Augmented Reality Aided Assembly Design and Planning

S.K. Ong[2] (2), Y. Pang[1], A.Y.C. Nee[1,2] (1)
[1]Innovation in Manufacturing Systems and Technology, Singapore-MIT Alliance, Singapore
[2]Mechanical Engineering Department, National University of Singapore, Singapore

Abstract
This paper presents a methodology that integrates the assembly Product Design and Planning (PDP) activities with the Workplace Design and Planning (WDP) activities to improve the efficiency and quality of assembly design and planning at the early design stage. This methodology is implemented in an augmented reality (AR) assembly environment, where engineers can design and plan a product assembly and its assembly sequence through manipulating virtual prototypes in a real assembly workplace. In this AR environment, WDP information are fed back to the designers and engineers in real-time to aid them in making better decisions in assembly design and planning.

Keywords:
Assembly Design, Product Evaluation, Augmented Reality

1 INTRODUCTION

Manual assembly design and planning is a complex and time-consuming process as besides technical and economic factors, human factors have to be considered. It consists of two main issues: assembly Product Design and Planning (PDP) and assembly Workplace Design and Planning (WDP) activities. The basic goals of PDP are to make assembly easier, faster, less costly, and more reliable through Design for Assembly (DFA) techniques [1] and assembly sequence analysis. The main WDP issues include: workplace design, postural concerns, and workplace layout [2]. An improved workplace design enables the operators to work correctly, thus reducing hazardous and strenuous reaches, and preventing potential serious body injuries. Both PDP and WDP issues can greatly affect assembly efficiency and operator comfort during the assembly operations.

Computer-Aided Design (CAD) and Planning (CAP) systems have been developed to support the PDP and WDP processes. However, in these systems, information flow between these processes is mainly unidirectional, from the PDP process to the WDP process, in the early design stage (Figure 1). Information from the assembly workplace, e.g., the position and orientation of parts in the workplace, spatial constraints, the actual viewpoint of an operator, etc., are important for decisions making in the PDP process. A lack of this information in the product assembly design stage will lead to many drawbacks in the assembly design and plan, which cannot be identified until the assembly operations are evaluated in a real assembly workplace using physical prototypes, and costly and time-consuming redesign processes.

This paper proposes a two-prong approach to bridge the gap between the PDP and WDP processes in the early design stage. Firstly, an Augmented Reality (AR) [3] based human-computer interface is developed to provide a highly immersive and intuitive environment (Figure 2) that allows engineers to design and plan assemblies with sufficient information of the assembly environment during the early design stage. AR techniques can enhance a person's perception of the surrounding world through mixing real objects with virtual objects to create an AR environment. With this environment, engineers can manipulate and evaluate the virtual prototypes of new product designs in the real assembly environment. This will improve the assembly design and planning and reduce re-designing and re-planning activities.

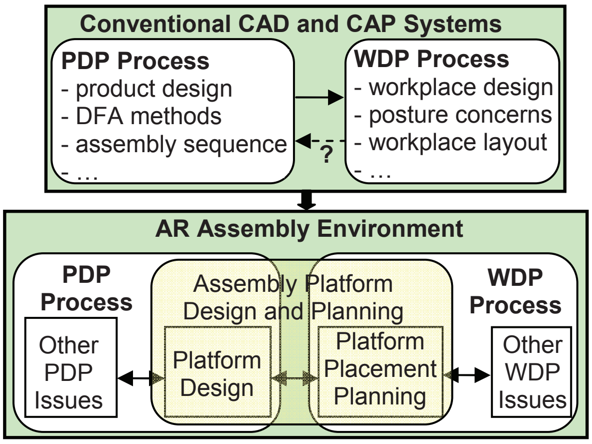

Figure 1: Integrating PDP and WDP processes.

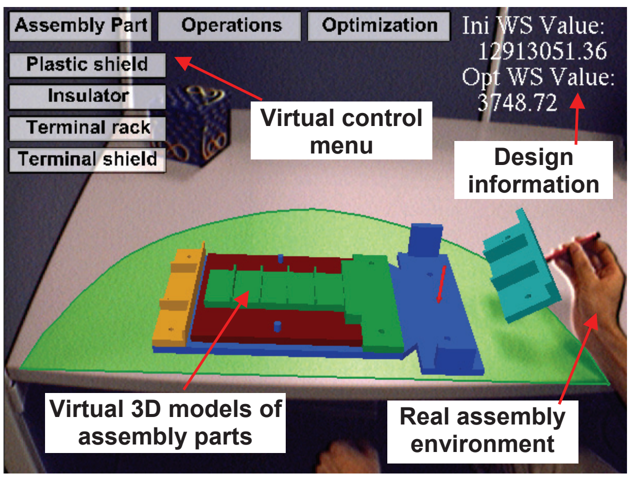

Figure 2: An AR assembly environment.

However, current AR applications [3] [4] are mainly concerned with assembly guidance [5] and maintenance or aesthetic evaluation. There is the lack of a systematic methodology to utilize the benefits of an AR environment to improve assembly design and planning in the early design stage. Thus, the second prong in this approach is a methodology that integrates the PDP and WDP processes in the AR environment based on the concept of an assembly platform, where information from the WDP process can be efficiently fed back to the PDP process. An assembly platform plays an important role in both PDP and WDP processes, as it can act as a common interface to bridge the gap between these two processes in the early design stage (Figure 1).

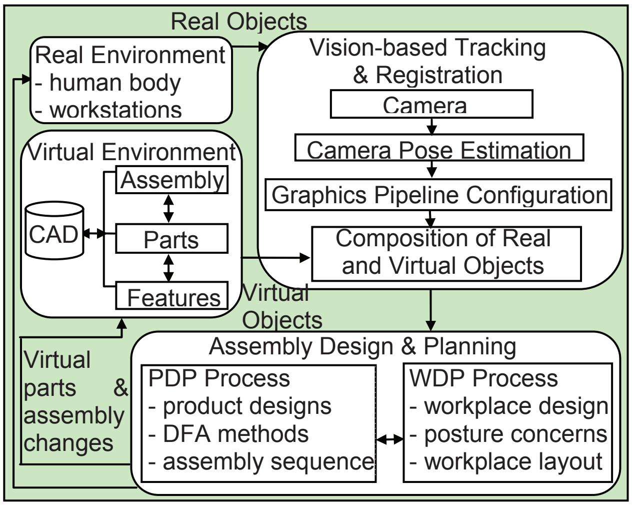

Figure 3: Architecture of AR assembly system.

2 OVERVIEW OF THE PROPOSED METHDOLOGY

2.1 AR Assembly System Architecture

Figure 3 shows the architecture of the AR assembly system, which consists of a head-mounted display for visualization and a video camera for capturing the real assembly scene. A computer vision-based tracking and registration technique [6] is used to render virtual prototypes in the real assembly environment. In this AR environment, there are two basic coordinate systems, namely, the coordinate system in the computer graphics pipeline (i.e., virtual world) and the coordinate system in the real world. Relationships between these coordinate systems must be determined in order to augment the virtual prototypes in the real world properly. This can be achieved by computing the transformation T_{WC} between the World Coordinate System (WCS) and the video Camera Coordinate System to estimate the camera pose; and using the pose parameters (T_{WC}) and the intrinsic parameters (T_P) of the video camera to configure the graphics camera to generate the proper graphics views in the real environment using graphics pipeline techniques.

In this AR assembly environment, engineers can design and plan the assemblies through manipulating virtual prototypes on a real workstation to identify the drawbacks of an assembly. Hierarchical feature-based models [6] [7] are used to model the assemblies. When an assembly design is changed, only the related feature models need to be updated instead of the entire product model. This offers computational simplicity and is important for the real-time requirement of the AR environment.

A CAD system is integrated with this AR system to make use of the geometry modeling kernel to model the assemblies. Design data can be exchanged between the AR and the CAD environments through the application programming interface of the CAD system. The CAD system can also provide interface with other computer-aided tools that support other production activities.

2.2 Integrating the PDP and WDP Processes

Assembly Platform Design

In assembly design and planning, an assembly platform, e.g. the computer case, car chassis, etc., is commonly used. During assembly, an assembly platform is usually mounted on a transfer pallet on the workstation and other parts are assembled onto it through different assembly features. Since the assembly platform serves as a common interface to other assembly parts, its design influences other PDP issues, e.g., assembly parts design and assembly sequence planning [6]. The attributes and positions of the features on the assembly platform are essential in evaluating a specific assembly operation. The attributes of the features determine the difficulty of the assembly operations [1], while the positions of the features affect the working posture of the operator.

An assembly platform can be designed and modified in this AR environment. In a hierarchical feature-based model, each part has its own coordinate system (PCS). The design modeling process involves defining the position and orientation of each feature with respect to the PCS and performing proper Boolean operations between the features. Platform design can be modified through feature operations, such as modifying the attributes of a feature, and changing the feature positions.

Planning Assembly Platform Placement

The placement of an assembly platform affects the operator's comfort level and other WDP issues, such as fixture design, the layout of other components (e.g., tools and magazines), etc. For any spatial planning problem, a reference coordinate system, i.e., WCS, is generally defined in the workplace. Hence, assembly platform placement planning involves determining the spatial relationship between the PCS of the assembly platform and the WCS (Figure 4). This spatial relationship in 3D space can be defined by a placement vector:

$$V=(x, y, z, \Phi, \theta, \psi) \quad (1)$$

where (x, y, z) and (Φ, θ, ψ) represent the position and rotation information respectively.

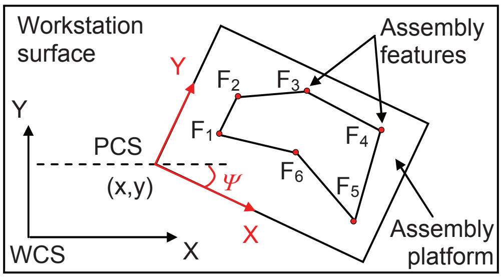

Figure 4: Assembly Platform Placement Planning.

To evaluate the comfort level of a manual operation, a work stress criterion (WS=T*P) is defined [8] in terms of the assembly time (T) and the posture rating (P). For an assembly operation i on an assembly platform, the Boothroyd and Dewhurst DFA method is used to estimate the assembly time (T_i) in terms of the attributes of the related assembly features. From ergonomic experiments, regression models [9] have been developed to estimate the posture rating (P_i) of the manual operations in terms of the positions of the assembly features in the workplace ($f_{wcs}(V)$), which can be computed using their part coordinates and the platform placement vector (V).

An optimum platform placement can reduce the risk of developing work-related musculoskeletal disorders and improve the assembly efficiency. This problem can be formulated as a constrained optimization problem (Figure 5), and converted into an unconstrained optimization problem using the penalty function method. The Nelder-