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Virtual disassembly sequences generation and evaluation

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Abstract

First this paper presents a method for generating selective disassembly sequences. The method is based on the Lowest levels of a disassembly product graph. Instead of considering the geometric constraints for each pair of components, the proposed method considers the geometric contact and collision relationships among the components in order to generate the so-called Disassembly Geometry Contacting Graph (DGCG). The latter is then used for disassembly sequence generation thus allowing the number of possible sequences to be reduced by ignoring the components which are unrelated to the target. A simulation framework was developed and integrated in a Virtual reality environment (VRE) thus allowing generating the minimum number of possible disassembly sequences. Secondly, a method for disassembly operation evaluation by 3D geometric removability analysis in a VRE is proposed. It is based on seven new criteria divided into two categories: *i).* for ergonomic evaluation, *ii).* and for traditional processing evaluation. All criteria are presented by dimensionless coefficients automatically calculated, thus allowing evaluating disassembly sequences complexity. For this purpose, a Virtual Reality disassembly environment (VRDE) is developed based on Python programming language, utilizing mixed VTK (Visualization Toolkit) and ODE (Open Dynamics Engine) libraries. The framework is based on STEP, WRL and STL exchange formats. The analysis results and findings demonstrate the feasibility of the proposed approach thus providing significant assistance for the evaluation of disassembly sequences during Product Development Process (PDP).

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Keywords: Disassembly operations, sequences generation, evaluation, Virtual Reality Environment

1. Introduction

Integration of disassembly operations during product design is an important issue today. It is estimated that at the earliest stages of product design, the cost of disassembly operations represents almost 30 % of its total cost. Disassembly operation simulation of industrial products finds a strong interest in interactive simulations through immersive and real-time schemes. Nowadays, Virtual Reality Environments (VRE) have significantly evolved towards assembly/disassembly (A/D) simulation, highlighting new needs for their simulation preparation, evaluation and integration in Product Development Process (PDP). A/D simulations address different objectives such as: sequencing modeling, path planning, collision detection, operational time etc., which are often complementary to each other [1, 2]. As known, the number of possible disassembly sequences increases significantly with the number of parts in a product (assembly). In VRE, a human model is often involved in a digital mock-up (DMU) model for A/D evaluation. However, it has limited application areas because of its high cost investment. Most of the recent work on A/D related with Virtual Reality (VR) technology focuses on the simulation itself. From this perspective, Aleotti and Caselli [1] proposed a physics-based VRE for task learning and intelligent disassembly planning. Ladeveze *et al.* [3] proposed an interactive path planning method for haptic assistance in assembly task. For generating disassembly sequences CAD models of the assembly are often used as input. In order to reduce the complexity of the problem Cappelli et al. [4]

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developed a model combining *CAD* and *and/or graph* representation, for generating the *transition matrix* of the assembly, and for binary tree's representation. Pomares et al. [5] also used assembly CAD model associated with a list of components' features in order to develop *local* and *global* strategies for component removal in a VRE. Concerning the evaluation of disassembly sequences different tools using novel human-computer interface of VR are proposed [6]. Some criteria for A/D sequences evaluation were proposed in [7] in order to minimize the assembly time through parallel execution of some tasks. A new method based on work factors and genetic algorithm models was put forward [8]. It can be stated that the existing VR approaches still have limitations in the generation and evaluation of disassembly sequences.

In this context, first: a new method for selective disassembly sequences generation in VRE based on *Disassembly Geometry Contacting Graph* (DGCG) is proposed here. It focuses on: the concept of geometric feasibility (including translation, rotation, helical movements); contact identification (based on ODE libraries) and mobility operator for generating the possible removing trajectories; and collision detection (based on VTK libraries). Secondly a new method for disassembly operations evaluation in VRE is proposed. Instead of the ergonomic simulations with a human model, it integrates a camera as the eyes of the operator (avatar) in performing disassembling task in a VRE. In order to improve the efficiency of disassembly operation evaluation, seven criteria are proposed here divided into two categories for: ergonomic evaluation (visibility score, neck score, bending score) and traditional processing evaluation (disassembly angle-SDR, number of tools' changes, path orientation change and sub-assembly stability).

The results of this study may be useful for designers and industrials, allowing them to: take into accountthe constraints of disassembly operations by automatically generating the selective disassembly sequences and their evaluation in a VRE during the initial phase of product's design.

2. Method for selective disassembly sequences generation

The proposed method is based on two main steps. The first one consists in building the *Disassembly Geometry Contacting Graph* (DGCG) of the product. The second one consists in generating the feasible disassembly sequences.

2.1. Building the Disassembly Geometry Contacting Graph (DGCG)

The DGCG aims to share the components related to the targets into different *disassembly levels* according to their order to be disassembled. If some components can be disassembled directly, without removing other components, those ones are called *1-st-disassembly level* components. Consider an assembly containing *m* components. For each of them, the *Set of directions for removal SDR (see Section 3.1)* and the collision detection are checked. Then, after *m* iterations, the *1st-disassembly* level components are obtained. Then, recheck the remaining components to obtain *2-nd-disassembly* components and so on. The process for building the DGCG stops automatically when the target component is reached. The following notations are involved in the graph (see Fig. 3): $C_n^{i,j}$ if component *i* cannot be disassembled in level *n* because of *collision* with component *j*, NS_n^{i} if component *i* cannot be disassembled in level *n* because of *no SDR*. The procedure for generating the DGCG consists in three main steps: *i).* Import the *3D* assembly models, coming from *CAD* software into the realized application through *XML* files (see Section 4). Each model is followed by *ODE* (Open Dynamics Engine) *Geoms* model used for contacts detection among the components. Then the contacts' arcs among the components in the DGCG are built; *ii).* Analyze the components' type and collisions detection checking. If a component is not fastener, check its *SDR*, if not, check for collision. If it has collision, build the related arcs and record that the component cannot be disassembled in this level (see Section 2.2). If not, the component can be disassembled; *iii).* Remove the components in the current level by cutting off their arcs; recheck *SDR* and collision detection for the remaining components again and so on.

2.2. Disassembly Sequences generation

For disassembly sequences' generating, three *micro-unites*, which consider all the possible relationships between the target component *x* and its surrounding ones in the *DGCG*, are proposed: *i).* Micro-unite *1*. Transition from No SDR (*NS*) to Collision (*C*) (Fig. 1a); *ii).* Micro-unite *2*. Transition from Collision (*C*) to Collision (*C*) (Fig. 1b) and *iii).* Micro-unite *3*. Transition from No SDR (*NS*) to No SDR (*NS*) (Fig. 1c).

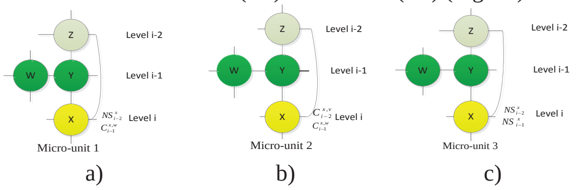

Fig. 1. Three types of Micro unites for the DGCG.

2.3. Case study

In order to compare the proposed method with other works an example for disassembly sequences generation of target *Cover 5* of an electrical motor, similar to the work of Popescu [9] is presented in Fig. 2.

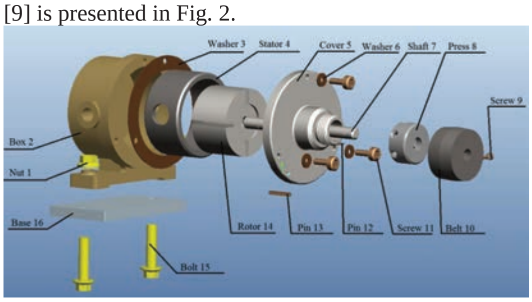

Fig. 2. Electrical motor.

According to the procedure for generating the DGCG [10] the five-level DGCG for *Cover 5* is built as shown in Fig.3. The target is appearing in level 5. It means that all its related