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A process demonstration platform for product disassembly skills transfer

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Abstract

Automated disassembly is challenging due to uncertainties and variations in the process with respect to the returned products. While cognitive robotic disassembly system can dismantle products in most cases, human assistances are required for resolving some physical uncertainties. This article presents a platform that the disassembly process can be demonstrated by skillful human operators. The process is represented with the sequence, position, and orientation of the tools, which are extracted by using vision system and tools' markers. The knowledge at planning and operational levels will be transferred to the robot to achieve automated disassembly. An operation for removing a back cover of an LCD screen with three disassembly tools is a case study.

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Keywords: Learning by demonstration; Skill transfer; Disassembly; Human-robot collaboration; Robotics.

1. Introduction

1.1. Product disassembly overview

With respect to the circular economy, End-of-Life (EOL) products treatment is one of the key steps that recovers remaining embodied value from the disposal. Product disassembly is one of the important steps for efficient EOL treatment. Disassembly process aims to separate the products into their parts, components, or subassembly. As a result, they will be treated in proper ways where the remaining value is maximized. However, disassembly is currently a non-profit and labor intensive process. As a result, it has become economically infeasible and ignored in most companies.

A number of attempts have been made in order to fully automate disassembly process. The research was conducted in a number of approaches, e.g. vision-based system [1-3], multi-sensorial system [4, 5], and smart and integrated disassembly tools [6, 7] However, due to the variations of products returned and uncertainties in disassembly process, fully automated disassembly has been challenging and mostly economically infeasible.

1.2. Human-machine collaboration in disassembly

Overcoming the aforementioned problems, Human-Machine collaboration can be occurred in various ways [8]. Types of human involvement in assembly and disassembly are explained as follows:

(a) *Semi-automatic* or *hybrid disassembly* – optimized disassembly plans consist of tasks performed by machine and human. Automatic workstations are equipped with sensor systems and automatic disassembly tools performing disassembly tasks. Human operators employed at the manual workstations make decision and perform more complicated tasks that is infeasible to be carried out automatically [9, 10] .

(b) *Augmented Reality (AR)* - Much research worked on using AR for facilitating the human experts to interact with actual products that the optimal plans are generated by the system for assembly [11, 12] and disassembly [13]. Human operators perform the process in this case.

(c) *Tele-presence of human* – human operators can control the robot to on-line perform the tasks that can be hazardous or difficult due to human's physical limitation. A number of

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related works were conducted for assembly, e.g. operator's movement is captured and translate to the program that controls a dual-arm robot in assembly of heavy products [14].

(d) *Machine learning (ML)* – experts are responsible for teaching plans and operations to the system. This is similar to (c) but learning capability is added. Eventually, the system is able to perform the tasks autonomously. Regarding ML in disassembly, much research focuses on optimization at strategic levels, e.g. [15-17]. To the best of our knowledge, only cognitive robotic disassembly system implemented ML at operational level to improve the performance of the process [18]. Human operators assist the system to resolve problematic conditions by demonstrating the actions required.

1.3. Learning by demonstration in cognitive robotics

According to the framework of using cognitive robotics in product disassembly, *learning* and *revision* of the disassembly plans are the cognitive functions that help the system to improve the process performance, i.e. time consumption and degree of autonomy [18, 19]. In the learning and revision process, *Cognitive robotic agent* (CRA) primarily interacts with the *knowledge base* (KB) by writing or rewriting new product-specific knowledge in regard to the disassembly sequence plans and operation plans (see framework in Fig. 1). This knowledge will be recalled when the foreseen models of the products are going to be disassembled in the future.

During the disassembly process, CRA performs two types of learning, namely *by reasoning* and *by demonstration*. (a) For *learning by reasoning*, CRA autonomously obtains the knowledge by executing the general plans and take the outcome into account. The knowledge can be obtained if the operations successfully remove the desired components. In case of failure, expert human operators may be called for assistance. This is where the (b) *learning by demonstration* takes place. The operators demonstrate actions to CRA how to resolve the problems which are the causes of failure, e.g. pointing out non-detected components, showing how to remove fasteners, etc.

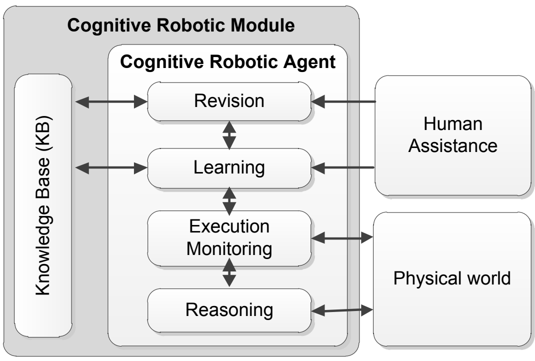

Fig. 1 Cognitive robotics disassembly framework

The failures are caused by *unresolved conditions* occurred at both planning and operational levels which are explained in [18]. This article focuses on the unresolved conditions at the operational level, which are:

- Inaccurate location of the components,
- Non-detectable fasteners,
- Inaccessible fasteners, and
- Improper method of disestablishing fasteners.

The skill transfer platform proposed in this article is designed to be capable of handling these problems. It should be noted that, to prove the concept of the training platform, the disassembly process was completely demonstrated without involving other cognitive abilities. As a result, a sequence of disassembly operations that is repeatable by robots is expected to be obtained.

1.4. Organization of this paper

This paper is organized as follows: methodology regarding learning by demonstration and skill transfer in Section 2, system design of the teaching platform in Section 3, experiment in Section 4, discussion and conclusions in Section 5 and 6, respectively.

2. Methodology

2.1. Complete system overview – skills and knowledge

The ability to disassemble the products is involved with *skills* and *knowledge* that can be extracted from the human expert's demonstration. In the context of product disassembly, (a) *skills* are sets of *primitive actions* that are used to perform tasks, in this case, disassembly operations. (b) *Knowledge* is physical information related to components or products to be disassembled. The information can be represented as parameters used in the disassembly operations. Skills aim to be transferred in order to make the demonstrated operations adaptable to different physical configurations, e.g. robots with different configuration [20, 21].

This project can be divided into two parts according to the sides: the training side and the playback side. (a) On the *training side*, a human expert demonstrates a completed disassembly process of a product. The disassembly operations are captured by using a vision system and other sensors. The abstract skills with the product specific knowledge are transferred to the robot. (b) The robot operating on the *playback side* will be able to disassemble the same product by using these skills and knowledge. The robot is equipped with sensors and cognitive ability, especially *reasoning* and *execution monitoring* [19], in order to overcome the physical uncertainties in automated disassembly process. As a result, the system is expected to be able to adapt the skills to carry out the process with respect to the actual physical conditions of the products that may vary from the conditions in the training scenario.

An overview of the complete system is shown in Fig. 2. However, it should be noted that in this article, only the system on the training side is presented.