Development of a Methodology for the Determination of Conceptual Automated Disassembly Systems

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Summary. At a certain point in its life cycle, a product will reach a condition where it partly or completely loses its functionality. When this happens, the disassembly has the ambition to regenerate a product-value or to enable an environmental friendly product recycling. With regard to the high workload and costs for manual labor one approach to increase the productivity of disassembly tasks is the use of automated disassembly systems (ADS). Depending on different life cycle scenarios, requirements on automated disassembly systems vary. Concerning this problem, a general methodology is developed, which enables the determination of a conceptual ADS by assigning automated modules that are processing the product disassembly. In the first place the objective of a disassembly is determined, followed by a closer investigation of the product. Thereby target components are defined, which has to disassembled. By looking at the connections between these target components suitable separation procedures are derived. Finally, modules of the automated disassembly system are determined.

1 Introduction

A product can reach the end of its life cycle for various reasons. It may be broken or it may be restricted in its operating life by legislations. In both cases, reaching the end of its life cycle does not mean that the product has no value anymore. Many consumer products that are not used anymore are shredded to recycle some of the materials with higher values [1]. Another possibility is, a product has not lost its functionality, so that shredding would eliminate its remaining usage potential [2]. The disassembly strategy is very different to both of these cases. In the case of component reuse a high quality disassembly process is needed, regarding a component-friendly disassembly as well as an automation concept offering promising support [3].

Furthermore, automation of a disassembly process raises its efficiency. The disassembly process cannot simply be considered as a reverse assembly process. Reasons worth mentioning are uncertainties regarding the products life cycle and different product variants [4]. Examples of these uncertainties are damages of components and connections, unknown up- and downgrades of products and different characteristics of these variants. Furthermore, the majority of products is not designed for disassembly, particularly not for automated disassembly. However, the design of automated disassembly systems (ADS) for products already existing is a challenging aspect. In many cases the design of the product is fixed and cannot be changed. Therefore, an ADS needs to provide the ability to adapt to different product variants as well as to face unplanned process disturbances caused by manufacturing uncertainties [5]. In order to design an ADS, a method for analyzing the disassembly task is presented from which the concept for an automated system can be developed.

2 Methodology

According to the claim for economical systems, the approach is to use as few different automated disassembly stations with a low number of automated modules and tooling as possible, but with the functionality to process all required disassembly tasks. To reduce the complexity of the disassembly stations, each station should provide as few different tools as possible, but enough to provide the flexibility to react to connections that cannot be detached. Furthermore, it is worthwhile, that non-destructive separation procedures are preferred over destructive separation procedures. The methodology is based on the assumption, that every disassembly station provides one automated process module (e.g. robot) for the execution of the disassembly task and eventually other handling devices that are not directly involved into the separation process. The selection of system modules is carried out in binary decision diagrams so that an automation concept can be derived from the product characteristics analytically.

2.1 Structure of the methodology

The methodology is structured in four categories (Figure 1). The first one, the determination of the objective of the disassembly task sets first boundary conditions for the processes inside the ADS. During the product analysis the components, the connections and their structural arrangement are characterized. In the following step the disassembly processes like separation and handling processes are determined. Finally, in the design of a conceptual ADS, the previous determinations are combined and the concept of an ADS can be developed.

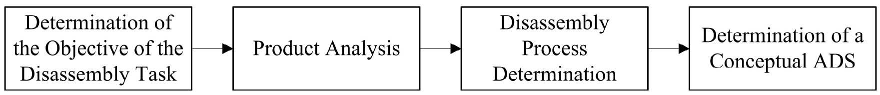

Figure 1: Structure of the methodology

2.2 Determination of the objective of the disassembly task

Determination of the objective of the disassembly task. In a first step the permitted destruction grade and the disassembly depth have to be defined. The permitted destruction grade is mainly influenced by the life cycle scenario of a product. Table 1 considers the resulting degree of destruction and the disassembly depth depending on the life cycle scenario.

Table 1: Life cycle scenarios of the product and resulting requirements for the ADS

Life Cycle Scenario	**Permitted Destruction Grade**	**Disassembly Depth**
Maintenance	No destruction permitted (Non-destructive disassembly required)	Component separation
Repair		
Product or component reuse	Minimal destruction permitted (Semi-destructive disassembly permitted)	
Remanufacturing		
Material recycling	Destruction permitted (Destructive disassembly permitted)	Material separation

2.3 Product analysis

The product analysis is divided into four steps, as shown in Figure 2. The first step includes the investigation of the target components and their connections, from which the requirements for the ADS are derived. In the next step, component levels which are necessary for the description of the product structure are identified.

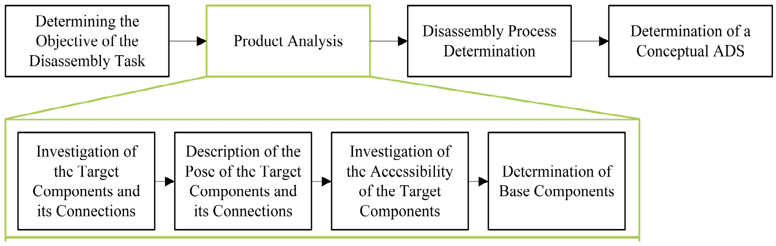

Figure 2: Product analysis for disassembly

As a first step a numbering of all target components and connections happens, so automated decision-making diagrams can be created, from which decisions can be made automatically. Connections by the same type are labelled with the same number and the numbering happens from the outer to the inner components of the product. In the following steps the number of a component is described by the counter variable k, while k_{max} describes the component with the highest number. The connection numbers are described by the counter n.

The description of the pose of the target components and their connections is essential for the separation process. To describe the pose of components to each other and related to the disassembly environment, coordinate systems (CS) are determined for every target component k of the product (Figure 3, left). Principally, the CS can be set at every position in the disassembly environment. However it is useful, to define a CS in the symmetry axis of a component. The z-axis of a component's CS is defined as the component's disassembly direction.

After determining the components CS, the connections between the target components have to be described. Thereby, disassembly vectors and disassembly points are defined (Figure 3, right). While the disassembly direction of a component is described by the z-axis of their CS, the disassembly vectors describe in which direction a connection has to be moved to be detached from the target components. The disassembly vectors of detachable connections can be identified by inverting their assembly directions. The vector $\vec{x}_{dis}$ defines the general disassembly direction. The magnitude of the vector describes the length of the disassembly movement.

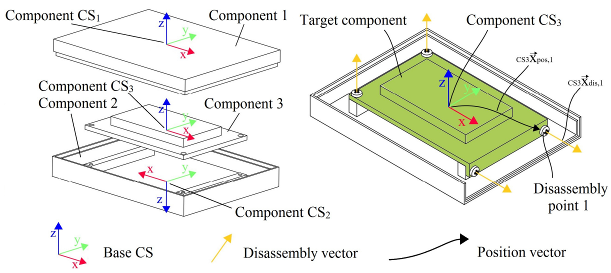

Figure 3: Determination of component CS (left) and disassembly directions (right)

After defining the disassembly directions, the accessibility of the target components has to be investigated (Figure 4). In this paper accessibility shall be defined as the visibility and physical reachability of a component or connection. Assuming that detachable connections are accessible, if the fixed target component is accessible, the accessibility can be investigated by checking the visibility of the target component. The visibility of the component, however, is checked by considering the component from a plane aligned vertically on the disassembly vector.

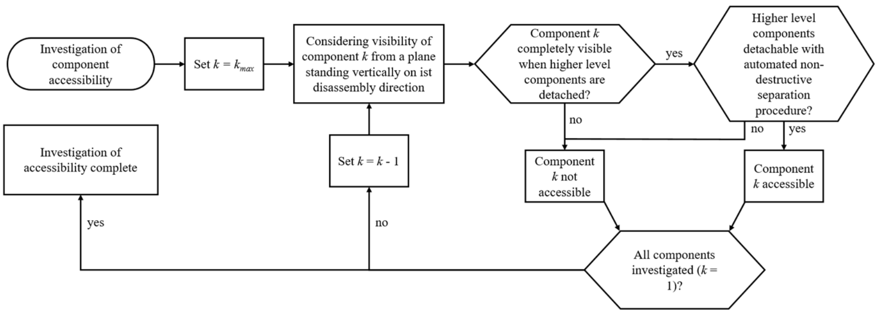

Figure 4: Investigation of component and connection accessibility

The last step of the product analysis is the determination of base components. Base components are target components, at which other target components are mounted. If a base component can be gripped at the beginning of a disassembly task, disassembly processes can be performed, while the base component is used as the foundation for these processes. Components, identified as a base for as many separation procedures as possible are determined as base components. According to this, the only reason why there are more than one base component in products is the presence of further target components, which are not accessible in the current disassembly situation.

2.4 Disassembly Process Determination

The determination of the disassembly process is divided into two parts. First the separation processes are determined, followed by the handling processes. The description of the separation process starts by checking whether a connection is detachable. When the separation of components is performed by a destructive separation procedure (non-detachable connection), there are different possibilities to use the separation procedure. The destructive separation procedure could be used for a direct destruction of a connection or to split the material at another point of the product. The choice of where the material has to be separated is made by considering the accessibility of underlying target components. The areas where the components are separated are called separation areas. To complete a product disassembly, all target components have to be separated from each other after completing the last disassembly task. To ensure that a component of a lower component level can be disassembled, this component has to be accessible after finishing the previous disassembly task. In case that a component is not accessible, destructive separation procedures have to be performed at a higher level component. Therefore, the structure of a product has to be investigated in a first step.

Figure 5 shows an example of the determination of a separation area that ensures the accessibility of the target component. The target component is screwed onto the back cover of a case; the front cover is fixed to the back cover. The connections between the cover components are not accessible for the ADS. The disassembly direction of the target component is the direction of the z-axis; the minimal size of the separation area is shown by looking at the xy-plane of the target component.

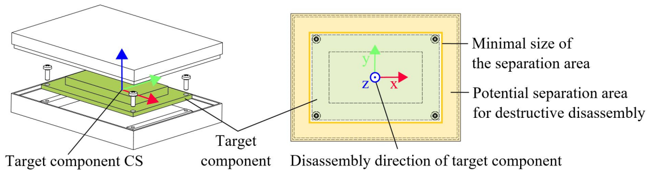

Figure 5: Example for the determination of the separation area

In order to find suitable tooling for destructive separation processes the geometry of the separation area has to be determined. If the required separation geometry is a point (e.g. for the destruction of a screw connection), a drilling procedure can be used; if the separation area is determined by a straight line, a sawing tool can be used. Separation areas with higher complexities require a milling tool to perform the separation task. The selection processes are also reduced to similar decision diagrams as shown in Figure 4.

2.5 Determination of a conceptual ADS

The disassembly process was determined by taking the separation and handling tasks that have to be performed to complete the disassembly into account. At this stage, modules and a rough layout can be developed, based on the disassembly product and the disassembly properties. The concept of an ADS includes the number of automated disassembly stations, the motion quantities in the ADS, the required size of the workplace and automated system modules for the ADS.

The number of automated disassembly stations depends on economic and technical conditions. Examples for economic conditions are a required payback period or the maximal investment costs. Technical conditions include the technical feasible function range of single stations and requirements on the disassembly process.

The motion quantities of tools and products in and between the automated disassembly stations are determined in a way that ensures a minimal amount of handling operations. For example, it is investigated whether it is more efficient to move the product or the disassembly tools in order to perform the separation task. This depends on the structural composition of the product, the weight of the separated components and whether the required separation tool is already mounted in the concerning disassembly station.

The required size of the workspace is an important parameter of an ADS. The necessary dimensions of the workplace are determined by the disassembly and separation vectors, thus the distance that is required in each direction to disassemble components. The workspace is described by the vectors with the largest magnitude in each direction, as seen in Figure 6.

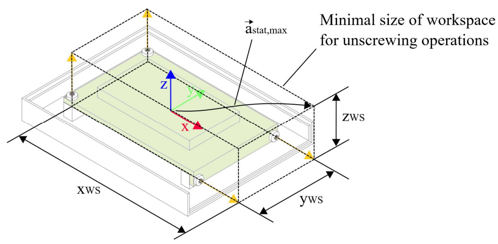

Figure 6: Determination of the minimal size of the disassembly workspace

In a last step of this methodology, the determination of system modules takes place. First, the transfer modules are determined. Afterwards process handling modules, which perform the separation process, are determined. Transfer modules fulfil the purpose of handling units between and within the disassembly stations, but are not involved in the separation process itself. The process handling modules are selected with the aim to perform the disassembly task while needing as few degrees of freedom as possible. This approach is chosen under the assumption, that modules/robots with a higher degree of freedom cause higher investment costs.

3 Exemplary Determination of a conceptual ADS

In this section the introduced methodology shall be applied to the disassembly of LCD screens (c.f. [6]). The LCD screens, as exemplary shown in Figure 7, exist in different variants and sizes, therefore the ADS has to be able to handle different model variants. The permitted degree of destruction of the electrical components should be minimal, while the structural parts can be destructed up to a high degree.

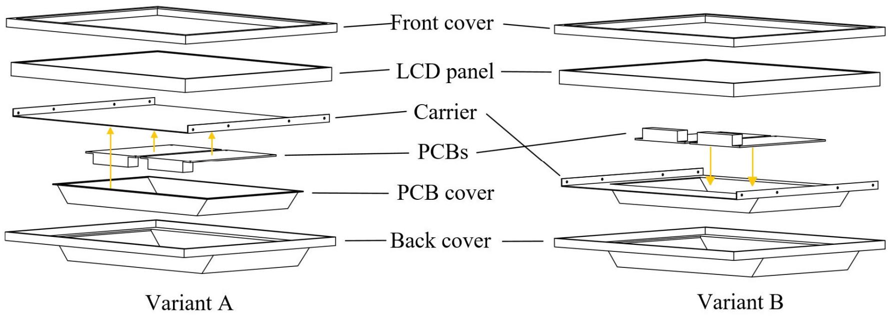

Figure 7: Explosion view of different model variants of LCD screens (c.f. [7])

By following the steps of the methodology introduced in this paper, the system can be realized as a robot cell with one disassembly station, as seen in Figure 8. The disassembly task (Step 1) is the disassembly of LCD screens while separating different materials for recycling. In the product analysis (Step 2) coordinate systems and base components are determined. Also the description of the connections is made. In the disassembly process determination (Step 3), separation and handling processes are defined. The separation of the back cover can be performed with a sawing tool, due to the high permitted degree of destruction. The separation of the electronic parts is carried out with a screw driver though, due to the minimal degree of destruction. According to the determination of the motion quantities, the product is stationary during the performance of the separating operations, but temporary moved for reorientation. The analysis of the product characteristics and going through the decision diagrams, leads to an adapted ADS system. It contains one SCARA robot that performs the separation procedures, a second robot, equipped with a magnet gripper for the material handling, a conveyer for the transfer of LCD screens from the storage, different storage boxes, a vacuum unit for gripping and turning and a tool changing station.

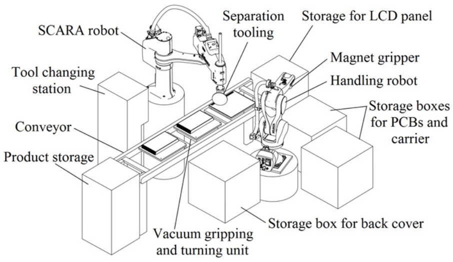

Figure 8: Exemplary concept of an ADS for the disassembly of LCD screens

4 Conclusion and Outlook

A methodology for an automated disassembly system is presented. The method aims to generate a concept objectively from analytical decisions. Therefore, product and process characteristics are translated into simple decision-making diagrams, so that a transfer into a software tool, in analogy to existing disassembly software [7], can be realized easily. After determining the objective of a disassembly task, a product analysis follows, from which the concept of an ADS is derived. In order to estimate the separation process, target components and their connections to each other have to be defined. Finally, modules of the ADS can be determined, which is shown on an automated concept for the disassembly of LCD screens.

The results of the disassembly analysis of LCD screens as shown in chapter 3 are currently only conceptual. In further work, the methodology shall therefore be evaluated in a more realistic scenario, to verify the feasibility of the methodology.

In a future-planned software tool, the product properties are entered and a concept for a conceptual layout is generated. Once converted into a software tool, the functionality of the methodology can be expanded by adding other tools (e.g. automated tool selection [8]).

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