HEATING CIRCULATION PUMP DISASSEMBLY PROCESS IMPROVED WITH AUGMENTED REALITY

by

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The purpose of the paper is to introduce the possibilities of the implementation of augmented reality concept in the disassembly process. The basic concept of augmented reality implementation in various applications, as well as the developed concept in the disassembly system is presented. Main objective of this paper was to test the influence of the implementation of augmented reality in the disassembly process with the goal of shortening the overall duration of the disassembly process. In this paper the experimental setup of the developed concept in the disassembly system for heating circulation pump that was conducted in laboratory conditions is shown, and conclusions are presented.

Key words: *pump, disassembly sequence, human-machine interaction, marker*

Introduction

Disassembly process has become one of the major aspects of life cycle engineering and environmental protection issues. When an end-of-life (EOL) product is disassembled and recycled, all hazardous substances must be identified and safely removed in order to comply with the waste electric and electronic equipment (WEEE) directive [1].

The main purpose of the disassembly process is to revalorize EOL products by a methodical separation of their parts and materials for recycling, remanufacturing and reuse [2]. When defining disassembly sequences, several issues must be considered simultaneously –geometric constraints, safety, economy, and environmental impacts [3]. Also, in order to assure the competitiveness of disassembly lines, the line designers have to deal with the uncertainty that characterizes EOL products and to be able to determine the level of disassembly for which the revenue obtained from retrieved parts is higher than disassembly cost [4].

Since disassembly sequences are different for each type of product, it is essential to supply disassembly workers with relevant information as efficiently as possible at the corresponding location and at the right time. Several methods and technologies have been used to achieve this goal like: Petri net [5], Monte Carlo method [4], barcode, RFID [6] and others. Augmented reality (AR) is a new concept that can also help in supplying workers with relevant information in real time.

Main objective of this paper was to test the influence of the implementation of AR in the disassembly process, with the goal of shortening the overall duration of this process. In

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this paper a strategy of the implementation of the augmented reality in the disassembly process in order to assist workers by suggesting adequate technological procedure for the disassembly operation will be presented. Likewise, results collected from the experimental setup of the developed concept in the disassembly system for heating circulation pump, conducted in laboratory conditions, are presented.

Augmented reality

Augmented reality allows a combination of real world elements, captured through a camera, with multimedia elements such as text, images, video or 3-D models and animations. AR environment allows the user to see the real world with virtual computer-generated objects superimposed or merged with real surroundings. In terms of used technology, AR can be said to require the following three characteristics: it combines the real and virtual, it is interactive in real time, and registered in 3-D.

Today, the implementation of augmented reality has been introduced in several non-industrial fields (fig. 1) [7] like: medicine [8], architecture [9], aerospace [10], education [11], construction [12], *etc*. There are also industrial applications in which augmented reality can be applied in all phases of product life cycle. In the product development phase, aesthetic designing has become an essential process that can be effectively assessed by using AR without making a real physical prototype, reflecting the immediate feedback of evaluators [13]. Also, the evaluation of the effectiveness of technical maintenance assisted with interactive augmented reality instructions has been presented in [14], while integrating AR into the planning process of manual assembly stations is presented in [15].

Figure 1. Implementation of AR in maintenance and service of a wide variety of products (Source: http://www.utrc.utc.com)

In order to enable AR in any process, there is a need for the implementation of four hardware components: sensors, processor, display and input devices [16].

Sensors in AR are responsible for collecting information about the environment. The most commonly used sensor in AR is camera, which is used for taking pictures of the actual world. The processor is responsible for processing images from the camera, and its enrichment with additional information. The display is used to display the results of image processing, or the image of the real world enriched with additional useful information. There are various technologies for displaying information such as optical projection systems, monitors, hand held devices, glasses, and display systems worn on one's person (Head Mounted Displays – HMD). Input devices are used for commands which affect information processing and displaying. Modern mobile computing devices like smart phones and tablet computers contain these elements which often include a camera and Microelectromechanical system (MEMS) sensors such as accelerometer, Global Positioning System (GPS), and solid state compass, making them suitable AR platforms [17].

There are two primary types of AR implementations: MARKER-Based and Markerless [18]. Marker-based implementation utilizes some type of image as a marker to produce a result when it is sensed by a reader, typically a camera on a mobile phone. Markerless AR is often more reliant on the capabilities of the device being used such as the GPS location, velocity meter, *etc*. Both Marker-based and Markerless AR require AR specific software or browsers to function. On the market, a large number of ready-made software solutions and platforms to work with AR is available.

To implement interactive instructions with the AR, in most cases, Marker-based AR is used, which can show videos, 2-D and 3-D animations. These instructions can be used both in non-industrial and industrial systems (instructions for home appliances, maintenance manuals for machines).

Using interactive instructions can have multiple advantages. Exemplar advantages in assembly systems are the following: no need for training of workers; lost assembly time is minimal; possibility for product withdrawal due to assembly mistakes is minimal [19]. Using some of the devices (mobile device, glasses, *etc.*), the user takes picture of the marker, and the device processes that picture to get the orientation of the marker, *i. e.* virtual local coordinate system in which 3-D model or 3-D animation is drawn and shown on the display. Mobile phones (and tablets), because of the large number of built-in functionality, are suitable AR platforms. On the market, there are a very large number of different types of products, different models and different manufacturers, and it is not possible to realize a universal application that would encompass all possible products. The solution to this problem is that the marker provides details about the product. Dedicated application detects the marker, reads information about the product from the marker, accesses the database using that information, and retrieves the data related to the product (instructions in the form of images, 2-D or 3-D animation, video files) [20]. After retrieving, this information would be shown on the screen or device display. Database can be local (for example, factory database with instructions for products assembly) or database can be on the Internet (manufacturer's database with instructions for using their products).

Disassembly process

Disassembly is one of the processes in the life cycle of a product which has a key role in remanufacturing, recycling of products and disposal. This is due to ecological and economical reasons.

The execution of disassembly process consists of a series of sequences that need to be done in order to take apart the product to elementary components, which then need to be distributed to the appropriate material flows for further processing in order to optimize their life cycle.

Figure 2. Disassembly work place

A typical disassembly work place (fig. 2) includes the basic elements, such as: tools, fixtures, containers for part selections, part holders and measurement instruments.

Disassembly sequence includes the following activities:

(1) Taking the product from the pallet;
(2) Determination of the variant and types of products;
(3) Description of the disassembly technology procedure;
(4) Execution of disassembly sequences;
(5) Determination of the condition of disassembled component (condition analysis);
(6) Diagnosed component condition;
(7) Component selection according to component condition and placing in adequate container.

It must be emphasized that in some cases the description of the disassembly technology procedure can be modified, *i. e.* some actions can be completely eliminated (when processing well known products).

Each of the mentioned activities (1-7) requires a certain time for accomplishment. However, in most cases the product information is completely missing and thus disassembly activities can unnecessarily last for too long. These cases represent a loss for the system. For example, the determination of variants and types of products often lasts several times longer than necessary.

The result of this situation is the reduction of the labour utilization degree, reduction of machines and devices used for the disassembly process, degree of utilization, reduced productivity, low quality materials that are obtained in the process of product disassembling, prolonged treatment products, *etc*. Result of all these problems is a reduction in the efficiency and effectiveness of the disassembly process, and the core of these problems is in the lack of information.

In order to efficiently deal with the lack of information, AR can be used for delivering interactive instructions for the disassembly process in the shortest time (fig. 3). These instructions include:

– Detailed instructions on how to perform the disassembly sequence,
– Detailed instructions on how to perform the analysis and diagnosis on component condtions, and
– Detailed instructions on how to perform the component selection according to the component condition.

Figure 3. The AR interactive instructions for the disassembly sequence

Methodology for AR concept implementation

When developing a methodology for AR concept implementation, one important issue was taken into account: this concept has to be easily implemented in the existing disassembly systems, meaning that it is not necessary to change the spatial structure of the existing system in order to implement the concept. A disassembly system with the implemented AR concept is represented in fig. 4. Block *collected products* represent an input buffer for the disassembly facility. In this buffer, all products that will be disassembled are stored. Examples of products can be different household appliances (washing machines, dishwashers, mixers, irons, televisions, stereos, *etc.*).

These products are then transferred sequentially to the work place where the trained worker defines a disassembly strategy for each specific product. In order to do that efficiently, he or she communicates with the server, with the database where the data about used materials as well as the process of disassembling and instructions for disassembly squence for each specific product is located (represented as the block *server with database*, fig. 4). Instruction for the disassembly sequence can be in different forms like: video files, simplified 2-D or 3-D animations. These data and animations can also be created by the manufacturer for each type and model of the product. Beside this information, in the database, there is a marker with a unique mark for each product.

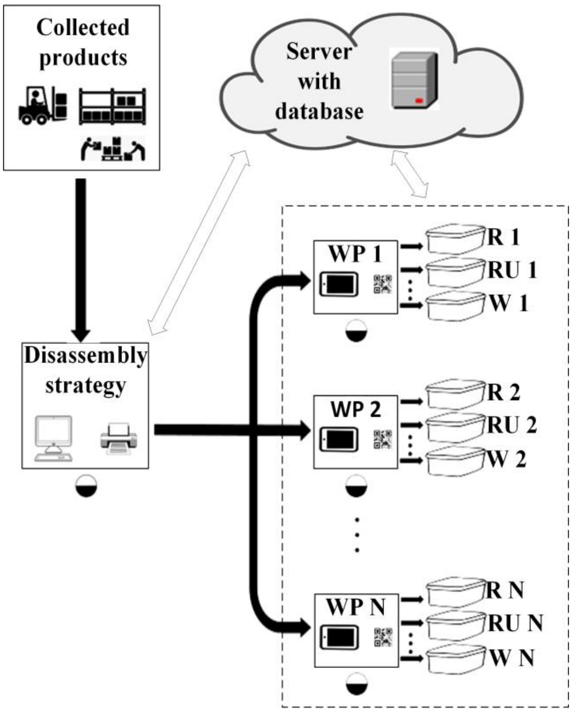

Figure 4. Disassembly system with the implemented AR concept

When a worker, who needs to define the disassembly strategy, gets a product, he or she firstly checks if the product information is in the database. If the product information is not in the database, it is necessary for the worker to generate a marker with the unique label for that product and obtain, from the manufacturer, data and instructions for disassembly process. If the manufacturer data are not available, he or she needs to suggest adequate instructions for the disassembly sequence. If product information is in the database, the worker prints the marker for that product and attaches it to the product or to the pallet on which the product is transported, and then sends the product to the disassemble line (block *disassembly*, fig. 4).

At the disassembly line, the worker at the work place (WP, fig. 4) takes the product with the marker and then scans the marker with the mobile device (mobile phone, tablet, *etc.*) and the dedicated application. After scanning the marker, data and instructions for product disassembly sequences are retrieved from the database on the server. After downloading needed information, instructions for specific product are displayed on the mobile device screen at the work place in the form of: video files, 2-D or 3-D animation. According to displayed information, the worker can perform the disassembly sequence, perform analysis and diagnosis on component condition and perform component selection according to component condition. After the component selection, the worker puts each component in the adequate container, fig. 4. *e. g.*:

– Re-use of used products (RU),
– Re-manufacturing of used products (R),
– Use of used products for spare parts (USP),
– Recycling with disassembly (RWD),
– Recycling without disassembly (RWOD), and
– Dumping of used products (W).

After the completion of the disassembly process, the worker, using a mobile device, can generate report and write in the database the specific result of the work that was done. In that way, gathered information can be used for analyzing the efficiency of the disassembly process.

Experimental system

The product chosen for the experimental research is the heating circulation pump (fig. 5). This product was chosen for the reasons of availability and the choice of a larger number of strategy options during its lifecycle, to show the potential variety of the disassembly process applied. This aims to create a research basis in which a model is tested in the conditions of the increased complexity of decision making and the execution of the disassembly process.

Figure 5. Heating circulation pump

Experimental testing of the disassembly system for heating circulation pump was conducted in laboratory conditions. For disassembly process an analysis of the process performance, done in several different variants, is carried out. Duration of the work process is tracked for different participants and product versions in the work processes. The process of disassembly is carried out on 3 different types of the heating circulation pump. This procedure was performed in 4 variant modes of operation:

– Manual disassembly performed by the worker who has not previously preformed pump disassembly (W1) with hard copy documentation.

– Manual disassembly performed by the worker who has previously preformed pump disassembly (W2) with hard copy documentation.
– Disassembly with AR use performed by the worker who has not previously preformed pump disassembly (W3).
– Disassembly with AR use performed by the worker who has previously preformed pump disassembly (W4).

The number of disassembled circulation pumps for each type of variant modes was 28, so the overall number of disassembled circulation pumps was 112. All pumps in the experiment were collected from the local household waste recycling centre in the wider area of the city of Novi Sad. The number of working hours for each pump differs and in most cases it cannot be determined since the reasons for their coming to the recycling centre differs: malfunction caused by electric shock, water quality, rotor imbalance, cavitations of the water circuits, corroding between gate valves, airlock within the pump, the propeller is jammed because of grime, internal corrosion stopping the motor from turning *etc*. For this reason the time scale for pumps in experiment was from 1-30 years.

Disassembled circulation pumps have basic characteristics such as: liquid temperature: +10 °C to 110 °C, maximum ambient temperature: 40 °C, maximum system pressure: 10 bar, mean sound pressure level: <43 dB, pump head 1.5-5.5 m, pump power 40-71 W, number of shaft rotation 1400-2400 rpm, pressure necessary at the suction point to avoid cavitations: 2 m (at a water temperature of 90 °C), motor is asynchronous single phase with 3 speed operation, power supply voltage: single phase 1 x 230 V - 50 Hz.

Both disassembly systems, with hard copy documentation and with AR implementation, were set according to the concept shown in fig. 4. Experimental disassembly system consisted of three workstations for determining the disassembly strategy (fig. 6), and two workstations for performing disassembly sequences. Workstations for determining the disassembly strategy are equipped with devices needed for: pump sealing check, checking of the number of shaft rotations, and nominal current check. Other two workstations are equipped with standard tools for mechanical disassembly and fixtures for pump positioning during the disassembly process.

Manual disassembly is performed by workers with hard copy documentation (W1, W2). Figure 6 represents a workstation for determining the disassembly strategy with the usage of hard copy documentation which has been previously prepared according to the type of the pump. This documentation consists of a large number of papers and thus it is difficult to handle. Since in this experiment only three types of products where handled, it can be concluded that, if a number of product variants is larger, required documentation for performing the disassembly process becomes too extensive and its retrieval and use in the workplace is becoming more complicated. Workstations are burdened with supporting documents which also causes an extra space and extended time to find needed information.

Disassembly process with AR implementation (W3, W4) used for this research is following: when the worker at disassembly strategy work place (fig. 4) gets the pump for the disassembly, they immediately check if the general information about the type of the pump exists. Information about the pump is the following:
– name/type of the pump: Heating circulation pump,
– name of the manufacturer *e. g.*: Sever/Siemens/...,
– graf precedence of disassembly, and
– needed tools for each disassembly sequence.

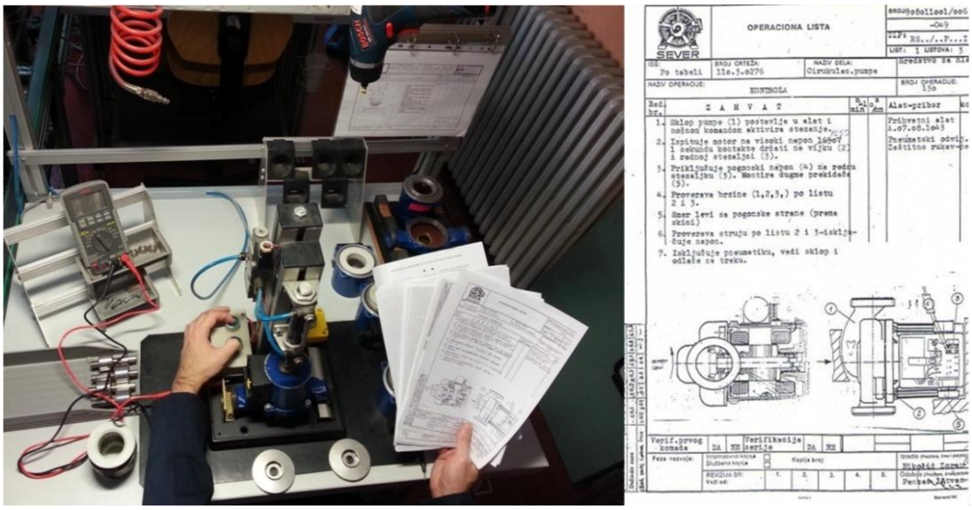

Figure 6. Manual disassembly performed by the worker with hard copy documentation

In the case that there is no information in the database on the product type/pump, it is necessary for the worker to visually detect the product and the manufacturer label and to put this information in the database as a new type of product. Important information possible to be collected for the disassembly process includes the following:
– production year,
– country of origin,
– date of service, and
– changes made to the product during maintenance.

The next step is the product condition analysis in order to make a conclusion about a suggested strategy to be applied to the observed product. The worker can choose only the strategy available in the database, although there is a possibility to define not just one but multiple strategies. Heating circulation pump strategies that are available are: re-manufacturing the used products (R), use of used products for spare parts (RU), and recycling with disassembly (RWD). For the chosen strategy, the disassembly sequence and needed tools for the disassembly process are defined. After entering all necessary data for a specific product into the database, a single marker is printed and it will follow the product during the disassembly process. Each product is labelled with a marker in the form of the QR code with the coded name of the product. After this, the product is placed on a pallet with the printed marker and via conveyor transferred to the disassembly work place.

Upon arrival to the work place, the worker takes the heating circulation pump and with the mobile device and the dedicated application detects the marker (fig. 3). This application is then used to scan the QR code and decode the name of product. After decoding the name of the product, the applications get a zipped file which contains instruction for the disassembly process from the PC. In this particular case, a server with the database is used, acting as a File Transfer Protocol (FTP) server. Android mobile phone was used as the device for showing the interactive instructions. Dedicated application is developed by using the Zxing library for scanning QR codes and MetaioSDK as the library for Augmented Reality.

In addition to instructions for the disassembly, tools for each disassembly sequence that needs to be used are listed. Properties of the required tools are clearly and visually defined. There are also recommendations provided for the tool selection to perform the disassembly sequence when the joint is disrupted and cannot be disassembled with originally envisaged tools.

After the completion of the disassembly process, the analysis and the diagnosis of the disassembled components is necessary to be performed. The quality of the components is determined during this analysis. In this specific case, the parts of the heating circulation pump which are under heavy load and affected by frequent failures and damage are: rotor, water wheel, bearings and stator. The instructions that are given to the workers show the components that need special attention and the method of the estimation/analysis of the situation and possible options as conclusions of the data analysis/ diagnosis. Thus, for example, the conclusion of the analysis and diagnosis of the rotor can be: 1) carry out additional processing due to loss of balance, 2) going to the recycling centre, or 3) component can be reused.

After the analysis and the diagnosis, the selection procedure follows in order to put disassembled components into the appropriate material flow. Detailed instructions on the selection of the disassembled components are also displayed through the same application on mobile device.

For each type of product, the mean time of the disassembly includes the time between the arrival of the product at the disassembly strategy work place (fig. 4) up to the disposal of materials after their selection in the appropriate container (tab. 1).

The duration of working sequences is calculated by the eq. (1):

$$t_{\mathrm{ii}} = t_{\mathrm{i0}} + t_{\mathrm{ip}} + t_{\mathrm{id}} \tag{1}$$

Mean disassembly time is calculated as the sum of all duration of the disassembly sequences divided by the number of disassembled products (eq. (2)).

$$\bar{t}_{\mathrm{ii}} = \frac{\sum_{i=1}^{n} t_{\mathrm{ii}}}{n} \tag{2}$$

where the *n* is a number of disassembled products and $\bar{t}_{\mathrm{ii}}$ is a mean disassembly time.

Table 1. Experimental results

Average time for disassembly (min/pump)	$\bar{t}_1$	$\bar{t}_2$	$\bar{t}_3$
W1	17.4	16.8	18.1
W2	10.1	9.9	9.8
W3	13.2	13.1	14.4
W4	8.9	9.5	9.5
Model-type of heating circulation pump disassembled	MT1	MT2	MT3

The results shown in tab. 1 indicate that the variant of the product affects the duration time of the disassembly process. In addition, the efficiency of the process of disassembly depends on the way of information distribution about the disassembly sequence and their quality. Distribution of information implies information form for instructions (written form on paper or electronic form). In the process W1 and W2 in tab. 1 ways of information distribution are in written form, whereas W3 and W4 are in electronic form. Average time for the disassembly compared to the different variants of the products is less if information is submitted in electronic form. The quality of information is reflected in the noticeable visually display of required information which in the case of an electronic form can be in the form of video files, 2-D or 3-D animation.

The quantity of information means providing the minimum amount of necessary information that are sufficient for the efficient disassembly sequence execution by workers, and it is equal for all product variants and all the ways of performing working processes.

In the case of the process W3 and W4, there is flexibility on information submission independently of the workers position in the layout. A worker at any time according to current needs of the disassembly process, can change position and use another position where the proper specific tools and devices are. In addition, at any time information about the availability of certain working places can be provided. This way of information delivery is faster and more efficient as compared to the processes of W1 and W2.

Conclusions

AR is a new concept that is nowadays implemented in various applications. In this paper AR was implemented in the disassembly system in order to test its influence, with the goal to prove the hypothesis that the implementation of AR will shorten the overall duration of the disassembly process. For this reason, the experimental setup of the developed concept in the disassembly system for the heating circulation pump was conducted in laboratory conditions.

The experiment was carried out on three different types of the heating circulation pump, and with the disassembly procedures done in four variant modes. These modes were the combination of using AR and hard copy documentation, and performing the disassembly sequence with the worker who has and has not previously preformed pump disassembly. Experimental results show that the mode, the disassembly with AR performed by the worker who has previously preformed pump disassembly – W4, is most efficient for all pump types, and average time for the disassembly process significantly differs comparing to W1, W2, and W3. The reason for the difference is mainly caused by the number of documentation that is difficult to handle at the workstation in case of modes W1 and W2, and in case of W1 and W3 performing disassembly sequence by workers that have not previously preformed the pump disassembly.

The general conclusion that can be drawn from this research is that the implementation of AR in the area of disassembly systems can lead to the improvements of overall disassembly process. These improvements can be characterized by the following:
– shortening duration of the procedure of disassembly,
– shortening time needed for component condition analysis,
– shortening time needed for component condition diagnosis, and
– shortening time for appropriate material flow selection for disassembled components.

Important information of EOL products after the disassembly refers to the component status and in case of AR implementation can be easily collected and transferred to the original manufacturer. That information can be used for designing product excellence (DfX). In that way, both sides, the manufacturer and the disassembly centre, have benefits. A better connection between them can be established because in this way manufacturer gets quality feedback about their products and disassembly centre gets data and instructions for the disassembly process.

This research did not include, and that can be the subject of future research, the quality of selection of the disassembled components as a result of errors that may arise in the process of W1, W2, W3, and W4. The reason for the longer duration of the process W1 and W3 is partly due to poor cognitive adoption of received information and their physical interpretation in performing disassembly sequence.

One of the main problems that arise in the process of disassembly is to provide necessary information about the products and procedures for their disassembly. For this information, manufacturers who are currently not obliged to give the information on disassembly of their products are the ones who are particularly responsible. There are certain EU directives that point out the necessity for this and impose an obligation, but they are generally not implemented. Additional problem is permanent development of new products for which it is necessary to provide the information needed. The question of publishing this information is mainly linked to the protection of patent rights.

In experimental system, represented in the paper, Marker-based AR for showing interactive instructions was used. Marker-based AR is currently the most prevalent and easiest to accomplish, and that is the reason for using it in this application.

The problem that has been observed during the experiment is related to the positioning of markers, so in further research the Markerless AR will be used.

Nomenclature

t_{id} – additional disassembly time [s],
t_{ii} – duration time of (i) disassembly sequence [s],
t_{io} – basic disassembly time for whole sequence [s],
t_{ip} – provisional disassembly time [s].

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