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Semi-automatic design for disassembly strategy planning: an augmented reality approach

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Abstract

The mounting attention to environmental issues requires adopting better disassembly procedures at the product's End of Life. Planning and reckoning different disassembly strategies in the early stage of the design process can improve the development of sustainable products with an easy dismissing and recycling oriented approach. Nowadays many Computer Aided Process Planning software packages provide optimized assembly or disassembly sequences, but they are mainly based on a time and cost compression approach, neglecting the human factor. The environment we developed is based upon the integration of a CAD, an Augmented Reality tool, a Leap Motion Controller device, see-through glasses and an algorithm for disassembly strategies evaluation: this approach guarantees a more effective interaction with the 3D real and virtual assembly than an approach relying only on a CAD based disassembly sequence planning. In such a way, the operator may not test in a more natural and intuitive way automatic disassembly sequences, but he/she can also propose different strategies to improve the ergonomics. The methodology has been tested in a real case study to evaluate the strength points and criticalities of this approach.

Keywords: Design for Disassembly; Augmented Reality; CAD; Disassembly Sequence Optimization;

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1. Introduction

Nowadays, the world-wide request for more efficient products is arising in order to decrease energy and raw materials expenditure: attention is given to the whole product cycle from cradle to grave. In particular, the end of life of a product is fundamental to environmental issues since it is possible to select recyclable components, thus reducing the waste. Hence, disassembly strategies became a very important issue at products End-of-Life (EoL) where it is fundamental to separate parts made of different materials. For this reason, taking in account and planning the right disassembly process during the Early Stage Design (ESD) may lead to improve the products sustainability.

Assembly and disassembly are very different each other. Aim of the assembly process is to put together several separate components in order to create a functional product. On the contrary, disassembly could be performed to achieve different goals, as a function of the sub-group hierarchy where the disassembly ends. For example, during the entire products lifecycle, a lot of products undergo maintenance and repair operations (MRO) in order to keep it fully functioning. In this case, it's required only a partial disassembly. On the other hand, disassembly can be performed for several reasons at the product EoL. In many cases, substances and materials requiring special treatments due to their hazardousness may be lie inside the product; in another scenario, components or subassemblies in plastics, iron, glass, paper may be recycled. The type of joint and connection features is another important aspect to consider in the disassembly process design: some types of joints, like fastening or gluing, make the assembly process irreversible, due to the joint breaking; other joint kinds require special tools or unfriendly moves by the operator to disassembly the products. Furthermore, the joint position and the contact surfaces are significant in the disassembly process design because they influence the way in which a product lie in the working area, posing a risk for the worker safety if an unstable position or object pose is obtained during the sequence. Finally, the joint disassembly time and easiness must be considered since they impact the cost of labour and the stress on the worker respectively. There are several ways to evaluate different disassembly sequences for a product. One way is to exploit optimization methods consisting in finding the best values for a given objective function enhancing an aspect related to disassembly like for example the time and cost, as proposed by [1]. The object function to maximize/minimise in optimization should translate in an effective way the need of the disassembly operator to obtain a suitable solution. Another way to plan disassembly is the use of CAD tools, which provide a visualization of geometric constraints and disassembly path [2]: however, they lack physical interaction capabilities. In this case, the operator deals only with a virtual model where it can be difficult to evaluate dimensions, weights, disassembly path ergonomics and time. A more effective approach requires the use of more interactive tools, but such a kind of devices isn't currently available in the ESD to Small and Medium Enterprises (SMEs).

As literature suggest, a crescent number of methods and algorithms have been proposed in the recent years to assist designers and product developers in discovering and choosing the best disassembly sequence. These methods generally rely on cost compression and time compression criteria, but also others disassembly sequence evaluation criteria have been implemented. For example, in [3] the author has introduced four different level of disassembly difficulty that may be encountered during the disassembly process: accessibility, positioning, force, base time. According with these four parameters, the disassembly sequence may be evaluated. In [4] the optimized disassembly strategy is developed in order to derive the greatest possible profit from the recovered material. In [5] the proposed method, depending on the product bill of material and product 3D model, suggests the ideal disassembly stage of the product and the best EoL strategy for each subassembly. In [6] the author assigns a score to the disassembly sequence, based on five dimensionless coefficients: visibility, disassembly angle, stability of subassembly, number of tool's changes and path orientation changes. With these five coefficients, it is possible to estimate the complexity of different disassembly strategies. However, these methods still do not take full advantage of the disassembly process knowledge of designers and maintainers in the disassembly sequence planning. The recent AR applications [7] focused their interest more on the assembly phase rather than on the disassembly one, and, in particularly, on three aspects of assembly operations: AR assembly guidance; AR assembly training and AR assembly process simulation and planning [8]. The AR Assembly Guidance (ARAG) researches have been concentrated on the data integration, coming from different software tools (CAD, CAM, PDM, PLM), and instructions visualization on Head Mounted Devices (HMD). Using these ARAG software tools, worker's skills may be improved, allowing them to execute more complicated assembly task, in an easier way rather than using cumbersome manuals or technical drawings. Although these benefits, the primary focus of ARAG is to supply only the step-by-step information and instructions to perform the assembly task. Moreover, very few AR assembly guidance tools are able to distinguish in real-time the assembly stage achieved or to detect assembly sequence errors. Coming now to the second topic of AR applications, the AR Assembly Training (ARAT) researches have been focused on determining a formal procedure through which the worker perform a specific assembly task, in order to maximize employee efficiency. The assembly and disassembly instructions are implemented in several ways, such as video projections and 3D animations of the given task. Also, the specific tool and the unmounting direction and movement are visualized. For example, in [9] a AR prototype application has been applied in training soldiers performing assembly and disassembly operations on a military vehicle. In all AR training sessions, the test subjects demonstrate a higher accomplishment speed and a lower error rate. Concerning the AR assembly simulation [10] and planning, many of the proposed AR assembly simulation systems lack haptic feedback and intuitive interaction with the real object, due to the limited gestures set, that are clearly intended and designed to be easily recognized by the tracking system rather than to be natural and spontaneous. For example, in [11] the authors proposed a AR application for the disassembly sequence evaluation. The suggested system does not have a sufficient haptic feedback in performing disassembly tasks due to the use of a simple wireless controller (Nintendo Wii remote controller), so the user may not be able to fully conceive of disassembly directions, movements and limitations, although sound feedback is returned to the user in case of unfeasible disassembly operations. On the other hand, the disassembly sequence graph visualization has been greatly appreciated by the users thanks to the simplicity of the viewing but they found it restrictive in exploring new and original disassembly sequences. However, the examples seen in this overview show that the major effort of the scientific community went into the direction of elaborating and implementing AR systems specifically for assembly purpose, rather than disassembly. This paper tries to bridge this gap presenting a novel environment based on AR to support the development of smart disassembly sequences, called ARDET acronym standing for Augmented Reality Disassembly Evaluation Tool (ARDET).

The paper is organized as follows: after this Section 1 reviewing existing computer aided disassembly process planning methods available in literature, Section 2 describes the architecture and implementation of ARDET. A case study is presented in Section 3, while results and discussion will be presented in Section 4; conclusion and future works are included in Section 5.

2. Software and Hardware Environment

2.1. ARDET features

This research introduces a tool based on a novel evaluation method for the explicit disassembly strategy planning. ARDET allows the user to place real-size 3D models in the working area and to accomplish disassembly operations: AR is used to superimpose symbols, texts and animations useful to suggest the operation to carry on during the disassembly to images framing the real object. Thanks to the real-time tracking of user hands, the results of the user operations on the real part can be displayed in AR showing where the virtual parts move after the human intervention. By using hands tracking and gesture recognition devices (e.g. LEAP Motion) real-time interaction and truly immersive AR disassembly experience is achieved. ARDET is a tool based on a Graphical User Interface (GUI) which manages a set of tools useful to develop new disassembly strategies. It performs step-by-step removable components visualization, step-by-step specific tool detection and joint unmounting movement and

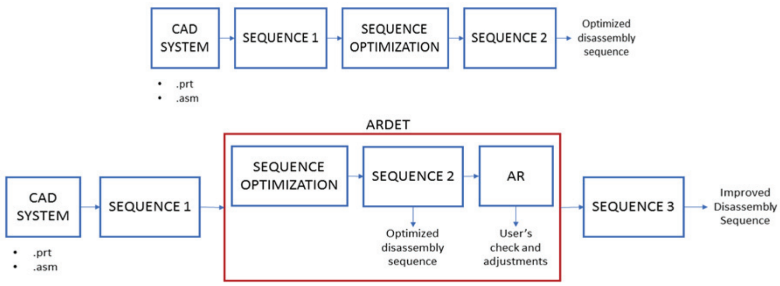


Figure 1: a) Classic disassembly sequence optimization method; b) ARDET disassembly sequence optimization process

direction, step-by-step feasibility and usefulness evaluation of the removed part and finally step-by-step obstructions prediction for the disassembly procedure completion.

The outcome of the ARDET application in the ESD is the enhancing of the disassembly process planning as it constitutes a Decision Making (DM) tool: it helps designers to discover new original disassembly strategies based on the direct user's participation and interaction with the product. Furthermore, the disassembly sequences can be simulated in the first stages of the products development where only a virtual model is available, thus keeping into account the problems related to products end of life. It is worth to note that the disassembly sequence suggested by the optimization algorithm embedded in ARDET can be modified by the user if unfeasible or unfriendly moves are suggested.

2.2. System architecture

ARDET is composed of three modules: Images Acquisition System (IAS), 3D Modeling System (3DMS) and the User Interaction System (UIS). ARDET interface, whose architecture is described in Figure 2, is developed in Python language in order to allow an easier interaction with the libraries of the 3DMS and an easy integration with the open-source Python language based FreeCAD necessary to model the virtual 3D parts and manage the assemblies.

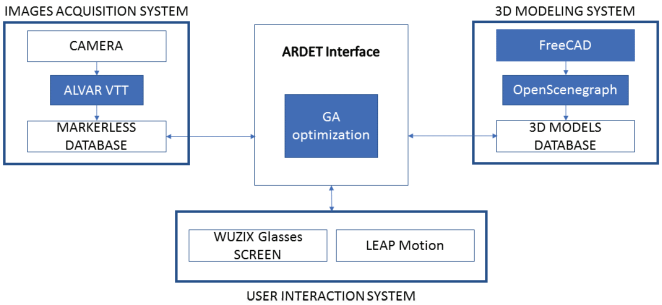


Figure 2: ARDET architecture

2.3. Image Acquisition System: ALVAR VTT

IAS is necessary to manage the AR part of the ARDET tool. The ALVAR VTT [12] AR software has been integrated in ARDET to detect in a framed scene objects and to guess their position in space and pose. ALVAR VTT is a suite of products for creating augmented reality applications developed by VTT Technical Research Centre of Finland. It supports markerless tracking, based on point clouds created from photos of the component taken in

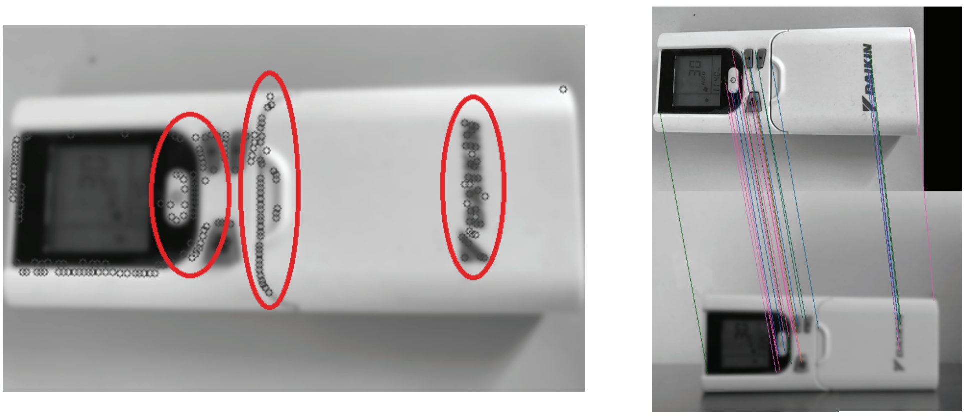


Fig. 3: (a) Features recognition during Fern Training Session; (b) Features Tracking

different position and angles and stored in the database: the image of the real component is than compared to the database to obtain its position in the ARDET reference system. The first step of the acquisition procedure is the training of a Fern classifier with a component picture. The component picture must be in the range of 200 x 200 up to 500 x 500 pixels and it should contain a number of unique features sufficient to train the pose and position estimation algorithm. Once the training is complete, the points cloud is stored in the markerless database and it can be used for tracking and superimposing the 3D model on the real object in real time. The Figure 3 (a) shows the unique features detected in the picture of a remote controller for an air conditioner by ALVAR during a training session; Figure 3 (b) presents the recognition of the same features on a picture of the controller taken in real time from a user-set point of view. It is worth to note that the comparison of the key point distances in the database pictures and in the video streaming allows to ALVAR to guess the camera point of view in terms of positions and angles in an absolute and camera reference systems.

2.4. 3D Modeling System: FreeCAD and OpenScenegraph

The 3DMS is based upon the open source FreeCAD 0.16 3D modelling software. FreeCAD has been chosen due to its easy personalization capabilities. FreeCAD is based upon a set of workbenches, each one specialized to perform a task among with parts modelling, assembly, and sketching. New user-developed workbenches can be implemented with Python code and a lot of them is freely available on the Internet. Following the ARDET procedures, once the parts of the product to study has been modeled and assembled, it is necessary to define the disassembly trajectories. These can be derived from the Genetic Algorithm Optimization (GAO) process. In order to do this, a specific workbench of FreeCAD has been used, named Exploded Assembly. This workbench allows to visualize the disassembly trajectories (Fig. 4) of every component and it allows to show the movement required to disassembly the component. After the creation of the product 3D model in FreeCAD, it is than necessary to convert

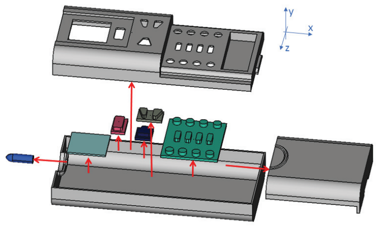


Fig. 4: Example of disassembly paths generation in FreeCAD environment

it to .OSG format, the OpenScenegraph native format. This is necessary because ALVAR VTT supports only the OpenScenegraph format. Osgconv, a free plugin of OpenScenegraph, has been used to convert the model from the FreeCAD native format to .OSG format. All the models are then stored in the ARDET 3D models database.

2.5. User Interaction System: Vuzix Glasses and LEAP Motion

In order to make ARDET more adequate for the disassembly operations, a see – through pair of glasses has been adopted. This solution provides immediate heads up access to information that the user would normally access by looking down at a hand-held display or a screen, thus losing the contact with the real product being under the disassembly process. The Vuzix Star 1200 XL Glasses has been used in this study.

LEAP Motion Controller device has been integrated in the ARDET platform to achieve a real-time user interaction with the 3D model. Leap Motion allows hand tracking and gesture recognition in a conic space centered in the LEAP Motion with a diameter of 0.4m, and an height of 0.4m. As noticed by [13] the best performances are obtained with palms facing down hands at a distance of 0.2m from the LEAP. A preliminary set up is necessary in order to define the tracking sensibility, focusing on finding a compromise between precision and usability. The interaction with the model is obtained by a pinch gesture made with fingers. While maintaining the pinch, the user can translate and rotate each component in accordance with the disassembly path. If fingers are released, the interaction ends and the selected component remains in the last tracked position. The scene has been set up in Unity. Vuzix Glasses and Leap Motion have been chosen because in both cases a Unity package which make easy the integration of both devices can be downloaded from the web.

2.6. ARDET disassembly optimization algorithm

ARDET algorithm, which is necessary to optimize the disassembly sequence, is configured as a matrix decision making approach. It is based on product geometry analysis, components relationships, joints classification and unmounting movement. The algorithm steps are listed below:

- The first operation required is the training session with a picture of the real object and the identification of multiple unique features. The acquired data are stored in the database. The point cloud of unique features is used to tracking the real object and to superimposing the 3D model.
- The assembly relationships are derived from the assembly parametric model presented in literature in [14]. According to the assembly constraints [15], a Disassembly Strategy Matrix (DSM) is automatically composed. The DSM comprehends the mutual moving directions of each components. Each matrix value represents the mutual Degree of Freedom (DOF) of each couple of components present in the assembly. If contact between two components does not exist, the matrix position of these two components is filled with a zero;
- the Genetic Algorithm (GA) optimizes the Disassembly Strategy (DS) once the DMS is created. The proposed DS is the sequence from which the user can explore different disassembly solutions, based on his skills and experience.
- Thanks to the DSM, the presence of a removable component is checked. The values in the DMS represents the direction in x, y, z axis reference system along with the disassembly is possible. The first component that must be disassembled is the one which presents the lower number with non-zero values in the DMS matrix correspondent row. When two or more values in the DSM matrix are different from zero, the part is removable only if the values are similar (e.g. +x and +x).
- According to [14], if a removable component exists, the algorithm assigns a score in order to define the component disassembly precedence. The score is given according to four parameters: the first one represents the number of subassemblies that are unconstrained after the given disassembly operation. The second parameter corresponds to the number of tool changes: precedence is given to the operation not requiring tool changing. Third parameter concerns product handling: precedence is given to the operation not requiring product repositioning. Fourth parameter evaluates the overall easiness of the disassembly task with the combined use of two scores: one ergonomic, obtained from standard tables of ergonomics; one visibility score, derived from the worker optimal visual area [16]. The two stated scores are then combined in order to form the fourth parameter, named accessibility score.
- If all the matrix positions are equal to zero no component one is removable, so that the disassembly process has been finished.

3. Case study

The ARDET tool has been tested in several case studies, one of which is reported in this section. The object selected for this example of disassembly procedure planning is a remote control (Figure 5) composed of nine parts:

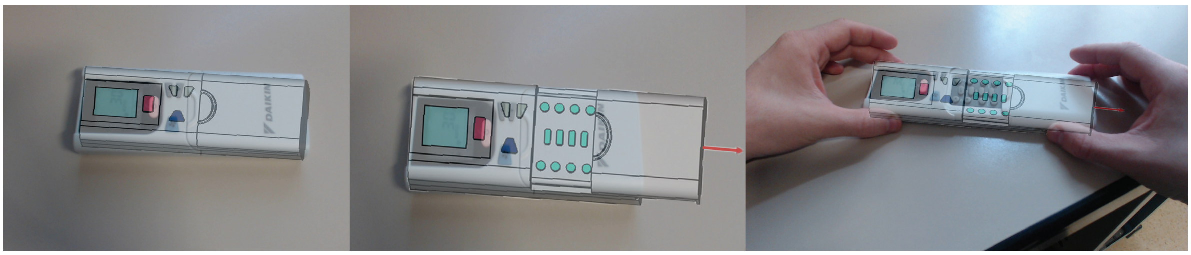
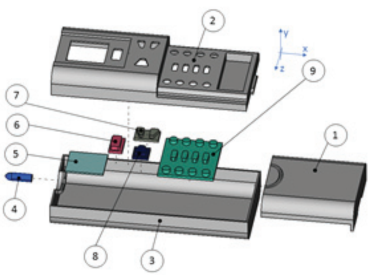


Fig. 5: user's see through view

upper case; lower case; sliding cover; LCD display; transmitter's infrared light; buttons (see Figure 6). The user starts the disassembly simulation wearing the Vuzix glasses and frames the remote control. ALVAR VTT recognizes the set of unique features and accesses the markerless database in order to superimpose the corresponding 3D model upon the real object. Since ALVAR VTT can read only .OSG format, it has been implemented a macro in FreeCAD for the automatic conversion from .FCStd format to .OSG format, using the OSGConv plug – in. Due to the conversion in .OSG format, the model has no parametric information about assembly relationships. For this reason, the animation of the disassembly operations along the disassembly path is made as follow: the component requiring to be disassembled is superimposed at the beginning and at the end of the disassembly path, in subsequent frames. LEAP motion device is positioned above the working area in order to tracking the hands movement. Once the disassembly session is started, ARDET suggests each disassembly operation to accomplish the entire disassembly task. The operator can simply follow the GA optimized sequence or eventually he/she can create new disassembly sequences, in accordance with instructions of the DSM. In fact, the DSM points out the subsequent possible removable component for each disassembling step: for example, after removing the sliding cover, the operator can decide whether to remove the upper case or the lower case. In this example, the upper case removal gets a higher score compared to the lower case removal. Indeed, the second operation demands the remote-control repositioning, in accordance with the ARDET algorithm. The disassembly sequence score is updated in real time after sequence changes made by the operator and the new score can be compared with the GA optimized sequence scoring. In this way, the operator immediately realizes whether the change he wants to implement introduces some ergonomic improvements, maintaining a score similar to the optimal one.

	Sliding cover	Upper case	Lower case
Sliding cover	-	+X	0
Upper case	- X	-	+Y
Lower case	0	-Y	-



ITEM	DESCIPTION
1	Sliding cover
2	Upper case
3	Lower case
4	Lamp
5	LCD Display
6	Power button
7	Up/down velocity
8	Fan button
9	Keyboard

Fig. 6: DSM and BOM of the remote control

4. Conclusions and Future work

The ARDET platform could be considered as a new tool to support disassembly strategy design and evaluation. The use of ARDET allows to superimpose real size 3D model upon the real object and permits the visualization of information concerning disassembly path and/or specific tools required for the accomplishment of the desired task.

The first benefit deriving from the use or AR is a greater interactivity in the design of disassembly sequence planning. Thanks to ARDET, the designer can immediately test the ergonomics and easiness of the different operations. Another advantage derived from the adoption of the tool is the possibility of introducing the worker disassembly experience in the sequence optimization process. In this way, the expertise and know-how relating to the disassembly operations are actively exploited in the definition of the unmounting path and disassembly sequence. The

integration of the user know – how in the automated optimization criteria for the disassembly planning ameliorates and upgrades the disassembly process design. On the other hand, ARDET platform suffers from some cons. A laborious work is necessary to prepare the model for his use with ARDET: modeling geometry and his conversion in the .OSG format; the identification of the disassembly relationships from the assembly and the statement and animation of the disassembly procedure. Furthermore, the limit on this method is that the new disassembly sequence could not be better than the one obtained with the simple GA optimization process. Notably, the implementation of

AR tools in industrial scenarios is subjected to some difficulties due to low/weak textured objects with shiny surfaces: these features can generate inaccurate 3D model pose; furthermore, the images definition and accuracy depends on the lighting conditions of the environment: this limitation of the use of AR tool in industrial scenarios can be overcome by using more advanced devices, like Microsoft Hololens, which can better manage sudden changes of lighting conditions. Another aspect to be considered is the user's acceptance: the hand gestures set implemented in ARDET is quite limited and the fingers and hands movements are not so natural and intuitive. For these reasons, ARDET implementation in industrial context requires a preliminary training session for the user. Moreover, the use of HMD can be cumbersome and space limitating due to the necessity of WI-FI connection with the computer. Major effort concerning the methodology could be made aiming to a more precise and accurate scoring of the disassembly operations ergonomics. In such a way, the disassembly sequence generated by the user could results an improvement solution respect to the automated GA solution. On the other hand, future works could involve making ARDET interacting with a commercial CAD software, in order to test the platform in a more plausible industrial scenario. Another focus should be the integration with more recent and advanced HMD, such as Microsoft Hololens, which are available on the market.

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