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Multi-modal augmented-reality assembly guidance based on bare-hand interface

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ABSTRACT

One of the most beneficial applications of Augmented Reality (AR) technology is in the traditional manual assembly domain in manufacturing. However, in order to improve the usefulness and effectiveness of the state-of-the-art AR assembly guidance systems, it is imperative to integrate human cognition support to deliver the most appropriate modality and amount of information so that the users can receive and process it effortlessly. In this paper, a novel human Cognition-based interactive Augmented Reality Assembly Guidance System (CARAGS) is proposed to investigate how AR can provide various modalities of guidance to assembly operators for different phases of user cognition process during assembly tasks. An intuitively enhanced bare-hand interface (EBHI) is integrated to facilitate the interaction between the user and the rendered contents. In order to evaluate the benefits of CARAGS for assembly operators, the proposed system is benchmarked against two baseline conditions, namely, a LCD screen-based digital documentation system and a traditional AR assembly guidance system. In addition, a qualitative evaluation of the system performance is performed in terms of intuitiveness, ease of use, and satisfaction of the proposed system.

1. Introduction

Augmented Reality (AR) has been a popular technology, which can provide a seamless interface that bridges the gap between the real and virtual world [1]. One of the most beneficial applications of the AR technology is in the traditional manufacturing assembly domain [2]. In manufacturing, there are still a significant number of assembly operations that require manual human effort, especially for products which are highly customized or with high complexity. For example, in automobile fabrication, the assembly of body and chassis are typically automated, while the final assembly of internal and electrical devices is usually manual. In manual assembly, the majority of operations are conducted by trained assembly operators applying established procedures. Due to the increasingly flexible and reconfigurable procedures, interfaces designed to support operators in manual assembly become increasingly imperative [3].

AR has been widely implemented to improve the manual assembly efficiency because it can display virtual digital information blended with the real work scene in the operator's view (e.g., step-by-step instructions and 3D illustrations) in real-time during an assembly operation [4]. In comparison with conventional guidance methods, such as paper-based work instructions, assembly guidance systems based on AR can help reduce search time for relevant instructions [5], and allow the user to focus on the task by rendering guidance materials close to the working area spatially to minimize attention switching [6]. However, user cognition support in traditional AR assembly guidance systems during assembly operation may not be well understood. For current systems, the assistance level for all users is identical without considering the users' individual cognitive characteristics, the users' cognition state and task progress [7]. Consequently, the efficiency and effectiveness of skill transfer and task execution will be reduced. To address this issue, AR assembly guidance systems need to consider a user's cognition state with regards to the ongoing workflow. Continuous and seamless interaction between the user and the system is imperative to provide timely and multi-modal guidance appropriate to the current situation.

In this paper, a novel human Cognition based interactive Augmented Reality Assembly Guidance System (CARAGS) is proposed to explore how AR can provide different modalities of guidance to assembly operators for various cognition phases. CARAGS provides (1) a semantics-based workflow model taking into consideration user cognition, process information, and component

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configuration, (2) multi-modal AR guidance and feedback according to the workflow manager, and (3) a natural user interface to enhance the interaction between the user and the system. In order to evaluate the benefits of CARAGS for assembly operators, CARAGS is tested against two baseline conditions, namely, a LCD screen-based digital documentation system and a traditional AR assembly guidance system. During the experiment, behavioral and attitudinal experiences of the participants are collected and analyzed.

The paper begins with a review of the state-of-the-art AR assembly guidance systems (Section 2) and an overview of the proposed system (Section 3). The details of CARAGS, i.e., the function modules and workflow, are described in Sections 4 and 5. The design and user testing of the system for assisting assembly operators in an industrial assembly case are described in Sections 6 and 7 summarizes the study and recommends the future work.

2. Related work

2.1. AR-assisted assembly systems

AR assembly guidance systems have been developed generally to augment virtual instruction information onto a user's view to facilitate the assembly processes. Caudell and Mizell proposed the first implementation of a classic AR assembly guidance system by combining head position sensing and real world registration with head mounted display (HMD) [8]. Yuan et al. proposed a guidance information panel rendered on screen or on a marker, and the operator needs to use a stylus with a color feature to request for the relevant assembly guidance data [9]. Zhang et al. proposed a method to integrate the RFID technology with AR assembly guidance, aiming at providing just-in-time information rendering for the assembly operator [10]. As can be seen, instead of replacing manpower with machines to improve work quality, AR enables operators to perform tasks which require a higher level of qualification. Henderson and Feiner presented an AR system to aid users in the psychomotor phase of procedural assembly tasks [11]. Radkowski et al. presented an analysis of two factors that may affect the effectiveness of AR assembly guidance systems, namely, the complexity of the visual features, and the complexity of the product [12]. Makris et al. proposed a system which integrated AR technologies with the use of CAD data to provide visual instructions of assembly tasks [4]. However, although much effort has been expanded on this topic, some of the AR assembly guidance systems seem to focus solely on providing step-based instructions for the user, i.e., overlooking a user's need of timely guidance in assembly operations. In addition, the interaction mechanisms between the user and the system are generally based on external devices, such as control stick, mouse and keyboard, which may disturb the on-going assembly operation.

Context-aware systems were proposed to deliver appropriate information to help engineers and technical personnel make real-time decisions, by monitoring the workspace context, and then adjusting the retrieval of digital information with the identified context parameters [13]. In the area of assembly guidance, context-aware AR assembly systems were proposed to keep track of the status of user and assembly operation in real-time, recognizing manual errors and completion at each assembly step automatically, and displaying multi-media instructions corresponding to the recognized states [6]. Rentzos et al. proposed a context-aware AR assembly system, which integrates the existing information and knowledge available in CAD/PDM (Product Data Management) systems based on the product and process semantics, for real-time support of the human operator [14]. Recently, there are also works to investigate the recognition and tracking of the pose of objects in an assembly, such that the corresponding information can be retrieved from the system [15,16]. Chen et al. proposed an adaptive method, in order that the virtual guiding instructions can be displayed on suitable screen region from a comfortable viewpoint [17].

In manual assembly tasks, the operators can encounter with multiple sources and forms of guidance information, and therefore pertinent information has to be filtered, organized and executed appropriately according to the user's cognition. From a technical perspective, this can be realized with a context-aware system equipped with multiple sensors (context-awareness guidance) [18]. However, a prerequisite for the sufficient utilization of context information within a guidance system is the knowledge and understanding of the cognition process of the users which is currently lacking attention in the study of assembly guidance systems. By investigating the user's cognitive capability, the mechanisms of automatic reasoning and adaptation to the changing tasks and environments can be achieved [19].

2.2. User cognition in AR assembly guidance

In order to study the benefits achieved from AR in assembly tasks through supporting the whole spectrum of cognition processes, Stork and Schubo investigated human cognition, i.e., from attention allocation through action execution, in AR production environments [20]. In order to improve this issue, Gorecky et al. proposed two methods for cognitive aided training, i.e., the active recognition using sensor networks and workflow recognition [21]. Webel et al. proposed a multi-modal AR-based assembly system in order to guide the technicians in the underlying skills (sensorimotor and cognitive) [22]. All these studies created new possibilities for AR assembly guidance and thus could improve the way user acquire practical skills. However, few works in this field give special attention to the recognition of the user's cognition during the performance of single actions. Several papers were published by Webel et al. [23,24] and Gavish et al. [25] to describe their design recommendations for AR assembly guidance based on the fusion of cognitive science, psychology and AR. In future, more functional modules related to user cognition should be integrated with the AR assembly guidance system, and hence, further studies should focus on the investigation on the compatibility and optimization of such integration.

2.3. Summary

A review of the state-of-the-art AR guidance systems for assembly operations reveals that there is not yet a study on exploring benefits by providing various specific modality of guidance to different phases of the user cognition process, to support the user in receiving and processing the guidance materials effortlessly and reduce the misunderstanding. Although some human cognition based assembly support system prototypes and test-bed applications using AR have been proposed, they are primarily proof-of-concept applications, and many of them are not implemented in an industrial case. In addition, the natural interaction between the user and the AR guidance system, especially between the user and the rendered contents, is neglected in the reported studies, i.e., the concepts and techniques for the natural user interface without the support of external devices have yet to be explored thoroughly.

3. Overview of CARAGS

CARAGS primarily consists of four modules, namely, the AR-based Task Environment (ARTE) module, the AR Kernel Functions (ARKF) module, the database of Source Media Files (SMF), and the AR Guidance Manager (ARGM) module (Fig. 1). The assembly