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AR-guided Product Disassembly for Maintenance and Remanufacturing

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Abstract

Product disassembly is an inevitable operation during the two essential modules in realizing a sustainable product life cycle: routine maintenance and end-of-life strategies particularly remanufacturing. In this paper, an AR-guided product disassembly (ARDIS) framework with an automatic content generation module is proposed to improve the efficiency of the disassembly process performed by human operator without expert intervention. Through intuitive AR-guidance in disassembling a product, the quality of maintenance services and effective core-retrieval during remanufacturing can be improved. A disassembly sequence table is first generated based on product ontology. Next, an automatic content generation domain will link the generated sequence with appropriate virtual information based on the taxonomy of visual cues. The final virtual content rendered on the real scene serves as straightforward step-by-step guide to the human operator. A case study of Nespresso machine is presented to demonstrate the preliminary workflow of the proposed framework.

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Keywords: Product life cycle; Disassembly; AR guidance; Maintenance; Remanufacturing

1. Introduction

Over recent decades, tremendous growth in consumerism as well as increasing environmental awareness have led to stricter recycling regulations and an urgent demand for remanufacturing to reduce resources depletion. As shown in Fig. 1, two important modules, namely, maintenance services to prolong product life cycle and end-of-life (EOL) strategies, such as remanufacturing to retrieve usable parts before final disposal of the products, have been introduced to achieve a closed-loop product “industrial” life cycle [1]. In both modules, disassembly operation is essential. Unfortunately, disassembly operation is often regarded as a non-value added operation to the companies considering that it requires additional effort and cost. Hence, disassembly operation has to be optimized such that it can be cost-efficient [2]. Numerous algorithms, such as optimization techniques [3,4], intelligent genetic algorithm [5] and CAD-based disassembly planning [6,7], have been proposed to increase the overall efficiency of the disassembly process.

Despite active research in disassembly planning, there is a lack of an intuitive platform to translate the resulting disassembly guidance information effectively to the human operators who will eventually dismantle the products. In most cases, these human operators rely on hardcopy manuals or past experience to perform the disassembly tasks. This is non-ideal because the operators have to shift their attention from the task on hand to the instruction manuals, which could cause the disassembly process to be error-prone and time-consuming.

Notably, an evaluation study by Havard et al. that compares maintenance efficiency across different media support, such as paper maintenance manuals, video instructions, augmented reality (AR) tablets and AR Smart Glasses, has concluded that the AR technology can reduce maintenance time with improved quality as compared to using hardcopy manual or video instructions [8]. Drawing inspiration from AR applications in maintenance, this paper thus proposes an AR-guided product disassembly (ARDIS) framework with an automatic content generation module to convey disassembly guidance information intuitively to the human operators.

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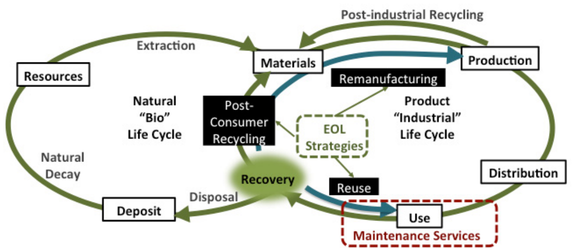

Fig. 1. Maintenance and EOL Strategies: Close-loop Product Life Cycle [1]

2. Related Work

2.1. Augmented Reality

Augmented reality (AR) is an emerging human computer interaction (HCI) technology that renders virtual information on a real scene. An AR system is formally defined as an application that fulfills the following three properties, namely, (a) able to blend real and virtual content in a real environment, (b) is real time and interactive, and (c) can register virtual content in 3D environment [9]. As shown in Fig. 2, a typical AR application consists of five modules, namely, registration, tracking, rendering, interaction, and content generation. In short, computer-generated information, such as annotations, graphics and 3D models, should be rendered and registered on the real scene with accurate tracking and alignment, followed by user-friendly interaction modes, such as gesture-based input, speech input or with the help of external input devices, such as data gloves, ray casting using mouse, etc. Lastly, relevant content in response to specific request or task should be generated and displayed to the users [10].

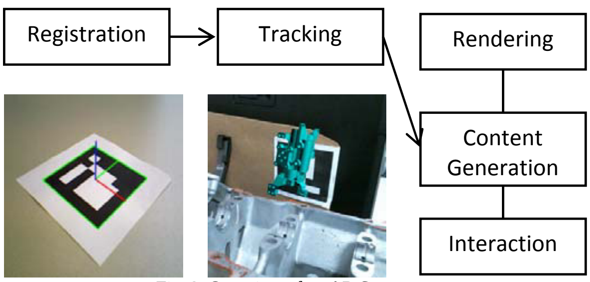

Fig. 2. Overview of an AR System

2.2. Product Disassembly

Disassembly is formally defined as the systematic separation of parts from a system. A system can refer to anything, such as machinery, equipment or even space stations. In particular, this paper will focus on product disassembly. Products refer to physical objects that are created and assembled to perform specific tasks, such a ballpoint pen, photocopy machine or a car. Depending on the task requirements, product disassembly can be divided into different types, namely, complete or partial, destructive or non-destructive [11]. For recycling, complete disassembly is often required since the product has reached its end of life. For remanufacturing, maintenance and repair, partial disassembly is conducted since only certain parts require servicing or retrieval. Generally, non-destructive disassembly is preferred especially in the latter because destructive disassembly is an irreversible operation.

Over the years, research development of disassembly sequence generation has advanced from general disassembly process planning to optimal disassembly sequence generation from all possible solutions using optimization techniques. The most common disassembly sequence generation methods are based on graphical representation such as AND/OR graph [12], process graph [13], and precedence constraints graph [14] that reveal all feasible sequences and form the search basis for an optimal sequence. Meanwhile, Moore et al. [15] proposes Disassembly Petri Net (DPN) methods that modeled uncertainty of product conditions using transition probability for product recycling or remanufacturing. Other methods such as dynamic disassembly sequence planning based on product information model [16] and optimization techniques [3,4] have also been reported recently. In this paper, an AR platform is proposed to effectively convey the disassembly sequence information generated from these algorithms to the human operators intuitively.

2.3. Related AR applications

There is a long history of applying advanced HCI techniques in the industry to enhance manufacturing operations. As early as the 90's, virtual reality (VR), which is more immersive as compared to AR, has been applied in different manufacturing domains, such as prototype design, simulation and virtual machining [17]. Since AR enables the overlay of virtual components with the real life scene, it is more favorable in facilitating real life manufacturing tasks and is often applied in virtual assembly design or training. According to a recent survey paper, reported research work in AR for assembly till date can be categorized into three areas depending on the goals of proposed system, namely, (a) Assembly guidance in AR environment, (b) Assembly design and planning in AR environment, and (c) Assembly training in AR environment [18].

In contrast, there is less research work reported in AR applications for disassembly and this is intriguing because disassembly is often required in many stages of a product life cycle, such as maintenance, repair, and remanufacturing. Some early work on augmented disassembly guidance includes a disassembly operation support system with motion monitoring of a human operator using 3D position sensors for the disassembly of photocopy machines [19]. For disassembly training, Farkhatdinov and Ryu developed an AR educational system for automotive engineering that guides users to disassemble mechanical parts of a transmission through animating the 3D virtual models. Notably, both virtual models and disassembly sequences were modeled and defined manually by an expert in this system [20]. In the research reported in this paper, the disassembly sequence is generated based on product contact and translation functions and