Virtual and Augmented Reality Applications in Industrial Design

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Abstract—Industrial design has become crucial to the products innovation and value-added process in current highly competitive marketplace. In order to provide designers nature and intuitive means to express their ideas freely and overcome the technical gap in the iterative design process, virtual and augmented reality technologies are employed to supplement the traditional Computer Aided Design – Rapid Prototyping (CAD-RP) iterative design process. Although there is a vast amount of literature on facilitating mechanical design and manufacturing with virtual and augmented reality technology, not much has been summarized specially on the mixed reality aided industrial design space. This paper has surveyed the development of virtual and augmented reality applications in industrial design from a designer’s perspective, with a particular focus on spatial design, hybrid prototyping and assembly in an augmented environment. It provides a comparison between traditional design process and the improvements affected by mixed reality technology that both designers and researchers could benefit from it.

Keywords—Virtual reality; augmented reality; industrial design; spatial design; hybrid prototyping; assembly.

I. INTRODUCTION

To succeed in current highly competitive marketplace, reliable functionality and attractive appearance are crucial to product innovation. People have more critical requirements on the ergonomics, comfort, appearance, color, texture and decoration of the products. In fact, these characteristics and attributes of products are adopted at the early industrial design stage, which consequently affect the engineering design, manufacturing process and products performance. To meet the increasing expectations and decreasing product life cycles, real-time information exchange between stakeholders with different background is essential in the design process. Thus in addition to computer aided design (CAD), more and more advanced supporting technologies such as virtual reality (VR) and augmented reality (AR) technologies are introduced to speed up and optimize the development process.

Although there exist a vast amount of literature on facilitating mechanical design and manufacturing with virtual and augmented reality technology, not much has been summarized specially on the virtual and augmented reality applications in industrial design. This article reviews that combines virtual and augmented reality applications in industrial design. In the rest of the paper, section 2 introduces the traditional industrial process, section 3 reviews the development of mixed reality aided industrial design space, and section 4 provides a comparison. Finally, section 5 gives the conclusions.

II. TRADITIONAL INDUSTRIAL DESIGN PROCESS

The typical workflow of industrial design usually starts from an interesting concept or idea, which is expressed through four view drawings sketched on plain paper by hand. In fact, real model is still the unique way to assess the design intent in this stage. With substantial prototype, designers and other parties could share and evaluate the intent of the design directly, which are difficult to acquire from some 2D drawings. If needed, design changes or modifications also can be reflected directly onto the model by increasing or decreasing material. Thus after the draft is confirmed, a next step is converting the sketch into real model with oil-clay, wood or fiberglass by handcraft. Dependent on how well the project proceed, sometimes the initial prototype also can be sculptured by woodworking machine on oil-clay or wood. Usually 3D modeling based on the sketch must be performed by computer aided industrial design software (Rhino, Alias for example) in advance. After full discussion and revision of the oil-clay model, it could be scanned into 3D points and processed by reverse engineering software. This will later be translated into 3D models and real-scale physical mock-ups (RP models for example) to provide better visualization and understanding of the design. The iterative design process has to repeat until there is nothing to modify. Figure 1 represents a typical example of motorcycle in existing design process.

Figure 1. Motorcycle design process. (a) effect drawing of design concept, (b) oil-clay model, (c) 3D scanning points data, (d) 3D data model, and (e) RP model.

Undoubtedly, the process is time and cost consuming. It is still conventional to the designers to express their creativity by sketching on paper in the early styling phase, which
means the existing interactive interface cannot provide better solutions. Hence developing a more intuitive and interactive design interface, decreasing the number of the real models, allowing communication between designer and other stakeholder more conveniently and making the process completely digitalized are the aims of employing virtual and augmented reality technology in industrial design.

III. MIXED REALITY AIDED INDUSTRIAL DESIGN SPACE

In comparison with traditional industrial workflow, the improvements affected by virtual and augmented reality mainly occur in three subsequent aspects. Firstly, spatial design utilizes AR to conceptualize an interactive, tangible design interface that allows users visualize and sketch the augmented 3D data model spatially like a real physical object in the early styling stage. Secondly, hybrid prototyping allows users to evaluate, analyze and test augmented 3D model collaboratively in an interactive environment. At last, assembly in an augmented environment mixes real objects (e.g., physical prototypes, tools, robots, etc.) with virtual objects (e.g., virtual prototypes, information, tools, etc.) for assembly design work.

The following reviews the development of spatial design, hybrid prototyping and assembly in an AR environment in sequence.

A. Spatial Design

From designer’s point of view, existing commercial CAx software cannot express their creativity in the complex model creation. Their creativity is mainly limited by the graphical user interfaces (GUIs) and un-natural input devices such as the mouse and keyboard. Developments in spatial design that combine augmented reality (AR) systems and tangible user interfaces (TUIs) have the potential offer designers tools for creating and manipulating shapes in a natural and interactive way. The related research on the 3D interface for free form modeling begun in the early 90s last century. About ten years ago, some 3D free form modeling approaches have been developed from a research perspective, such as Conceptual Virtual Design System (COVIRDS) [1], Responsive Workbench (RWB) [2], 3-Dimensional Immersive Virtual Sculpting (3DVIS) [3]. These systems employed multi-modal input devices and gesture-recognition for modeling in immersive virtual reality environment.

With the development of augmented reality, some free form modeling systems were developed based on augmented reality environment. Fiorentino et al. [4-5] developed Spacemotion to address aesthetic design of free form curves and surfaces in mixed reality. Santos et al. [6] described a prototype implementation that supports free form surface generation and manipulation in augmented reality. It furthermore highlighted a scenario of 3D virtual tape drawing in the automobile conceptual design process with two-handed 3D interactive technique. Dima et al. [7] introduced a 3D haptic conceptual design system which combined haptics, augmented reality and tangible computing.

The integration of tangible user interfaces in traditional design tools would improve usability and interaction of the design process. Tangible interfaces can be more natural, intuitive, and efficient than the way we currently interact with digital devices and interfaces [8]. The advancements of tangible user interfaces significantly facilitate interaction in free form modeling. Billinghamurst et al. [9] introduced tangible augmented reality that combined the enhanced display possibilities of AR with the intuitive manipulation and interaction between the real and virtual worlds. Kim et al. [10] revealed that the use of TUIs changed designers’ spatial cognition, and that these changes affected the design process by increasing their ‘problem-finding’ behaviors leading to creative design. The naturalness of the direct hands-on style of interaction promoted designers’ immersion in designing, thus allowing them to perform spatial reasoning more effectively. Couture et al. [11] also described a TUI platform that supported computer aided design (CAD) parts assembly operations in the mechanical product domain.

B. Hybrid Prototyping

During the traditional industrial design process, quite a few physical mock-ups of the same product are employed for their different development stages and purposes. However, existing manufacturing technique of physical prototypes has some limitations in the iterative industrial design process. In order to reduce the disadvantages of physical prototypes, virtual reality technology is applied in the digital models instead of a physical prototype to evaluate and test the design output in an artificial world. A virtual prototype or digital make-up is a computer simulation of a physical product that can be presented, analyzed and tested for aspects related to the life of the product such as the design, engineering, manufacturing, service and recycling, the same as with a physical model. The construction and testing of a virtual prototype is called virtual prototyping (VP) [12]. Some solutions have been developed to provide the users the sensations of being involved in the simulated environment, supporting exploration presentation and even touch, such as CAVEs. The users can also interact with the 3D virtual world in the same way as he does with the real world toward visual, tactile and sound aspects utilizing sensors and hardware devices, such as data gloves [13]. However, the cost of developing VR environment limits use in a wide range. In addition, the burden of generating the complex 3D environment and learning to use the VR system reduces the naturalness and intuitiveness.

The combination of physical and virtual artifact models offers new opportunities. The concept of augmented prototyping employs mixed reality technologies to combine virtual and physical prototypes at a relatively cost. Extensive research on this topic has been carried out widely and intensively. However, most of the augmented prototyping systems developed so far are still laboratory-based
implementations. Verlinden et al. [14-15] employed direct projection of digital images onto physical prototype of automobile (or scale oil-clay model). The material, texture and color were able to alter. Different components could be evaluated using a turntable to track orientation. Jin et al. [16-17] developed an AR-based re-formable mock-up system for design evaluation that enabled interactive change of shapes as well as colors, textures, and user interfaces by assembling different parts to the main body of the prototype. The hand and fingertip tracking was used to manipulate the products interactively. Park et al. [18] also proposed a tangible augmented prototyping system to realize appearance evaluation and functional behavior simulation of digital handheld products. Regenbrecht et al. [19] described a practical augmented prototyping application that allowed multiple participants to inspect and interact with 3D data model and 2D annotations using a turntable, each user has his own view and shared objects of the augmented space. Bordegoni et al. [20] used sound as well as touch and vision to evaluate the geometric properties of virtual object.

Beyond the shape inspection and functional behavior test, hybrid prototyping is promising to be employed in some other applications that physical mock-up play an important role. Niebling et al. [21] integrated hybrid prototyping and interactive user interface to help a water turbine computer fluid dynamics (CFD) numerical simulation process and result presentation. Pentenrieder et al. [22] introduced some practical augmented reality cases in vehicle industry, including interfering edge analysis, change verifying in factory planning and head space analysis in car assembly. Nolle et al. [23] used augmented reality as a comparison tool in automotive industry to superimpose the latest CAD model on the real parts checking correspondence with appropriate precision.

A variety of successful hybrid prototyping application scenarios have been proposed [24]. One of the scenarios assembled the virtual prototype of a set of engine, tubes and cables into real components precisely aided by tactile measurement arm hardware devices. Qualitative statements of build-in and assembly possibilities were easy to inspect and verify. Another example superimposed 3D data model of vehicle backdoor on a real car to evaluate the design effect.

C. Assembly in Augmented Environment

Most of complex products are divided into quite a few components or functional units to facilitate production, use and maintenance. Assembly design and evaluation during the initial design stage are highly significant to industrial product development [25]. Traditionally, physical prototyping in the design loop to verify proper functioning and ease of assembly is the main method for assembly design and evaluation. Thanks to the emergence of virtual and augmented prototyping, assembly work could be executed in a virtual and augmented environment currently.

VR attempts to replace the designer’s perception of the surrounding environment with an immersive, interactive and 3D computer-synthesized environment. By adopting VR, a designer can see, touch and operate a future product before its physical implementation with lower cost and effort. The elimination of physical prototyping and on-site verification makes virtual assembly a powerful tool to reduce the time-to-market of a product and adapt changes or introduce new products. However, there is an obvious shortcoming of current virtual environments as a medium for assembly evaluation which is that the “realism” experience is limited while users operate virtual objects due to a lack of suitable sensory feedback. In addition, a great deal of computational resources is needed to simulate a complicated assembly process in a pure virtual environment.

An innovative alternative that is growing in popularity in simulating and evaluating assembly in the early design stage is the use of the augmented reality (AR) technology [26]. Displaying the assembly information to guide the assembly operations is the main application of AR techniques in most of the existing AR assembly research projects. In comparison with traditional assembly design systems, virtual information can be displayed in the workspace in a spatially meaningful way in AR applications. AR can significantly reduce head and eye movements and attention switching, improving spatial perception and increasing productivity [27]. Zauner et al. [28] developed an AR-based step-by-step furniture assembly system in a mixed reality environment. Engineers at Boeing Co. [29] demonstrated an AR-based system to aid workers to assemble cable harnesses. The ARVIKA project [30] uses AR to support development, production and servicing with relation to complex technical products in a user-oriented and application driven manner. Reiners et al. [31] described an AR demonstrator for the task of door-lock assembly into a car door, which was developed aiming to create a practical, realistic application that can transport the concepts behind AR to a causal observer. Halttunen et al. [32] developed the WebShaman Digiloop system augmenting digital virtual prototypes with physical objects to examine the functionality and features of products in an AR environment. Yuan et al. [33] and Li et al. [34] described a scenario for assembly guidance using a virtual interactive tool and a visual assembly tree structure respectively. Wiedenmaier et al. [35] presented a typical scenario for assembly and service personnel in an AR environment.

IV. Optimization of the Process

The advanced industrial design technology depends mainly on the development of computer science. The adoption of the CAX has realized a big transformation in the workflow from manual and 2D means to computer-aided and 3D work techniques. In order to provide designers nature and intuitive means to express their ideas freely and overcome the technical gap in the repeated design process, virtual and augmented reality technologies are employed to supplement the traditional Computer Aided Design – Rapid Prototyping (CAD-RP) iterative design process.

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The existing traditional design process can be shown in Figure 2.

![Diagram of traditional design process]

Figure 2. Traditional industrial design process.

With the development of mixed reality aided industrial design supporting technology, it has the potential to evolve from serial process to parallel design space shown in figure 3.

![Diagram of industrial process improved by virtual and augmented reality technology]

Figure 3. Industrial design process improved by virtual and augmented reality technology.

V. CONCLUSIONS

This paper has reviewed the development of virtual and augmented reality applications in industrial design from a designer’s view, with a particular focus on spatial design, hybrid prototyping and assembly in an augmented environment. The aim is providing users natural and interactive means to express their innovative ideas freely and overcome the technical gap in the iterative design process by upgrading from traditional computer aided design process to mixed reality aided design space.

Although both the academia and industry are aware of the huge potential that virtual and augmented reality could improve the industrial design process, the solutions and supporting hardware and software are still far from practical engineering applications. Virtual and Augmented Reality technology seems to be a meaningful alternative for quite a few periods of time and specific applications.

REFERENCES


