Control and Decision-making Process in Disassembling Used Electronic Products

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Abstract: Due to awareness of the product life cycle's impact on the environment, manufacturers have started to embrace the concept of resource recovery systems as an intermediate solution to the environmental problem. The disassembly process is the main stage in recycling of the manufactured products. Disassembly promotes reuse, recycling, material and energetical recovery. It needs advanced control and real-time decision making schemes. In this article, the authors aim at surveying several state-of the art solutions of robotized disassembly cells.

Keywords: decision trees, electronic equipment recycling, flexible manufacturing cells, models, Petri nets, real-time

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1. Introduction

For environmental and economic reasons the objective of modern technology is turning away from deposition and incineration of end-of-life products towards a far reaching product recycling. Disassembly is the main stage in the product end-of-life treatment. The aim of this process is to extract the reusable parts of the product, as well as the dangerous materials. Products submitted to the disassembly process are out of use so we have to take into account their physical state. The major problem in a disassembly process is the occurrence of an uncertainty in the possibility of components separation. Deteriorations and deformations of some elements, the absence of one or more components, the presence of corrosion and rust are perturbations often encountered in the process of dismantling (Duta, Henrioud , Filip, 2002).In the case of the manual disassembly, the perturbation is analyzed by a human operator who must make decisions in real-time. In the case of an automatic process, specialized detection and analyze tools are needed. That is why, at present, an entire automatic disassembly system has proved to be an expensive investment. Consequently efforts are made to design appropriate methods to optimize the process of components valorization. The aim of disassembly process is to regain the value of parts and materials by repairing, reusing and energy recovering operations. Due to the difficulties in disassembly of electronic devices as well as other industrial products, continuous research has taken place in this area. Since the early '90s research works have addressed four major problems: a) evaluation of the disassembly process, b) design of disassembly cells, c) planning of disassembly motions and sequences, and d) disassembling products by use of intelligent sensors and flexible actuators. At the beginning, most work aimed at proposing concepts and generic models of disassembly cells, for consumer goods, cars, TVs and PCs. Nowadays, several initial solutions have been developed and employed for semiautomatic disassembly. In Europe there exists new pressure in the area of electronic disassembly since in February 2003 the European Parliament passed a directive of the European Commission (ED, 2003) which states that, from August 2005, each industry has to take back its end-of-life products without charging a fee, being then responsible for their ecologically acceptable annihilation. This paper aims at surveying a number of solutions in the field of disassembly cells for electronic devices and proposes several further development directions.

2. Reported results

2.1 Disassembly of printed circuit boards

On old or new PCBs there are several re-useable parts. These chips can be soldered in old or new technique or socket. The task was to develop a semi automatic disassembly cell for both kinds of chips. At the Institute for Handling Devices and Robotics of the University of Vienna a disassembly cell for printed circuit boards was conceived. The layout of the cell is shown in Figure 1. The basis of a disassembly cell is a very stiff frame construction developed from commercially available profiles. In a manual feeding station the PCBs with a maximum size of 300 x 220mm are attached on special work holding device (Kopacek and Kopacek, 2005).

The disassembly cell consists of four stations: vision system, laser dismantling system, removal station, heating removal station. The vision system has several tasks. It has to recognize the re-useable parts by means of a data base containing the data (production, company, dimensions). The vision system has to detect the re-useable parts and to determine the position, the size and the centre of inertia. Furthermore it has to classify the parts to be dismantled or removed from sockets. The dismantling station consists of a cross table –two linear axes – controlled to reach every point (centre of inertia) on the PCB.

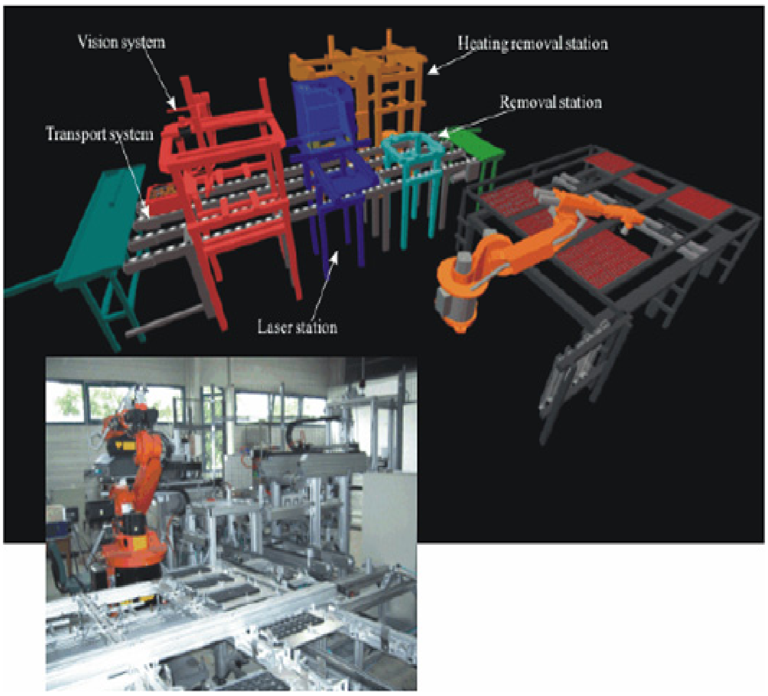


Figure 1. Disassembly cell for PCB (Kopacek and Kopacek, 2005)

The dismantling process is carried out by laser technology. The disassembled parts are put on a distinct area outside the laser from which they are removed by the industrial robot and to put into the appropriate magazines. The third station is the removal station for socket parts. An industrial robot equipped with special grippers as well as external sensors carries out the removing process. The robot removes these parts and puts them also in the right magazines. This is a robot with a reasonable accuracy ±0.2 mm, a reasonable payload (15 kg) and a relatively innovative controller based on the operating system Windows NT. This robot also offers the possibility to work with signals from simple low-cost sensors (e.g. micro switches). A multipurpose gripper equipped with simple sensors as a weighted compromise between flexibility, costs and time was developed. As the demand for real time could be branched out to lower level controllers, it was possible to implement the control system using Microsoft Visual C++ under Microsoft Windows.

2.2 Disassembly of mobile phones

2.2.1 An advanced solution

Having made a detailed analysis of used mobile phones concerning the parts as well as the assembly technology and tests for disassembly with the most frequent mobile phones, a concept for the disassembly cell was created also at the University of Vienna (Fig. 2.). It consists of five automated stations and a manual feeding and removal station: drilling station, drilling and milling station, removal station for the covers, circuit board removal station, drilling station (Kopacek and Kopacek, 2003). For disassembly, the mobile phones were fixed on a pallet in a distinct position. These pallets are moving around on a transportation system. According to the necessary disassembly operations the pallets with the mobile phones to be disassembled are stopped, lifted and fitted in a distinct station. Before the mobile phone is fixed on a pallet the power supply will be removed and the type of the handy will be recognized by a barcode reader manually. Now the control computer knows exactly the type of the handy.

The main dimensions of the handy are stored in a database of the host computer. In the drilling and milling station the upper part of the handy will be cut off from the lower part and the screws – usually between 4 and 17 – are removed by a simple drilling mechanism. The dust content is removed by air from the pallet. In the cover removal station the cover as well as the keyboard of the handy will be removed by pneumatic sucks. These two parts are separated in a storage device. In the drilling station, e screws which connect the printed circuit board on the lower part of the housing are removed. In the printed circuit removal station various other parts will be removed from the handy and separated in a special storage device. Because some mobile phones have additional parts connected with the power part of the housing of the handy the remaining screws will be removed in the last drilling station. Finally the lower part of the handy will be removed in the fixing and removal station.

As a development of this semi-automated disassembly cell for used mobile phones several tests were necessary. For the milling in the drilling and milling station it was necessary to make tests with grinding wheels, with different saws and with milling devices. Finally a milling device was chosen as the right tool for this task. Further extensive tests were carried out for the removal of the screws. At present there are highly sophisticated, complicated and therefore very expensive and heavy devices known (Lambert and Gupta, 2005). This is a very simple and very cheap method for the removal of the screws.

Figure 2. Disassembly cell for mobile phones (Kopacek and Kopacek, 2003)

For the control of the cell a hierarchical system was realized. In accordance with IEC 1131/ DIN 61131 (Van der Wal, 1999), he PLC-program utilizes as HMI (Human-Machine Interface) a display, lamps and buttons. Robot-Programs are written in a special „robot" language. The program of the Host is realized in Visual C++ with the HMI Windows and the Control program of the laser in Visual Basic.

2.2.2 A model –based solution

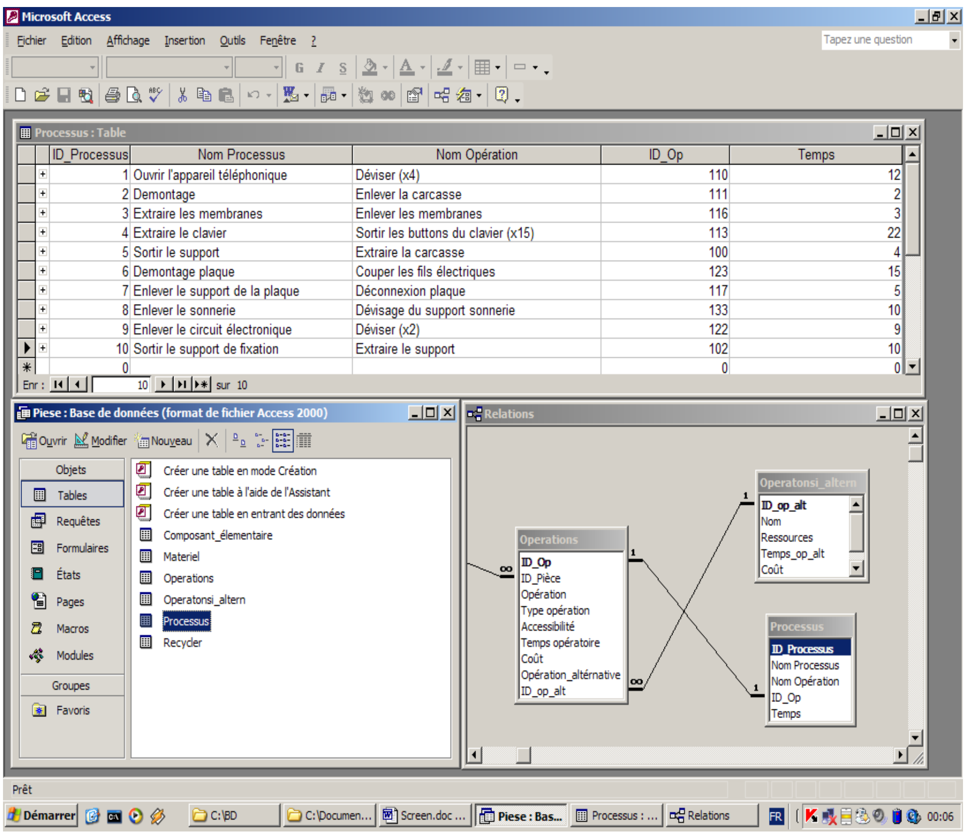
In the Laboratory of Automatics of Besançon (LAB), France, a mobile phone disassembly command system that integrates a decision intelligent system was conceived (Duta, Filip, Henrioud, 2003; Duta, 2004).. The software product LEGA (*Logiciel d'Evalation des Gammes d'Assemblage*), entirely conceived at LAB, was utilized as a planner. To support human decisions the software package was entirely conceived in Visual C++. LEGA gives all possible disassembly sequences of the product by using for modeling the Disassembly Petri Nets (DPN) (Addouche, Perrard, Henrioud, 2003). The Decision Support System (Filip, Donciulescu, Filip, 2002) is utilized to analyze these sequences and gives the best decision suggestion for disassembling the product (optimal disassembly sequence), so as to maximize the final profit (Duta, 2006):

Figures 3 and 4 (Duta , 2006) show how a Petri Net is transformed into a decision three and the simulation result, respectively. In figure 4 a decision tree associated to the disassembly process of the phone is represented. The aim of the model is to find the optimal disassembly sequence for the phone that maximizes the profit. Admissible disassembly sequences are described by the DPN. For each subassembly we have to take a decision: to disassemble or not.

Therefore, for each non-terminal place of the DPN, a decision node corresponds in the decision tree. Also, each transition represents a disassembly operation that can succeed or not. The probability of the operation success is calculated by using statistical methods after a great number of disassembly operations. So, a chance node corresponds to each transition. A *Policy Tree* shows all possible paths through the tree and indicates the value

of all expressions in the model, the probabilities associated with each chance event outcome, and the roll-back values (EMV- "Expected Monetary Value" for each node. In the right side of the interface from the figure 6 the optimal policy is indicated. This is obtained by the roll-back procedure. In each decision node we chose the branch with the greatest value of EMV.

Modelling disassembly sequences using decision trees is a method that permits us to apply all the instruments used in the decision analysis to study the optimal plan of disassembly. The decision trees are meant to assist the decision maker in finding-out the best option among the possible disassembly sequences as to maximise the final profit.



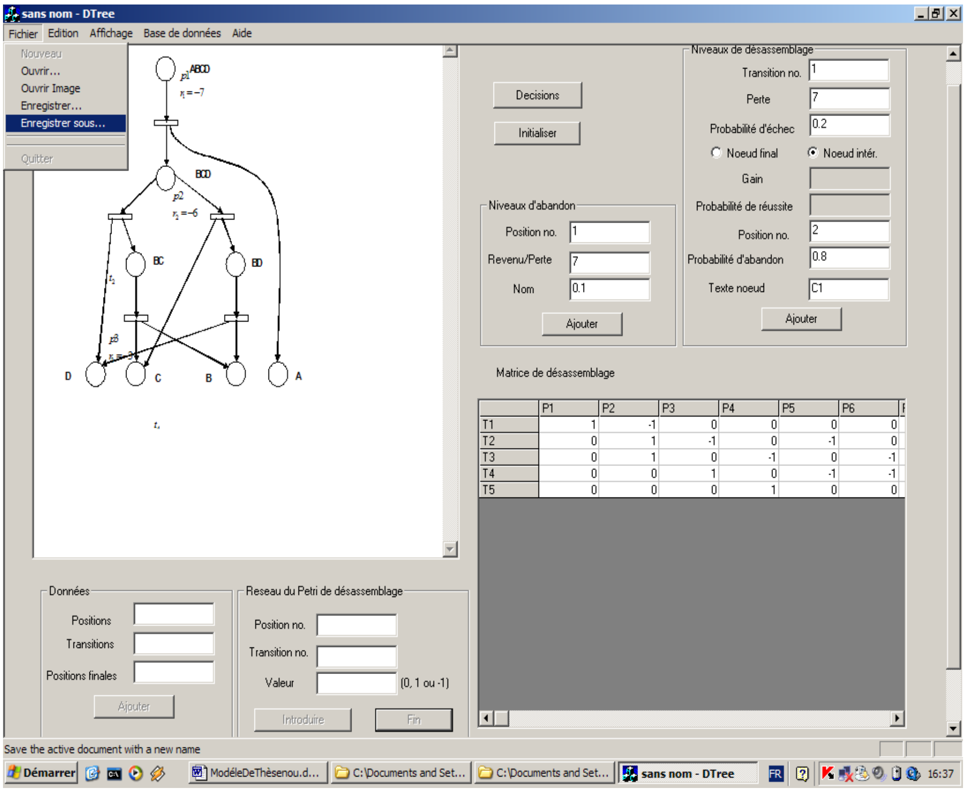


Figure 3. Mobile Phone Data Base describing the components properties (Duta, 2006)

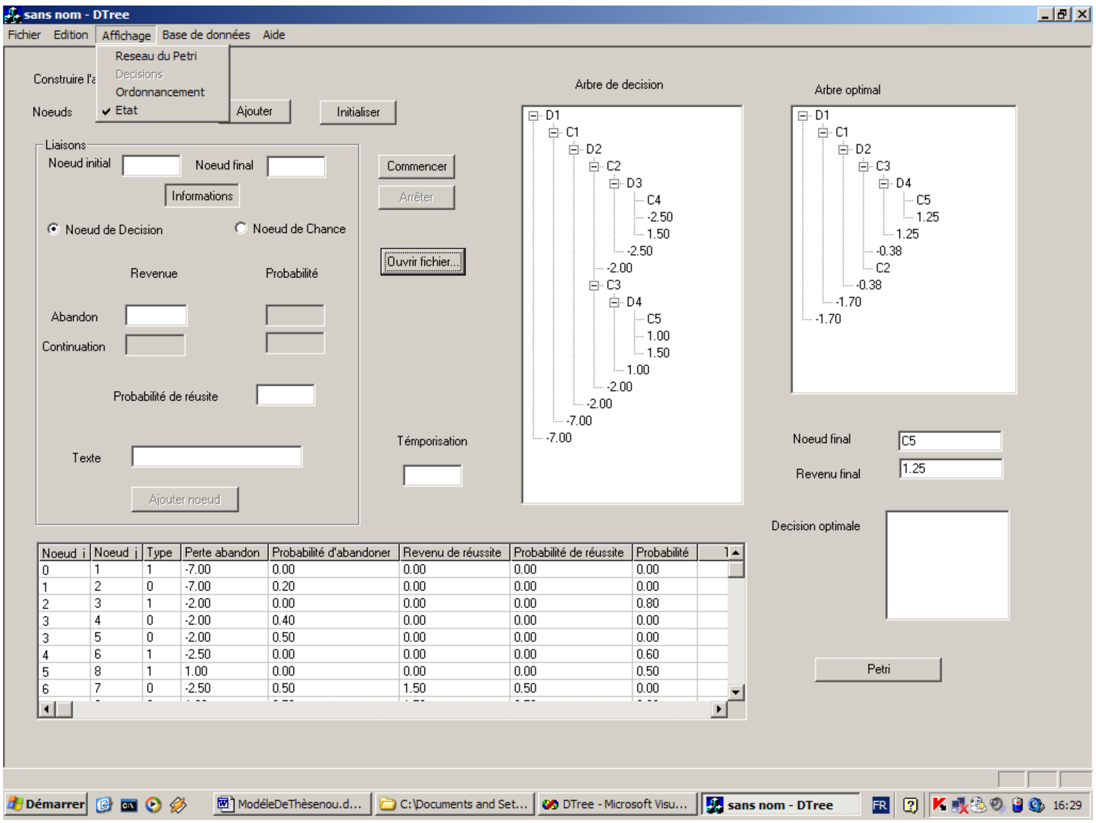


Figure 4. Decision tree model generated by DSS (Duta, 2006)

2.3 Disassembly of PCs

Puente (2002) utilizes the relational model to represent the links between the components of a personal computer. Before the disassembly process, it is necessary to have a model that provides sufficient information to the system for it to be able to do the disassembly. The planner used is the RobCAD 8.0. The geometric model is a multi-dimensional representation of the product, from polyhedral models of the components.

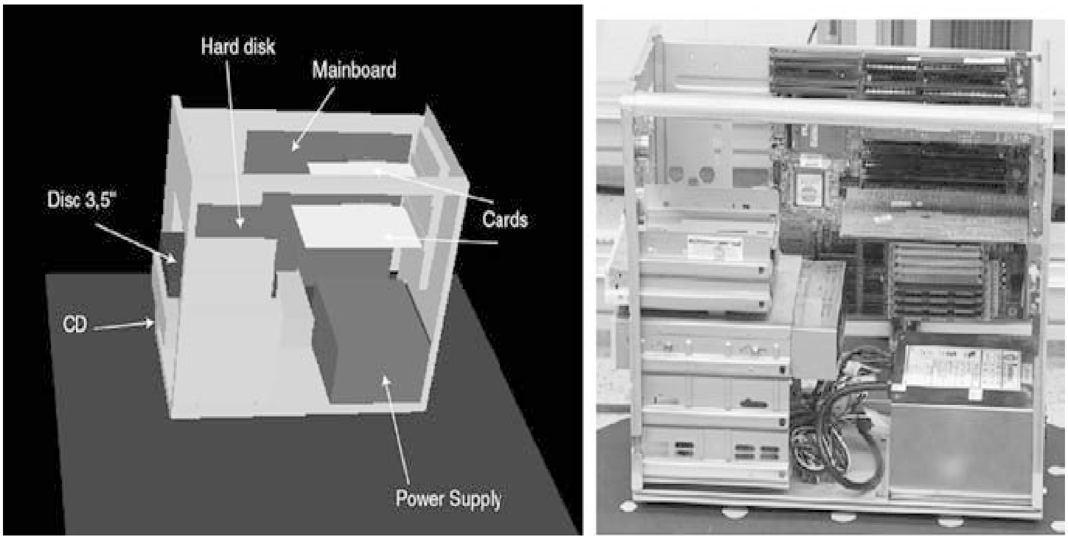


Figure 5. Geometric model of a PC (Puente, 2002)

The geometric model must reflect the main physical characteristics of the components of the product (size, geometry, etc.) as well as the relationships among the different components of the product (contact surfaces, type of unions, locations of components, etc.).

The model employed for the components (this information is stored in the components database) and the assembly model, which is generated automatically from the relational model and from the information processed by the computer vision system, are chosen.

The architecture of the disassembly cell contains a Scorbot ER-IX robot with five liberty degrees, a moving table where the computer is fixed, and an artificial vision system fixed on a Cartesian y-z robot that tries to localize the components of the product. The artificial vision system gives a three dimensional image of the product. The acquisition system consists of a pair of SONY EVID31 cameras in a stereoscopic system. These motorized cameras are located at the end the y-z Cartesian robot, which allows the pair of cameras to be positioned perpendicular to the base of the robot and the worktable (Fig. 6).

The recognition process has two basic objectives: a) to determine which element is the product and which are its components, and b) to detect the components that are to be disassembled. Once the product to be disassembled has been modeled, having identified the precise components of the products, the second objective is to detect which component is to be disassembled. To do this, the images of the product captured are processed to obtain a series of characteristics that must be compared to the information stored in the database.

The control program and interfaces are written under the Visual C++ environment.

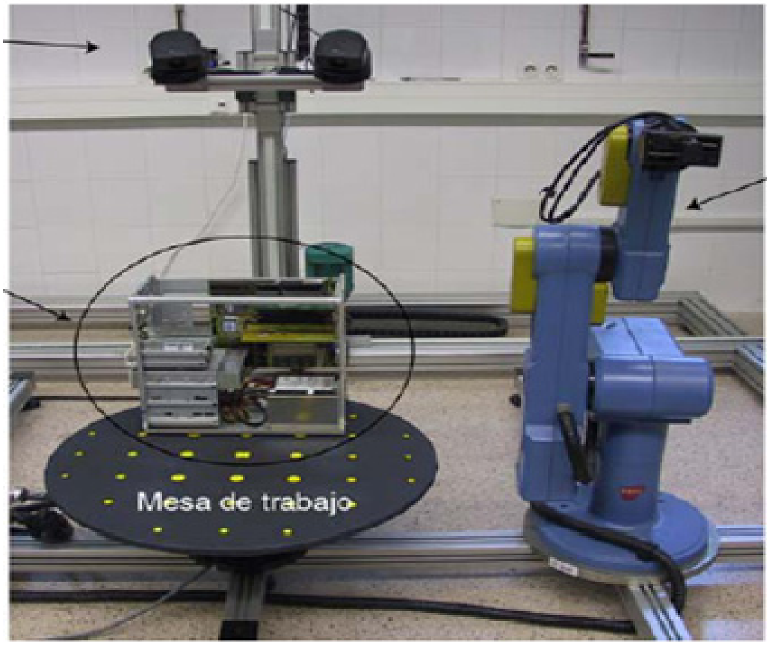


Figure 6. Disassembly cell for a PC (Puente, 2002)

2.4 Disassembly of Camcorders (CCD)

In Germany, at the University of Darmstadt a disassembly cell for video cameras was designed (Weigl-Seitz, et al., 2005).

The major problems with the Camcorder (video camera recorder) being representative of some problems of disassembly–are:

- Taking off the viewfinder, which requires careful extraction from its fixation, with stopping at the right moment and extraction in another direction
- Gripping of the very irregularly shaped top of the cabinet, which has to be removed to reach the most valuable part-the objective block-which can be reused
- Cutting simultaneously some cable connections between the upper and lower part of the casing
- Gripping and extraction of the objective block

First, the gripping of the objective block by the fingered gripper takes place, then the extraction of the block, which needs solving of the undercut problem is carry out. Before gripping the objective block, it is necessary, however, to find it in the picture of the internal structure, taken by the CCD-camera after taking off the upper casing.

Once the objective block has been located, a grip for the two fingered gripper adequate here has to be selected. To achieve a firm grip, a depth analysis of the narrow gap between casing and objective block has to be performed, for which the best solution is to apply a laser scanner.

Figure 7 shows the robot with gripper, sensors and small fingers added to the two finger gripper above the open camcorder.

The movements of the robots as handling devices can be specified in a general way, e.g. moving a module for extraction upward and placing it into a container by following a certain trajectory. These are called “global movements”. They are a given basis for the task to be fulfilled on each station.

However, disassembly itself has to take into account product uncertainty and diversity. So the direct extraction is either not specified in advance or (/and) is too complicate to be accurately specified. Therefore sensor-based behavior embedded in a “movement skeleton” seems to be the adequate solution.

We will call the respective procedures skills and speak of local (sensor-based) movements.

Artificial intelligence-based methods are utilized in this solution. The control of the griper is performed by an expert system. Rule based inferences are carried –out to imitate the behavior of a skilled operator. The grip imitates the behavior of a blindfolded human being, who relies on his tactile abilities.

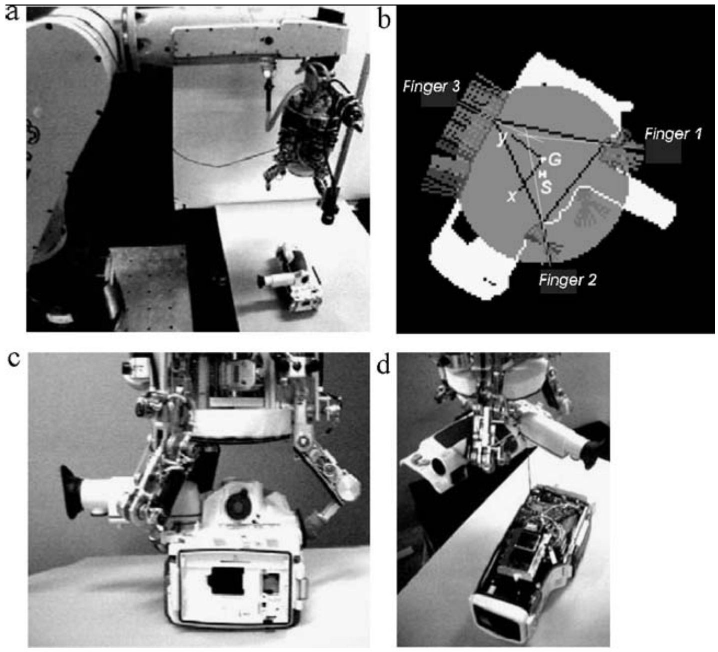


Figure 7. Removal of the upper casing of the camcorder (Weigl-Seitz, *et al*., 2005).

3. Prospects in Disassembly Cell Design and Control

Disassembly cells presented in this article mostly utilize unintelligent stationary robots. Currently available disassembling cells are only "single purpose cells" e.g. the system is dedicated to a single type of product or to a family of products with similar structures. Majority of electric and electronic products can be classified into product groups and disassembled either semi or fully automatically. A modular system for creating flexible, intelligent, "low cost" disassembly cell is usually developed. It consists of fully compatible hardware (robots, tools, grippers, changing systems for tools and grippers, transportation devices, image processing systems, etc.) and software modules (cell planning, simulation, control, image processing, knowledge based systems, etc.), partially adapting commercially available modules, and some additional developments.

Different grippers and sensors will be necessary for disassembly of a specific electronic device. This may also be the case for the robots to be utilized, either in connection with the specific device considered or with the different steps in disassembly: For some problems one may need a 6-axis industrial robot as we have utilized in our experiments (Duta, 2006), for other tasks much simpler robots with fewer degrees of freedom may be sufficient. Also for some tasks a second, simple robot is necessary, e.g. for cutting the upper part of a housing which is connected to the lower part by a cable.

These considerations led to the conclusion that a disassembly system will, in general, be made of different disassembly stations. However, mobile robots provide new possibilities for flexible disassembly of huge and heavy devices. In addition to stationary robots, mobile robots for disassembly should be intelligent in the sense of path-planning and able to communicate with other robots, cooperative with other (stationary or mobile) robots, and able to form a disassembly multi agent system, which is one of the future possibilities for reducing disassembly costs. Derived from multi-agent-systems, such systems are one of the key technologies for constructing decentralized, adaptive, intelligent and complex automatic systems. For heterogeneous robots it is difficult to implement the communication because each robot has its own kinematical structure and programming language, etc. Furthermore, the range of frequencies used for communication and the capability of these modules is limited. It is necessary to develop standardized communication protocols and methods, which should be one area of study in future years.

4. Conclusions

Semi/fully-automatic disassembly, especially of electronic devices, is a hot topic today and not only because of the standardization by the European Commission (directive on waste from electrical and electronic equipment—WEEE). Usually, only toxic components are removed manually while the rest of the materials are shredded and disposed. Manual disassembly of such devices is today state-of- the art. Because of this EC regulation and the increasing amount of electronic scrap, manual disassembly will be viewed as even more inefficient in the near future. Therefore, automation of the disassembly process is necessary.

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