Improved Nondestructive Disassembly Process using Augmented Reality and RFID Product/Part Tracking

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Abstract **– The waste from electric and electronic equipment and discarded automobiles in the past grew rapidly and resulted with waste in billions of tones. The aim of this paper is to present an improved non-destructive disassembly process of electromechanical products using augmented reality based devices, such as glasses, tablets or mobile phones, and RFID technology for valuable product/part tracking. The proposed method includes tagging of components of interest in the product assembly by using a RFID tag. The valuable product is marked with specific ID number written in the RFID tag, in order to declare the product. The relevant data such as material and weight of components, guidelines for non-destructive disassembly for the valuable product and removing of component of interest will be obtained with the assistance of RFID tag and a centralized database. This modular system offers guidelines for the non-destructive disassembly process for obtaining valuable component of interest intended for easy repairs, remanufacture, reuse or recycling. The guidelines are in video presentation format using augmented reality for easy visualization of non-destructive disassembly process. The benefits of proposed modular system includes biggest percentage of reuse of the valuable components, easy maintaining, improved material recycling, environmental protection and greater total return form end of life products.**

Keywords **– nondestructive disassembly, reuse, augmented reality, RFID.**

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1. Introduction

Waste created by obsolete equipment and other machine assemblies and white goods becomes actual problem in the modern society. This problem is interesting for investigation for a lot of institutions and scientists. The problem arises from the nature of these products. For some reason some of the parts inside the assemblies should or must not be destroyed along with the whole product. Some parts from the product are valuable for reuse, remanufacturing or recycling and should not be deposited, this means that the component can be reused avoiding the whole refabricating of the component. Other products cannot be discarded along with the other materials because they are toxic and need to be discarded in specialized facilities. The waste from electric and electronic equipment and discarded automobiles in the past grew rapidly and resulted with waste in billions tones. For instance, "around 3 billion tones of waste are generated in the EU each year - over 6 tones for every European citizen [1]." The extensive usage of personal computers arises from the question for the privacy of the data discarded along with the device. Some companies acquire certificate for proper data destruction. The list goes on and every product may or may not have some part that needs to be extracted by hand before it is all discarded or recycled for reuse of the materials. Facilities for proper recycling of this assemblies are created that will discard or obtain these parts in a proper manner. Because of the different nature of different products there are facilities specialized for each of the products. For example, facility for batteries, facility for recycling of computers and other IT equipment, facilities for recycling refrigerators because of the environmentally hazardous CFC-12 or other materials used in the cooling process etc. We believe that there is place for improvement in this process.

Current European regulations clearly indicate that the new electric and electronic products or vehicles should be designed considering the recovery of the product at the end-of-life stage. The designers in Europe have to follow European directives for environment protection such as Directive 2000/53/EC for end-of-life vehicles [2] and 2002/96/EC for waste electrical and electronic equipment (WEEE) [3]. The designers have to use the directives into the designing of product in order to protect the environment and reduce the pollution to a minimum level.

2. Background

This paper deals with problems on how to reduce hazardous substances in products, to prevent pollution of the environment and to incorporate design for the environment early in the product design stage in order to facilitate product dismantling and recovery, and to achieve the quantified targets for reuse, recycling and total recovery.

In order to provide easier visual instructions guide for the process of disassembly, the augmented reality (AR) technology was selected. This technology provides the ability to link the location-dependent information directly to the physical objects. Each product or assembly is consisted of many sub-assemblies or individual components, like nuts, bolts, holders, brackets and other smaller or bigger parts that have a predefined location in the product, which is important from the disassembly aspect. Compared to other visualization technologies, the benefit of AR is in the fact that it utilizes the actual physical products [4]. Usually the result of such visual guides is presented as a mix of the virtual and real world displaying the instructions for disassembly in the user's viewpoint on a specified screen. The 3D scene is generated using the principles of perspective projection. Today CAD software allows us to create algorithms that automatically extract the feature's bounding box model [5]. This data is then used as input in the process of design of 3D disassembly instructions sequences. The disassembly process is one of the most attractive industrial uses in which AR can be applied. In the paper [6], the authors present the potentials of AR application in a disassembly process focusing on shorter total time of the process needed for disassembling a circulation pump.

Zhang et al. [7] suggest addition of RFID technology as a way of part identification in an augmented reality enhanced instructions of an assembly process. The research presented in the paper is quite novel providing on-time information rendering and user-friendly navigation through the information. Stankovski et al. in the papers [8, 9] present a novel way of product identification and tracking of products/parts up and down the supply chain. Using the RFID technology, a tag containing specified data is placed to selected product using robot for in-mold labeling (IML). In the paper [10], the authors present an integrated method for decision-making for disassembly of electromechanical products. Chen et al. demonstrate how RFID technology can be used for acquiring and tracking lifecycle information of a product in order to optimize the disassembly process. This method also presents how the recovery efficiency can be increased. At the same time, the model is highly extensible, with the opportunity to be used in different type of products.

Mircheski et al. in the paper [11], presented a method for improving the process and cost of nondestructive disassembly of a newly designed product. The nondestructive disassembly process is analyzed with help of developed software package for determination of improved disassembly sequences for conceptual design solutions of given technical device. The main steps in the proposed method are determination of disassembly interference matrix, feasible disassembly sequences and improved nondestructive disassembly sequences. The newly developed software package used 3D CAD model of product assembly in SolidWorks format file.

In this article, a nondestructive disassembly process of electromechanical product is improved using augmented reality based devices such as glasses, tablets or mobile phones and RFID technology for valuable product/part tracking. Compared to other methods and strategies, this method uses a system, which marks the components of interest from the product using RFID tagging. The tag contains the ID number of the product and additional information such as material and weight of the valuable components. Using the system and the data from the tag, one can easily access the guidelines for nondestructive disassembly together with video presentation in augmented reality. This modular system offers guidelines for the non-destructive disassembly process for obtaining valuable component of interest intended for easy services, remanufacture, reuse or recycling. The guidelines are in augmented reality format for easy visualization of the non-destructive disassembly process. The benefits of the proposed modular system includes biggest percentage of reuse of the valuable components, easy servicing, improved material recycling, environmental protection and greater total return form end of life products. The aim

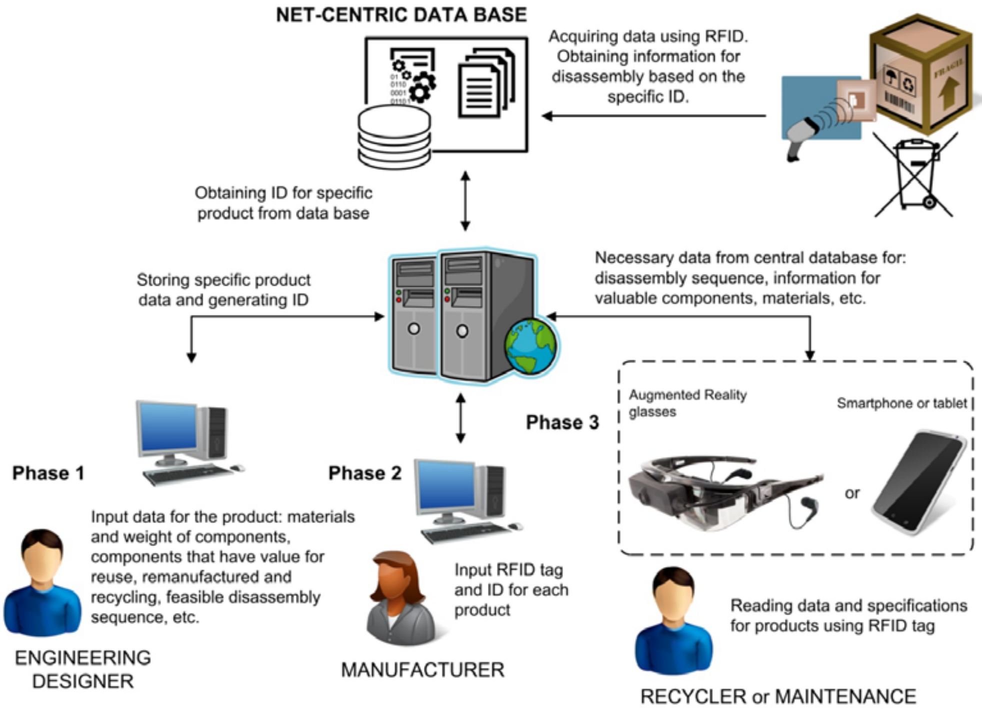

Figure 1. Flowchart of the proposed model for nondestructive disassembly using augmented reality and RFID technology

of this paper is the development of a new and improved concept for reuse and recycling by using the nondestructive disassembly process, augmented reality based devices such as glasses, tablets or mobile phones and RFID technology for valuable product/part tracking

3. The structure of the model

The research presented in this paper is oriented into creating and implementing of useful novel model for easy nondestructive disassembly process of electromechanical device supported with augmented reality devices such as glasses, tablets or mobile phones and RFID technology for valuable product/part tracking. In this context, the novel model is intended for end-of-life products which consists of valuable components or component of interest. The novel model for nondestructive disassembly includes innovative elements such as: planning of nondestructive disassembly process in the early stages of the design process; connecting with the production process and product marking with RFID tag which will indicate that the product consists a valuable component of interest; and into the end-of-life stage of the product will give procedure and order for nondestructive disassembly supported with augmented reality. The overall model is an iterative process that improves the product structure and some valuable components will be reused or recycled. As depicted in Fig.1., the proposed model is performed in three main phases.

Phase 1: Planning of the nondestructive disassembly process in the early stages of the design process which includes identification of fastener, component, contacts between parts, materials and weight for the parts by using of 3D CAD file as an input in SolidWorks assembly file of product with extension ".SLDASM". Also, this phase includes the automatic determination of the contact matrix between fasteners and components (FC), automatic determination of the contact matrix between components (CC) for all subassemblies (SA) within the product assembly (A), the disassembly operations, the disassembly interference matrix, all possible disassembly sequences, the improved disassembly sequence by using of developed software presented in the paper [11].

In order to demonstrate the proposed model, the product hair-dryer is used as an example. The main goal of the model is presentation of the improved non-destructive disassembly sequence supported with augmented reality and RFID technology. Constituent components of the hair-dryer are: C_1=Holder, C_2=Exit part, housing which consisted of two components (called C_3=Body part and C_4=Back part), C5=Propeller, C6=Electric motor, C7=Heating element. A discrete fasteners in the hair dryer are: F_1=F-Bolt M2x8-3, F_2=F-Bolt M2x8-1, F_3=F-Bolt M2x8-2, F_4=F-Bolt M2x28-1, and non-discrete fasteners are: F_5=F5-Virtual (between C1,C3), F_6=F6-Virtual (C1,C6) and F_7=F7-Virtual (C2,C3). In Figure 2., the CAD model of the product assembly for hair-dryer and its constituent elements is shown with exploded view. For simplicity of calculations the abbreviation names for components and fasteners (C_1, C_2, … and F_1, F_2, …) are applied.

The electric motor as valuable component of interest for reuse is aim of the disassembly process. The optimal disassembly sequences according to the methodology presented in the paper [11] are:

F2(-y), F3(-y), C4(-y), F4(-y), C5(-y), C6(-y)
F3(-y), F2(-y), C4(-y), F4(-y), C5(-y), C6(-y)

The optimal nondestructive disassembly sequence is usually a partial disassembly sequence, because not all disassembly operations return profit. The optimal nondestructive disassembly sequence gives insight into the disassembly cost, the percent of recovered material and other characteristics of the product. The lower the disassembly cost, the higher is the economic effect of the product recovery. The higher is the weight and volume of the recovered materials, the higher is the environmental benefit. These criteria can give important information to the designer in order to compare the design variants and select those that return higher value at product end-of-life and have lower negative effect to the environment.

Phase 2: The model for nondestructive disassembly process of technical device utilizes RFID technology. Radio Frequency Identification (RFID) is a wireless identification technology consisting of a RFID tag, RFID reader/writer, a RFID antenna and related software. The key advantages of this technology compared to other identification technologies, such as for example the barcode are: noncontact identification; long-distance reading of tags; simultaneous reading of multiple tags; high automation of the procedure; huge quantity of data can be processed very fast. The main disadvantages of the RFID technology are the limited amount of data that can be stored on a single tag and the price of a tag compared to a barcode sticker.

The developed model operates using a Neology Ultra High Frequency (UHF) Class-1 Gen-2 96 bit RFID tag containing a code in XML format. The products are marked with the appropriate RFID tag. The system is based on the software package of Inner Circle Logistics using the software Circus^{SM}, Jester^{SM}, Ringmaster^{SM} and Scarborough FairSM as is presented in Figure 3.

Circus^{SM} is a RFID interface software that provides the ability to tie passive RFID tag data to the database utilizing next generation security protocols. Jester^{SM} is an automated data exchange application designed to post data to a net-centric virtual relational database. In the same way that Scarborough Fair^{SM} makes data available to a variety of audiences, Jester^{SM} runs in the background and enables smart data transfer capabilities that tie directly to virtually any database. Ringmaster^{SM} provides the authentication and control functions for the systems as well as the domain name system (DNS) lookup and other web services. It guarantees the security of the system, ensuring that only those with proper authority can access the information.

When the RFID tag is read by a RFID reader (Figure 4.), the read information is transformed in order to access the centralized database and obtain the product ID code and the product design datasheet, such as shown in Figure 1. The database can be designed in a way to satisfy the needs of each member of the product lifecycle chain. At this point, the product design sheet contains data elements for the product name, manufacturer, dimensions, number of parts, materials of parts, whether the product contains hazardous materials, components of interest, and the most important, the disassembly sequence. The recycling facilities can use this ID to download data relevant for nondestructive disassembly of the product and obtaining the components of interest. The manufacturer inputs the necessary data in the database. The design of the database can be adapted to various requirements.

The proposed model is modular and extensible in terms of the services offered. The system may have forums that will be helpful in communication between recycling facilities and product designers.

This form of the system design provides the necessary security of the proposed model. The RFID tag contains only non-sensitive information that can be utilized after accessing a secure database. In that way, reading the information written on the tag during the lifecycle of the product does not present a security risk for any of the involved parties.

Phase 3: The system offers interactive video tutorials of nondestructive disassembly process and disassemble of valuable components of interest with visualization of the disassembly process supported with augmented reality.

Augmented reality (AR) is a technology that enables digitally stored spatial information to be overlaid graphically on views of the real world [12]. AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space. Augmented Reality enhances a user's perception of and interaction with the real world [13]. The virtual objects display information that the users cannot directly detect with their own senses. The information conveyed by the virtual objects helps a user perform real-world tasks.

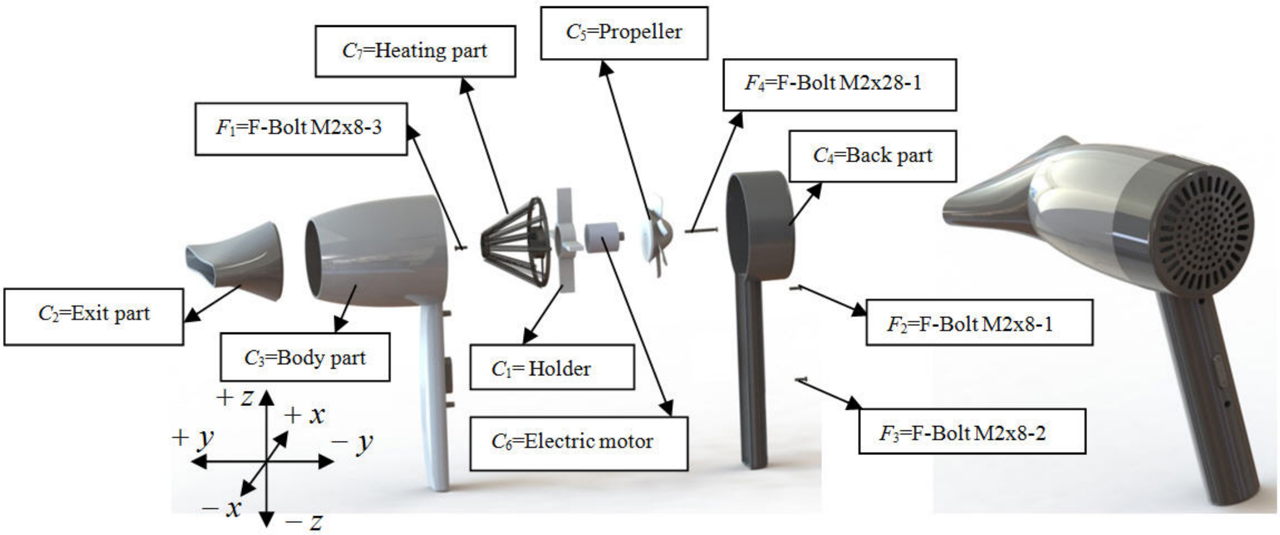

Figure 2. Exploded view and assembly of hair-dryer

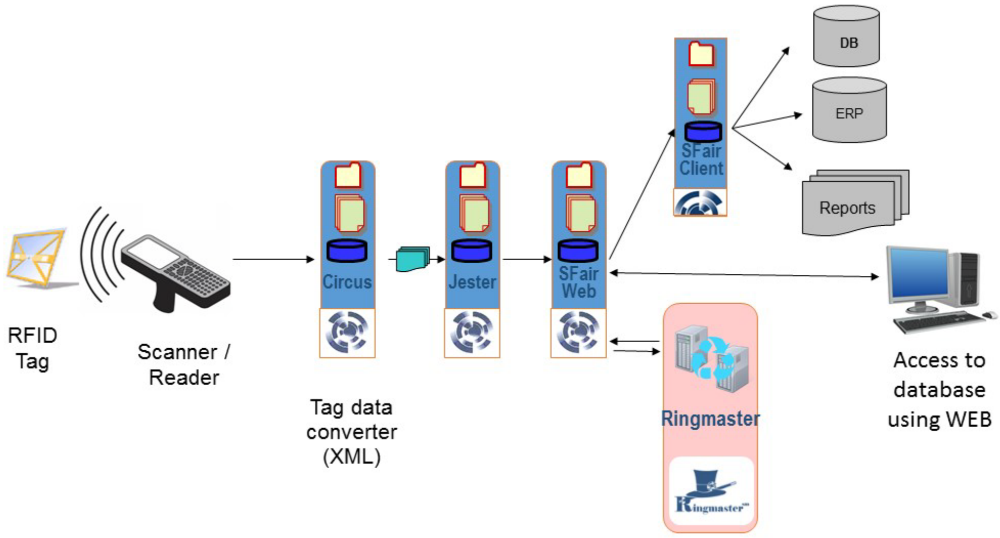

Figure 3. Diagram of the RFID software system architecture

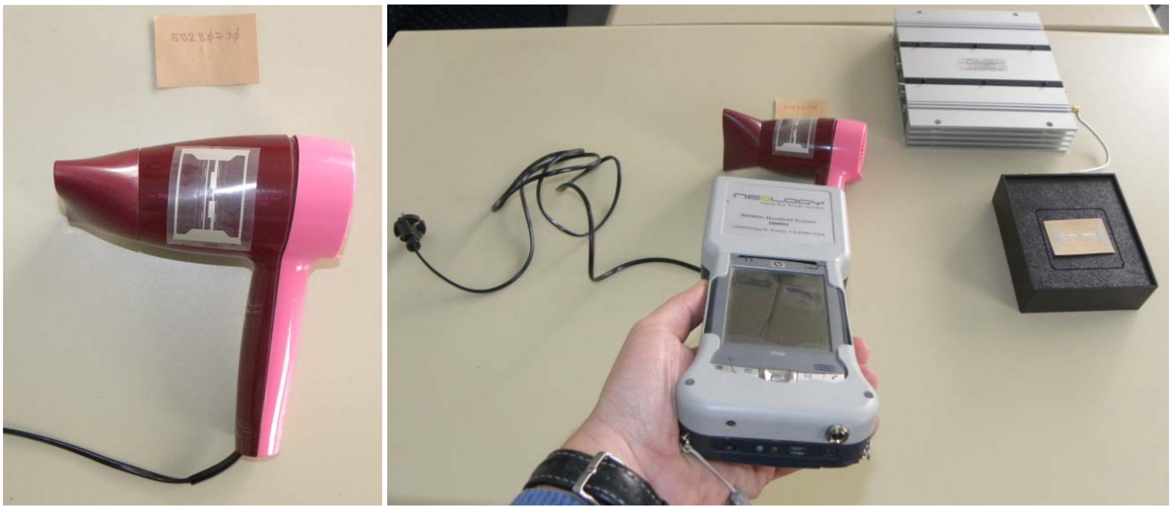

Figure 4. Placement of RFID tag and tag reading

The usual 2D technical drawings or 3D video animations of the disassembly process are difficult to understand and challenging to follow. The proposed model uses an interactive video guide superimposed on the real product. The system requires a hand-held device equipped with rear mounted camera, Android or iOS operating systems and access to internet. An animation of the disassembly process is created for the defined optimal nondestructive disassembly sequence from phase 1. Using the Augment software

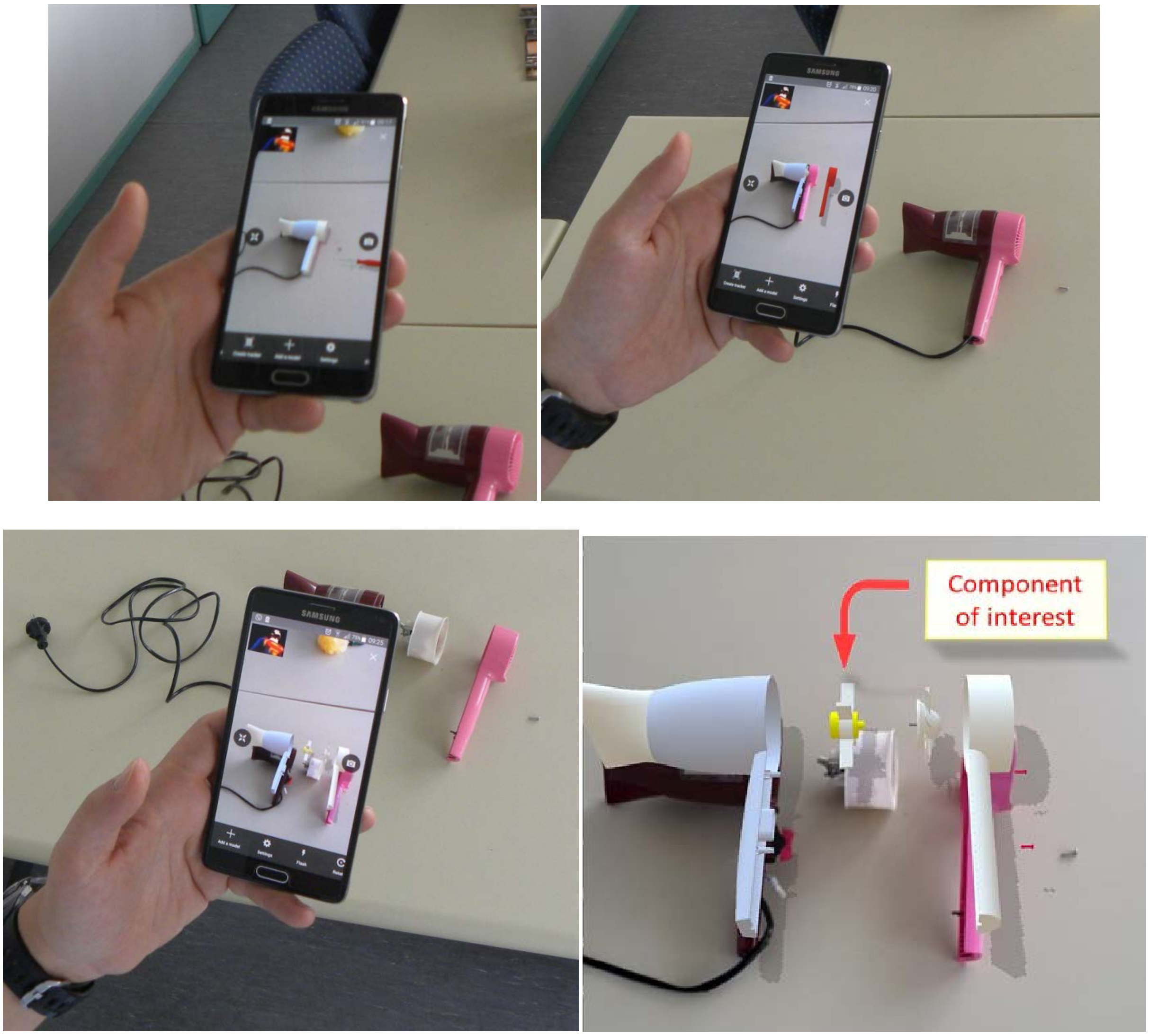

Figure 5. Step-by-step visual guide for nondestructive disassembly operations in Augmented Reality

platform the animation is uploaded to the Augment Manager providing the necessary information and tags. Using the data read from the RFID tag, a link to the 3D model in Augment Manager is generated and the animation is loaded on the hand-held device. The superimposed model in augmented reality is displayed on the screen. The animation guides the recycler in the process of the nondestructive disassembly step-by-step as shown in Figure 5. The system provides with corresponding views as the user changes the viewing angle and position relative to the product with real motion. The component of interest is highlighted and the corresponding information is displayed. In case of presence of hazardous materials, the animation will provide the procedures for secure disposal. The system is designed to operate using a hand-held device or a Head-Mounted Display (HUD).

4. Conclusion

In this paper, a novel model for nondestructive disassembly process of end-of-life product supported with augmented reality based devices such as glasses, tablets or mobile phones and RFID technology for valuable product/part tracking is proposed. Using this model, the information about the nondestructive disassembly process of end-of-life product and information regarding the valuable component of interest can be delivered directly via net-centric database by using of RFID tag and the nondestructive disassembly process will be shown with video presentation in augmented reality. The model provides the necessary security of the product information by not storing real information to the RFID tag. As a result, this proposed model can improve the percent of recovered material, recovered valuable functional component of interest for reuse, lower negative effect to the environment, biggest recovery profits, easy disassembly process by using of video presentation and augmented reality.

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