective data collection and analysis (usually involves a questionnaire comprising one or multiple semantic differential scales where the participant can indicate the experienced level of cognitive load), and rating scale technique (based on the assumption that people are able to introspect on their cognitive processes and to report the amount of mental effort expended) (Xie & Salvendy, 2000). Most subjective measures are multidimensional in that they assess groups of associated variables, such as mental effort, fatigue, and frustration, which are highly correlated. Rating scale may appear questionable, however, it has been demonstrated that people are quite capable of giving a numerical indication of their perceived mental burden. What is more, physiological perspective has also provided us some useful measurements that are based on the assumption that changes in cognitive functioning are reflected by physiological variables. These techniques include measures of heart activity, brain activity and eye activity. Typically, the possible trade-off is combining the subjective analytical methods (questionnaire, interviews) and objective methods (task performance observation, time recording), and adopting the rating scale technology based on questionnaire, e.g., NASA Task Load Index (Hart, 2006) (Fig. 6) and subjects' experience evaluation (Fig. 7), since the subjective workload measurement techniques using rating scales are easy to use, inexpensive, reliable, can detect small variations in workload and provide decent convergent, construct and discriminate validity (Gimino, 2002), meanwhile, the objective measurement techniques (task performance observation and time recording) are robust to conduct the susceptibility research and enable the experimental results of both subjective and objective analysis (Mulhall et al ., 2004). Last but not least, a counterbalanced means for minimizing the evaluation bias or order effects can also be applied (see Table 1). This is formulated on the basis of Wang's research work (2005), where he counterbalanced whether the Mixed Reality-based collaborative virtual environments for pipeline layout design were evaluated relative to the paper drawing and vice versa. Users can define any categories of counterbalanced evaluation in each questionnaire that handles the evaluation of one method against the other, and collect subjective data according to ranging scaled technique, for example, from totally agree, agree, disagree to totally disagree (4 scales).

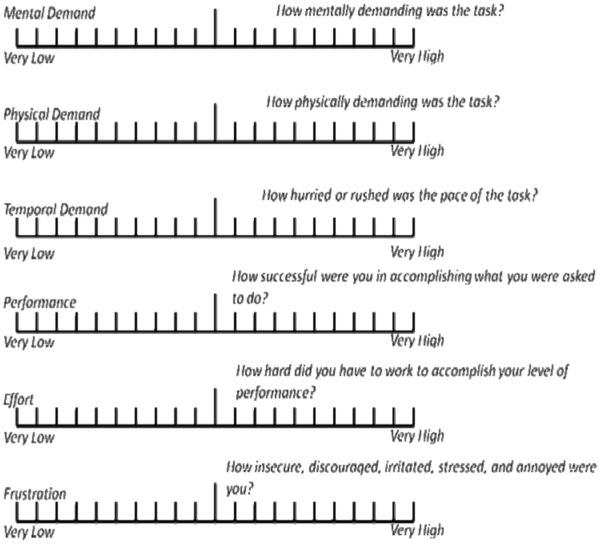


Fig. 6 NASA Task Load Index based on questionnaire, a hierarchical measurement for cognitive workload consists of six items. Each refers to the workload of a specific activity).

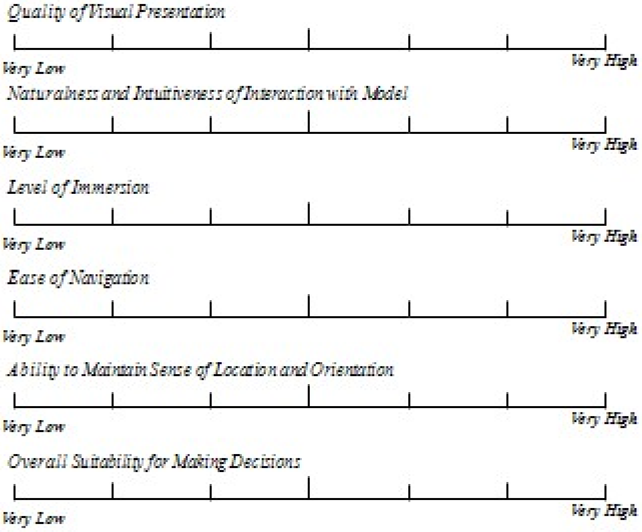


Fig. 7 Rating both methods in the six aspects based on the six levels.

Questionnaire #1	Questionnaire #2
Q1: I felt 3D interactivity in animated AR system aided assembly comprehension. Q2: Overall, compared with paper drawing, the animated AR system better facilitated assembly collaboration tasks. Q3: The animated AR system better facilitated information retrieval. Q4: The animated AR system better facilitated problem-solving. Q5: The animated AR system increased the overall quality of output from the screen view. Q6: The animated AR system better facilitated the quantity of assembly work could complete in a given amount of time. Q7: The animated AR system increased understanding of the guidance and me.	Q1: I felt that 3D interactivity in animated AR system aided assembly comprehension. Q2: Overall, compared with paper drawing, the animated AR system better facilitated assembly collaboration tasks. Q3: The animated AR system better facilitated information retrieval. Q4: The animated AR system better facilitated problem-solving. Q5: The animated AR system increased the overall quality of output from the screen view. Q6: The animated AR system better facilitated the quantity of assembly work could complete in a given amount of time. Q7: The animated AR system increased understanding of the guidance and me.

Table. 1 A counterbalanced means for evaluating whether AR-based guidance is relative to paper drawing.

4. CONCLUSION AND FUTURE WORK

Based on the reviewed AR applications, this article proposes some cognitive facilitations of integrating animated agent with state-of-the-art AR technology. The main contribution of this article is it formulates an experimental evaluation framework of validating AR systems for general assembly tasks. From a procedural perspective, such a framework elaborates how to apply the mental rotation task to divide the participants in terms of cognitive capacity in pre-experimental stage, how to utilize the secondary task technique to impose a cognitive workload on assembly task in main experiment, and how to exert the subjective and objective methods to process the data collection and alleviate the bias after the experiment. One of the future work/experimentation is to investigate whether or not users who are trained under animated AR system (compared with manuals) are capable of gaining more usable cognitive resource and are of more and longer mental resource rehearsal, which might further facilitate human short-term memory.

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