Intelligent Utilization of Waste Of Electrical and Electronic Equipment (Weee) with Robotized Tool

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Abstract:
The article examines the solution of intelligent robotic utilization of electrical waste and electronic equipment (WEEE), as means of materials recovery. The paper provides criteria for selection, identification and waste analysis, enabling application of robotic dismantling solutions. Based on proposed criteria, the waste of computer hard disk drives (HDD) was identified, analyzed, and their characteristics described. Furthermore applying described approach to robotized dismantling, the complete process of waste HDD processing, covering all the procedural steps was presented for the selected disk. Described intelligent utilization process can be performed with use of 2 robots equipped with, 2 tools and one conveyor handle. Authors also briefly presents issues related to proposed process approached during HDD waste disassembly studies. In addition, paper presents the quantities of materials to be recovered from the HDD waste.

Keywords*: WEEE, robotic, dismantling, disassembly, waste, recycling, recovery of resources, HDD.*

1. Introduction

Waste of electrical and electronic equipment (WEEE) is a global concern. In the 27 EU countries it is estimated that the weight of produced waste WEEE in 2005 was 8.3-9.1 million Mg (tones), 25% of which is collected and processed, while remaining 75% is not registered and does not occur in collection points [1, 2]. Such state of waste management system can be caused by lack of processing capacities and suitable technologies which can utilize WEEE effectively. The amount of WEEE rises continuously [3, 4]: in 2008 Sweden collects 16.7 kg per person of WEEE, Britain 8.2 kg per person, Austria 6.5 kg per person [5]. Moreover, European Commission proposes rising collection targets from 4 kg per person to 65% [6] of average mass of electrical and electronic equipment placed on market. WEEE has to be utilized, but it also can become a source of valuable resources.

The factors described above reveal the need for development of new ways to process WEEE effectively allowing recovery of valuable raw materials. It is believed that intelligent robotized disassembly can be the technology that will take a part in solving WEEE processing problem.

2. Currently used technologies for processing WEEE waste

There are two main WEEE waste treatment methods: manual dismantling, and mechanical methods based on shredding, and multistage separation of materials. Manual dismantling and mechanical processing approaches differs between each other, on the degree of recovery of raw materials from WEEE waste. Recovery ratios are presented in Table 1.

Table 1. Recycling methods recovery ratio [7]

	Washing Machine	**Oven**
Shredding	44.1%	74.9%
Manual system	95.6%	90.6%

Manual dismantling is the most flexible way to process wide range of different electrical and electronic equipment waste as well as have the highest recovery rate of raw materials. However, manual dismantling is very extensive and requires direct human contact with waste. Manual dismantling is based on removing the components from the devices and theirs segregation accordingly to the materials they are made of. Often manual removal is the first stage in the process of mechanized waste treatment technology (shredding), to extract the hazardous substances and components which cannot be processed together.

Mechanical treatment of waste is based on shredding process, after which, shredded residue is separated in multistage process to obtain rich fractions of resources. This method is useful to process large quantities of mixed WEEE waste, but its disadvantages are: high energy demand associated with the shredding of waste, lower level of resources recovery and impurity of recovered raw materials.

Nowadays, works are being carried out to robotize WEEE waste processing methods, as an alternative to existing processes, and as supporting solutions for others existing ones. The example of such works is modeling of the dismantling line to utilize LCD monitors [8]. Another type of work being carried out is to robotize dismantling process of desktop computers [9]. In literature are also presented works covering prototype automation solutions replacing certain activities in existing WEEE processing plants i.e. Automatic unscrewing of extracted washing machines engines, transporting released parts using robotic arms equipped with grippers, etc. [10].

Intelligent robotized dismantling is the alternative to traditional technologies, (shredding and manual processing). It combines the advantages of traditional technologies, theirs capability to adapt to various wastes, with large processing capacity. Intelligent robotized utilization allows for obtaining high purity of raw materials recovered from waste, with minimal energy input and no human labor (no human contact with waste).

3. Overview of intelligent robotized utilization technology

Robotics applications in waste dismantling are based on well known and applied in modern industry robotics and automation solutions. Intelligent robotized dismantling can be described, as reversed process of robotized manufacturing, or as replacing human labor by robot in repeatable operations during dismantling process. Knowing the dismantling steps, actions and procedures performed during manual WEEE processing, it is possible to replace them by robotized tools. Complete process can be organized in form of demanufacturing line, equipped with robotized tools. On this line, step by step performed are successive actions of dismantling process and resources are being recovered.

Due to the speed of robots, repeatability and positioning precision, it is possible that robotized disassembly unit will be small, and it will process large quantities of waste. The main advantage of robotized disassembly is its energy efficient method used to separate screwed together components. Energy efficiency is obtained by: applying automated screwdrivers controlled by robot arm to free screwed together parts, and robot arm grippers to remove freed parts, and carry them to right container. Unscrewing and carrying operation, are the least energy consuming actions, so they offer great energy savings in WEEE processing, combined with obtaining the highest possible purity of recovered resources. Such approach differs from shredding method that consumes huge amounts of energy, required for cutting metals and plastics into pieces.

Unfortunately due to extreme variety of WEEE not every waste can be processed in robotic disassembly unit. That is why it is fundamental to arrange ways allowing categorizing which of WEEE can be processed in this particular way. Moreover there are two approaches to robotic disassembly of WEEE that differ due to the level of theirs complexity.

4. Complexity issue in robotized disassembly – opposite approaches

The robotized disassembly can be performed in two ways: fully programmed, determined algorithm of operations, and on the other hand, cognitive algorithms, organizing the operations accordingly to the data collected from sensors.

Applications of **cognitive algorithms**, self adapting to the data collected from sensors, is very complex and multidimensional. Self adapting approach requires advanced sensors, operations on collected data and analysis of possible operations to be performed this makes it difficult and expensive. Due to such high application requirements, dynamic approach is not analyzed in this paper. However in future it is possible that this complex approach will may occur effective in mixed waste processing, or as a part of other systems.

On the other hand intelligent robotized disassembly can be based on **determined algorithms**, allowing effective and simple application of this technology in WEEE processing plants. Each step, in the disassembly process, is strictly programmed and is performed in its time, embedded in the chain of disassembly program. However this approach can be only applied to uniform wastes, where once programmed operations can be performed on large volume of devices, leading to the same constant and predictable effect.

Determined algorithms simplify the complexity of robotic solutions, decreasing the necessary data collection to minimum. Disassembly algorithm is in form of basic preprogrammed, repeatable operations, in a result of which appliance disassembly is performed. Once programmed disassembly unit, will carry out the program on any number of identical devices.

However due to wide variety of WEEE, even in categories of waste i.e. IT equipment – laptops, routers, differ between models and versions, so it is necessary to equip disassembly unit in optical recognition system (bar code reader, or camera) to identify its brand, model, version to choose the right program for identified device.

The drawback of simplicity of robotic disassembly based on determined algorithms, is that the disassembly unit is designed for specific waste (certain tools are used), so only similar wastes can be processed. That is why it is not possible to process i.e. LCD, laptops and ovens on one robotic disassembly unit. However, it is possible to process i.e. all models of all manufactures, of hard disk drives.

Identified specificity, of the intelligent robotic disassembly approach, based on determined algorithms, requires methods of selection and analysis, which of the range of WEEE can qualify, and is reasonable to process in this intelligent technology.

5. Criteria for identification and selection of waste qualifying for intelligent robotized utilization, based on determined algorithms

Not every waste can be processed in robotic disassembly unit, due to its characteristics and other factors that can limit applications of this method.

To identify WEEE qualifying for being processed in intelligent robotic disassembly technology, certain criteria were developed and verified. The criteria are:

- Physical characteristic: similar construction, standardized external dimensions, standardized placement of mounting holes, construction easy to dismantle, small amount of homogenous parts, good physical shape, no deformations, no dirt, way of identification i.e. by barcode.
- Market factors: life cycle of the product on the market, quantity and mass on the market, upward trend in sells.
- Resources to be recovered: amount of valuable/dangerous resources, which recovery is economically reasonable/necessary (law).
- Environmental impact: decrease of amount of waste, recovery of the resources decreases use of natural resources.
- Additional criteria: the ease of extraction of identified item from collected WEEE, currently ineffective recycling

Figure 1. Example of computer Hard Disk Drive (HDD) 3.5" view from electronics side

methods i.e. high energy consumption, low recovery rate, contamination of recover resources.

Applying above criteria to WEEE, several types of wastes have been identified and qualified for intelligent robotic utilization method. Detailed analysis was carried out on computer hard disk drive, which was chosen, as a waste appliance that meets all above criteria (Figure 1).

6. Characteristics of hard drives as a waste eligible for processing in the intelligent robotized utilization technology

Hard disk drives can be found in computers and other devices, like IT or broadcasting equipment, often HDD's are found alone in waste, due to rapid obsolescence of IT solutions. Given the number of hard drives sold worldwide in 2009 (550 million units), estimated mass of waste of HDD every year is 280 000 Mg [11]. The mass of HDD waste is arising annually, and is significant enough to justify materials recovery from it and search for the new technology to process this appliance waste alone.

Computer hard drive has standardized external dimensions (few models such as 2.5", 3.5"). The design is simple and based on uniform chassis in which components are installed. Extraction of the hard drives from computers is a standard procedure in many companies that process WEEE. Their physical condition is good - without deformation. Also important parameter is what kind of materials can be recovered from HDD waste. In the case of hard drives mainly they are: aluminum, ferromagnetic metals (and magnets), stainless metals and other mixed scrap (Table 2).

Table 2. Average mass and groups of resources in hard disk drives 3.5" [9]

Type of material	Average mass of material in 3,5" HDD	Content % in HDD mass
	Mass (g)	
Overall HDD	515	100,0
Aluminum	264	51,3
Ferromagnetic metals	90	17,5
Stainless metals	53	10,3
External electronics	41	7,9
Other components	66	12,8

Literature shows that, research is performed to robotize dismantling of computer [12] components. This will allow in future for integration of robotized computers disassembly, with intelligent robotized utilization of every component, directly recovering raw materials in one process.

7. Complete and partial disassembly of WEEE

Performed research showed [9] that the dismantling of waste can be performed in two ways, full and partial disassembly of appliance. The level of dismantling depends on quantity and purity of recovered raw materials, and on the other hand is limited by its difficulty.

In some cases the complexity of disassembly of appliance will be too high for its complete robotic processing, and only partial dismantling will take place i.e. to remove dangerous substances, covers, and other easy to remove parts, as the pre-treatment of waste method. Some of the raw materials will be recovered, overall mass decreased, labor saved, and energy demand for further processing decreased.

Both variants, full, and partial disassembly, are described on example of computer hard drives:

Partial dismantling – is the removal of the external screws and external electronics, as well as the closure of the disk, followed by several internal bolts. It is possible to carry it out using two tools – a screwdriver, and a gripper. As a result of the partial dismantling, 8% weight reduction was achieved (removed were: bolts, electronics, and closure of the disk). In addition, the source of heavy metals and organic matter – (electronics) is removed. This situation is presented in Figure 4.

Full dismantling – is the removal of every component from the HDD chassis. This procedure allows reducing the mass of waste HDD by 87% and recovering pure resources like aluminum, stainless, and ferromagnetic metals. The rest, 13% or the input mass is not processed, this "other" components group contains: plastic (2%), disk heads (3%), motor (8%). All components extracted from disk are shown in the Figure 2.

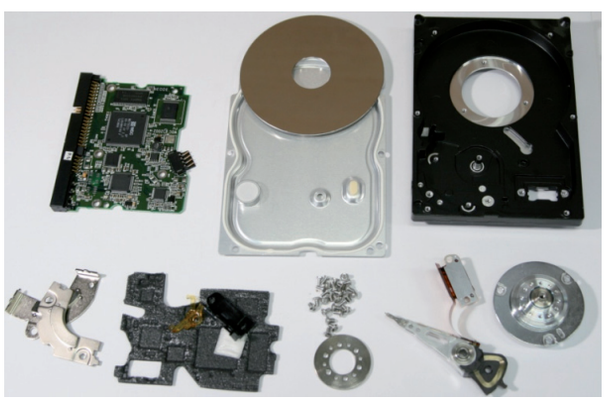

Figure 2. Fully disassembled hard disk drive

8. Intelligent robotized hard disk drive utilization – process simulation based on determined algorithm

Robotized process organization example, is presented on Western Digital Caviar WD400JB-00ENA0, hard disk drive manufactured in 2003 with a capacity of 40 GB. The block diagram with dismantling steps and percentage of resources recovered from waste is presented in Table 3 with described steps of disassembly process.

Hard drives, extracted from computers, are introduced into the disassembly line directly on the conveyor belt. HDD's are being queued and positioned on it, to allow each disk to be grabbed by the handle, enabling the spatial manipulation (1st step). Construction of hard drives is based on the aluminum chassis fitted with standardized threaded holes for mounting the drives. In the case of the disassembly those holes can be used to hold the disks in the handle and manipulate them. Placement of the holes in the chassis is shown in Figure 3.

Next step (2nd step) is identification of the hard drive. Model of the HDD is identified by reading barcode or other OCR method. On this basis program is selected and

uploaded. In the case of absence of the program for a given drive, or the inability to read the model, the disk is forwarded to the interim storage.

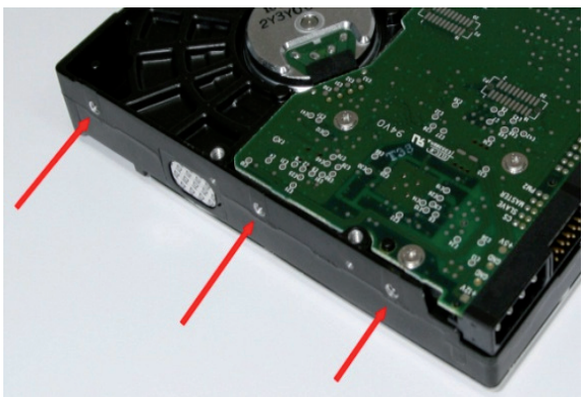

Figure 3. Placement of mounting holes in chassis of disk – pointing by arrows

Immobilized in the handle hard disk is transported to the robots operation area, where the first stage of dismantling is being performed (3rd step). Threaded joints are disconnected by first robot equipped with automatic screwdriver. This operation frees electronics. Second robot equipped with gripper removes electronic board from the drive and moves it into the container collecting those parts. Next, the drive is turned 180 degrees around in the holder and in the same manner, the removal of the top plate is executed. Threaded connections of the cover to the chassis are disconnected and the cover is transferred to the container collecting aluminum. Exposed components after disassembly of cover plate are shown in Figure 4.

Following, joints are unscrewed inside the disk (4th step), holding magnetic shields with magnets on them (Figure 5), than plates on the rotor, data connector and finally heads arm. In the case of plates mounted on the impeller it is necessary to immobilize the motor so the screws can be localized and unscrewed. This operation can be implemented using the gripper from the second robot arm. However, pinpointing the exact location of the bolts is only possible via optical system or proximity sensors in which the disassembly unit has to be equipped. Another element to disassemble is the disk head, this part is mounted using other type of screw connection, therefore it is necessary to replace the tip of the screwdriver on robot arm to perform this operation. The last operation is to dismantle the motor.

During each unscrewing operation, second robot equipped with gripper, simultaneously picks and moves released components to right container, collecting each

Figure 4. Exposed components after disassembly of cover plate

Figure 5. HDD during components disassembly – arrows pointing glued magnets

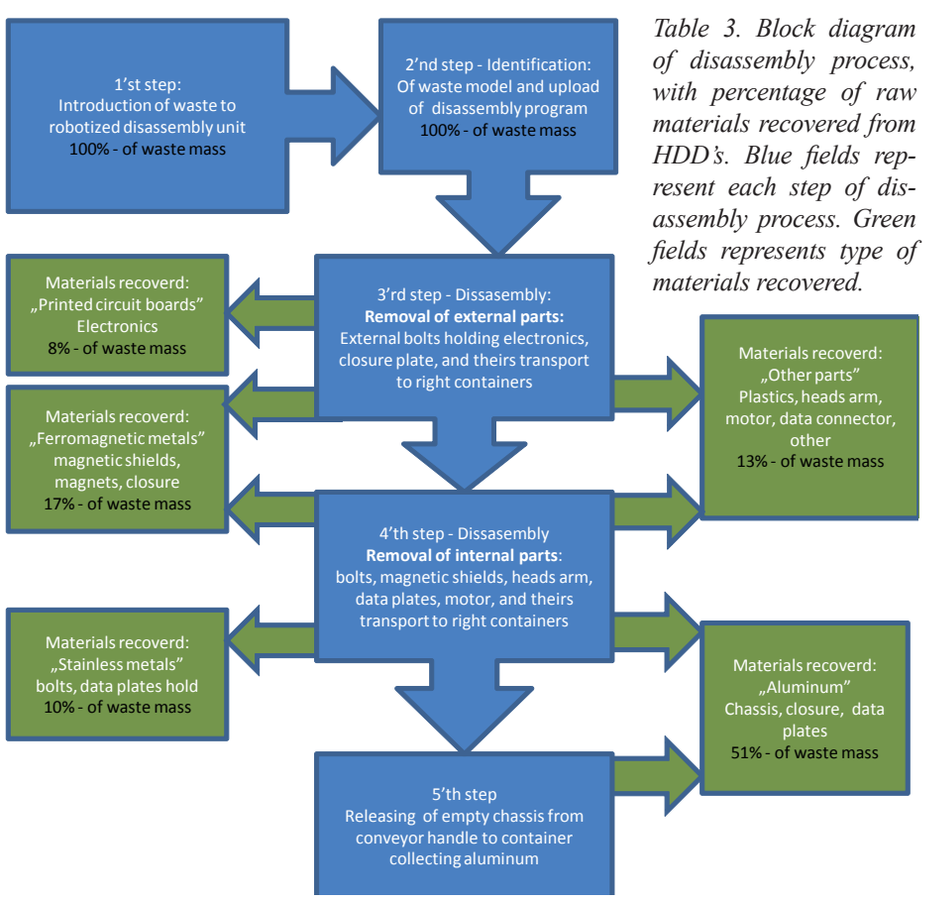

Table 3. Block diagram of disassembly process, with percentage of raw materials recovered from HDD's. Blue fields represent each step of disassembly process. Green fields represents type of materials recovered.

raw material. After disassembly of all components from the disk, its empty chassis made of aluminum, is released from the handle above the container collecting aluminum components (5th step). This operation finishes the process of intelligent utilization of the hard disk. All dismantled components from hard disk drive are presented in Figure 2.

Table 3 presents block diagram of the process described above, together with the participation of recovered materials [11].

Described investigation of disassembly process of HDD, covers all identified standard procedures and proposes solutions for process design. However, not all computer hard drives are made in the same way, some components are assembled by negative allowance or glued together, also some drives are sealed by aluminum seal tape etc., those non-standard construction solutions used in hard disk drives, complicate and require introduction of additional tools to disassembly process. In the case of uncommon, complex and uneconomical to process lots of drives it is possible to carry out a partial disassembly of them, and forward them to another process that can handle the rest of the process i.e. manual dismantling.

Currently manufactures of many appliances are foreseeing the utilization issue, at the end of life of theirs products, and the products are design much simpler than it was in the past. This approach brings savings during production, and utilization. The general trend is, the newer the appliance the less complicated its construction and more uniform each type of waste collected.

9. Conclusion

Presented in the article approach of identification of waste eligible for processing in technology of intelligent robotized utilization by determinate algorithms, allows recognition of fields of application of this technology, to provide significant reduction of cost in waste processing. Based on presented case of HDD intelligent utilization steps, whole process can be designed and calculated for research trails and testing purposes. HDD case shows that it is possible to implement whole disassembly process using: conveyor handle, and two tools mounted on two robotic arms.

Intelligent robotized WEEE utilization technology is new and effective way to process this group of waste. Its high efficiency and speed, allows to process large volumes of selected groups of wastes, recovery of valuable and high purity resources, and to avoid human contact with waste.

Estimated on example of robotic disassembly of hard disks, based on the volume of the world production of HDD's (550 million units = mass of 280 000 Mg), it is possible to recover: 143 600 Mg of aluminum, 49 000 Mg ferromagnetic metals, 28 800 Mg stainless metals, 35 800 Mg of mixed metals, and 22 100 Mg of printed circuit boards, each year.

With additional treatment of extracted components, it is possible to recover raw materials like rare-earth metals and certain quantities of precious and heavy metals embedded in released parts. This allows for almost 100% level of recovery in the case of presented hard disk drives.

The authors believe that the use of intelligent robotized utilization technology, on industrial scale is reasonable. It is believed that robotized disassembly is also the future of the waste processing industry, and a unique opportunity for companies offering robotic solutions to arise on the markets of WEEE processing.

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