Automated Disassembly: Main Stage in Manufactured Products Recycling

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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 energetically recovery. In this paper we present some methods for modeling the automatically disassembly process in view of recycling.

1. Introduction.

As a result of the development of the social-economical life in the second half of last century, the world was faced with a vital problem: how can we maintain a continuous development without harming the environment of our planet?

Since the success of industrial revolution at the turn of the century, technology has been consistently revolutionized. Technological development, diminution of the natural resources, exponential growth of human population, raise of consumer demands, waste of disposal, are factors that have contributed to an accelerating rate of pollution and degradation of the natural environment.

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That is why manufacturers are obliged to take into account the effects of their actions on the environment. There are more stringent regulations that call upon companies to be environmentally responsible, to search better methods to reuse and recycle their products. Nowadays, the designers are concerned about the destination of the products at the end of their life. Producers are obliged to design and manufacture their products in order to facilitate their recycling.

2. Product life cycle

Product life cycle is a concept, which refers to the product itself as well as its components.

The process of design used to work in open loop. Now we have to take into account a new stage that closes this process: **recycling.**

To recycle manufactured goods, several types of valorization are available: reuse of components, valorization by treatment of materials in order to reuse them or energy recovery by incineration. Disposal, which is the last solution, is done only if the other possibilities are impossible or too expensive. The choice between these different types of valorization determines the recycling process. These types will allow defining *end-of-life destinations* for components of manufactured goods [2].

Different recycling loops are different approaches of the process. The simplest approach is that of dismantling the product. By applying dismantling, a discarded good can be broken down faster and with small cost. In this case more pure fractions can be obtained with less efforts.

This simple approach exploits the value of the raw material. It doesn't take into account the functional value of the product or of its components.

Keeping the functional values requires a recycling process that minimizes the destroying effects on the product. This means to reuse, refurbish and capitalize the components of the used product in order to remanufacture a new one. Re-manufacturing is an economical form of reusing, since its objective is to maximize the value of repaired parts and to minimize the disposal quantity. Central to re-manufacturing is the **disassembly process** that decomposes a product into parts and/or subassemblies.

In Fig. 1, different loops of product life cycle are represented.

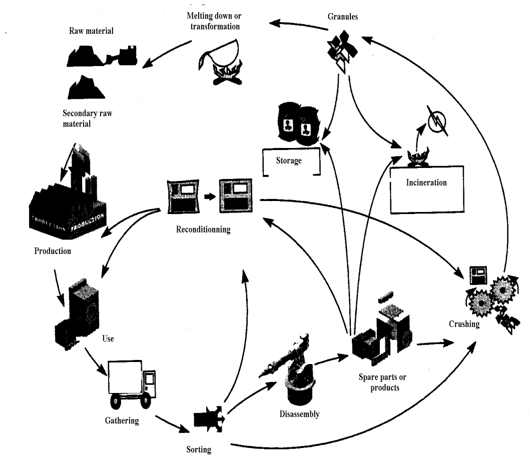

Fig. 1. Product life cycle [1]

Disassembling is a non-destructive technique; it implies the extraction of the desired components and/or materials. If the parts are not reusable after reconditioning, partial or total destructive operations are applied: drilling, cutting, wrenching, and shearing. These techniques are used in view of the material or energy recovery.

In this context, disassembly is the main stage in the product end-of-life treatment.

The disassembly process in view of recycling of the manufactured goods is considered in the literature as a *friendly environment technology*. It is integrated in a more complex system – the disassembly system that contains the resources, robots, automates, human factor and different devices used by the disassembly process. Each unit of a disassembly system is a disassembly cell. Nowadays, researchers are looking for methods allowing conceiving efficiently complete automatically cells.

3. Modeling a disassembly process

We can study the behavior of a disassembly system by using models that are easy to be experimented by simulation. In the literature, the methods used for modeling a disassembly process are devised in two categories: some for sequencing operations and others for planning and control. Most of the methods are based on the theory of Petri Nets.

Petri Nets are a graphical and mathematical modeling technique originally developed to model computer system. They have been extended and applied to a wide variety of systems, including manufacturing ones. PNs are useful for modeling systems characterized as concurrent, asynchronous, distributed, parallel, and/or stochastic, in which operations share multiple resources. PN models can be analyzed to determine qualitative and quantitative proprieties of the system.

For example, in [6] the authors use the Disassembly Petri Net (DPN) to represent the sequences. DPN is in fact an AND/OR graph which takes into account the precedence between the components.

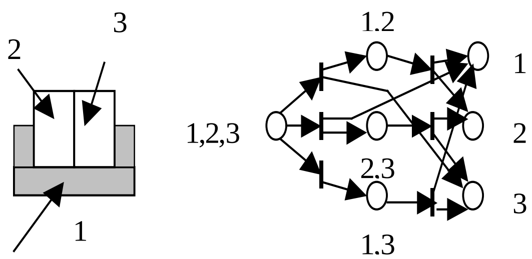

Fig.2. DPN

In [9] is presented a DPN in case of a telephone handset. In the associated Petri net a place is regarded like a product, subassembly or part, and a transition corresponds to a disassembly operation.

The handset is used as an example for modeling with DPN based on the given product specifications (Fig. 3).

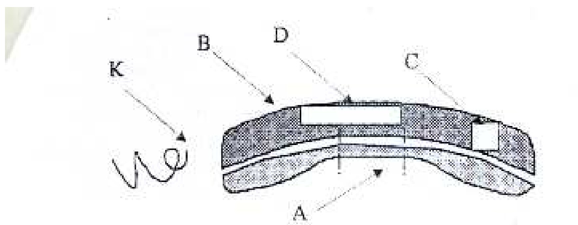

Fig 3. The components of a telephone handset

The handset consists of four parts, A, B made from thermo-set plastic, part C made from steel and part D is a printed circuit board. Fig. 4. represents the corresponding Disassembly Petri Net. If P is the set of places and T the set of transitions, we have:

$\pi : P \rightarrow R$ an utility function assigned to a place where R is the set of real numbers;

$\tau : T \rightarrow R^{+}$ a cost function assigned to a transition;

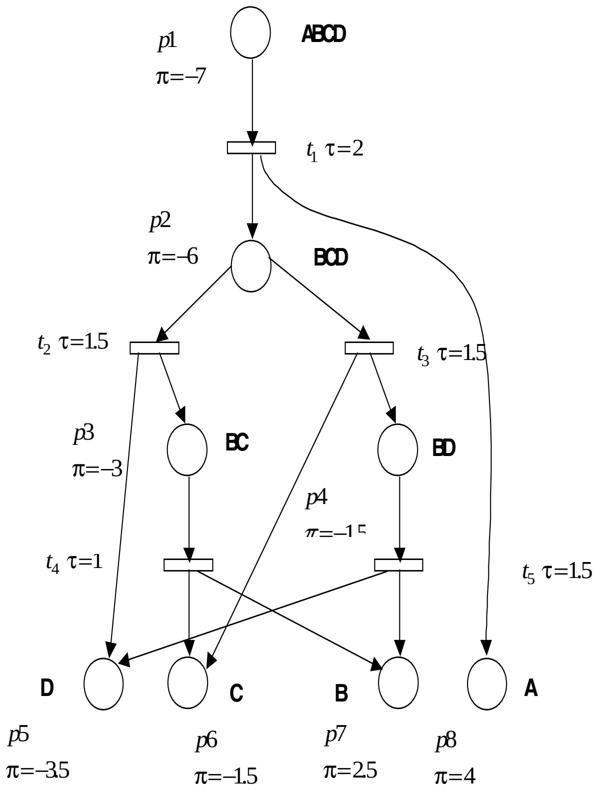

Fig. 4. DPN

In order to represent a disassembly sequence T.C. Kuo [4] uses a disassembly tree that associates for each branch the direction of the disassembly operation. The idea of using disassembly trees has the origin in that of assembly trees that are presented in [3]. Thus, the disassembly process is regarded as the reverse of the assembly. However, the success of disassembly operations can be affected by different characteristics of the components, by the uncertain product conditions, deformations, material deficiency, etc.

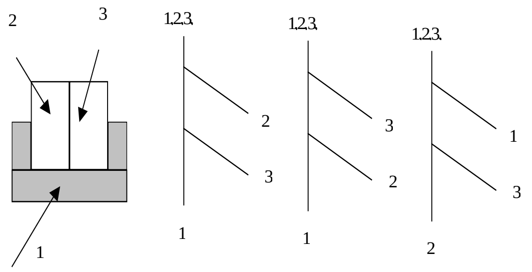

Fig. 5. Disassembly trees

In [7] the disassembly process is represented by a reusing point of view of a target component. The authors use the theory of graphs and the method of dynamic programming for the generation of the disassembly plans. They propose a disassembly graph (Fig 6.). The discarded good to be disassembled is in initial state A. The nodes represent the states of the disassembly goods. This means that every state contains a collection of parts and sub-assemblies; for each state the collection of parts and sub-assemblies is unique.

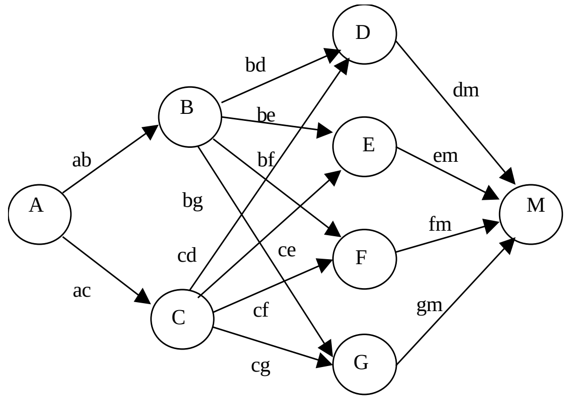

Fig 6. Disassembly graph

The state M obtained after a number of disassembly operations contains a desired part that has to be recovered.

4. Disassembly system control

There are few articles in the literature that treat control of automatic disassembly system, due to the natural reason that no automatic disassembly cell has been ever implemented. However, at the Institute WBK of Karlsruhe – Germany, was realized a hybrid disassembly cell in which cooperate a robot and a man [2].

The control of the disassembly system can refer to the production flow, balancing disassembly line, or to the command of different resources.

In this context we are proposing a new method: object-modeling technique (OMT).

The object-oriented approach provides decomposition of the disassembly system in objects with associated attributes and methods (operations). The product, subassemblies, robots, disassembly line, they can be objects and their main characteristics can be attributes.

In recent years there has been considerable interest in applying object-oriented technique to Petri Nets [5]. It is interesting to represent objects from a disassembly system using Object Oriented Petri Nets (OOPN).

In an OOPN places are *operations*, the mark of a place is the *state* of the object, and transitions represent *temporal or physical disassembly restrictions*.

Fig. 8. represents an OOPN for an elementary production cell. In the place FM (free machine) we have the initial mark. Objects type “products” are in a waiting supply WS. Due to transition E a mark goes from WS and from FM to the place OM (occupied machine) that corresponds to an executed operation. The transition “end of

execution" (EE) is fired only if the precedent operation is the last one from the operational chain. Else, the transition "end of intermediary execution" (EIE) is fired, so that a mark goes again to the WS, changing the state attributes of the object "product. After the transition EE the product goes to the final supply (FS).

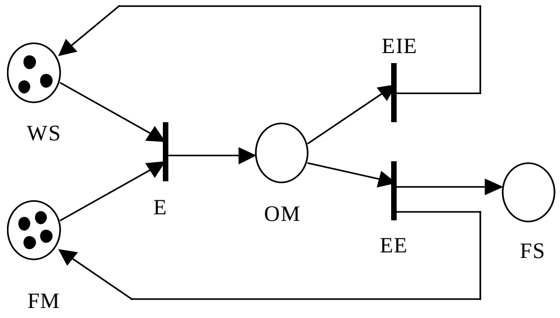

Fig 7. Example of an OOPN

Using this method we can represent the disassembly system as well as disassembly process with all its phases.

Now, assuming that we have to disassemble one component with an uncertainty state after usage, we must consult the end-of-life options of the component: reusing, recycling, material or energy recovery. Places can represent activities, waiting states or operation linking. Transitions correspond to events, pre and post conditions or run-time constraints. In the next figure P_1, P_2, P_3 are the places for the disassembly operations and places P_4, P_5 and P_6 can represent the end-of- life options.

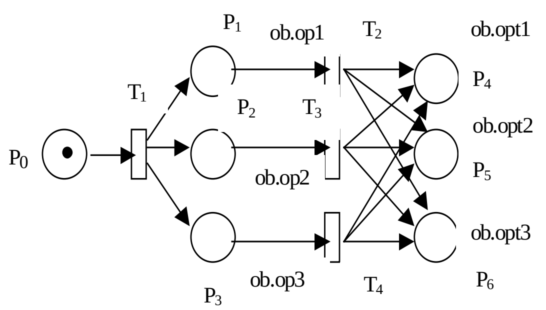

Fig. 8. Disassembly OOPN

P_0 is the initial state of the product and P_1, P_2, P_3 are the possible states obtained after T_1 occurs. It means that we have to choose between three types of operations: disassembly, dismantling or shredding, depending of the end-of-life options opt1, opt2, and opt3.

We can group the objects with the same attributes and end-of-life options in the same classes. This leads to a smaller knowledge base for the disassembly process.

Further, we can combine the power of OMT with the proprieties of RP. In such a disassembly OOPN (DOOPN) we can dynamically create objects, each encapsulating its own data and control structures, together with the ability to generate new instances of objects. This means that DOOPN support the dynamic interaction topologies, so they are suitable for system control modeling. Also, OOPN like an object-oriented modeling tool supports hierarchy control. For a disassembly system we can apply the same methodology in the problem of the resource planning and line balancing. DOOPN can provide a suitable tool for modeling, simulation and evaluation of the systems' behavior. In the recent years some new simulation tools for OOPN have been developed (BETA, LOOPN++, ARTIFEX, NETOBJ) [8].

Object oriented paradigm has the advantage that it allows the implementation of the system control using programming techniques and languages (for example C++ or Visual C++). Object Oriented Petri nets support encapsulation, inheritance, polymorphism and dynamic binding which are common in object oriented languages. We think that object-modeling technique provides an elegant tool for modeling discrete event systems such as disassembly systems.

5. Conclusions

For the last several years, recycling technologies have been continuously improving. However, in order to recycle products in an efficient way, a systematic process such as disassembly allows reusable, non-recyclable, as well as hazardous components to be selectively separated from recyclable ones.

In this article we tried to propose a new conceptual modeling method for the disassembly processes: object-modeling technique using Petri Nets. The researchers are often confronted with the great amount of knowledge for the disassembly systems. Object oriented disassembly can be a method to store the information needed by the recycler in a computerized way. The aim is to store a large amount of data in a better-structured way. Object Oriented Approach has the advantage that it provides well-structured information for the development of computer aided decision tools.

Future work has to concentrate on the analysis and evaluation of the proposed object-oriented models and has to find a suitable tool for simulating the activity and the control of a disassembly process.

6. References

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