INTRODUCING AN AUTOMATIC COOPERATIVE DISASSEMBLY ROBOTIC SYSTEM: DEVELOPMENT OF THE TASK PLANNER TO ACHIVE COOPERATIVE DISASSEMBLY

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Abstract: this article include two cooperative robotics-manipulators in an automatic disassembly working cell, to perform recycling task. The task planner, for a disassembly cooperative robotic system, is also proposed in this article. This is based on the construction of decision trees schemes that allows the system to determine a general method to plan all the disassembly actions in a cooperative and coordinated way. To work in a cell composed of *j* robotic manipulators. It Is important to highlight the Task Planner proposed in this paper; provides a simple solution to a complicated problem that is sharing the same work area.

Keywords: *recycling, automatic disassembly, cooperative manipulator, task planner.*

1. Introduction

Environmental considerations in industrial activities have been growing continuously, thus the government propose regulation in these aspects in different industrial areas. In 1998, the European Community introduced a report that contains regulation and norms to treat the waste production in electrical and electronic devices. This regulation is still in effect (Waste Electrical and Electronic Equipment, Directive, 2003). These norms have implication in the development of the products. The environmental considerations must be taken into account in all the cycle of the production. They must be involved in all the period of life of the product; from the design stage passing through the consumer's delivery until the end-of-life stage. This politic application pretends to eliminate the toxic waste generated by a product when its useful life ends, reducing the damage caused to the environment.

In the electronics industry the initial responses to these trends were mainly of a defensive nature, directed towards compliance with legislation and towards preventing a negative image developing in the press and with the public. Emphasis was therefore on issues such as eliminating banned substances, cleaner production, recycling of packaging, and power management for the standby mode (ECO-DESIGN GUIDE, 2002).

The automatic disassembly allows (Hesselbach et al., 1994):

- Elimination of toxic substances. Here the RoHS (Restriction of Hazardous Substances) directives have been taken into account.
- Concentration of value materials. Like metals, their are interesting to separate not only for the ecological reason as well as economical too.
- Reuse of components. Like energy sources, memory chips, etc. These make the disassembling a profitable process.

Companies normally have a distinctive and customised product development process. Therefore, it is necessary to customise the integration of the environment into the process according to the company's culture, and the characteristics of its products and processes.

It is necessary to customize the integration of the environment into the process according to the company's culture, and the characteristics of its products and processes. The disassembly process for recycling is introduced in the design of new products, to optimize the resource uses. Some objectives for disassembly products are: the recovery of pieces, the defective pieces elimination, the pieces extraction that can be reused in future, and mainly the diminution of waste that reduce the environment contamination (Güngör &Gupta, 2001).

To integrate fully the environmental concerns in the design process, companies develop design methods (standards) for example the ISO 9000 norms. Figure 2 gives some example of such integration.

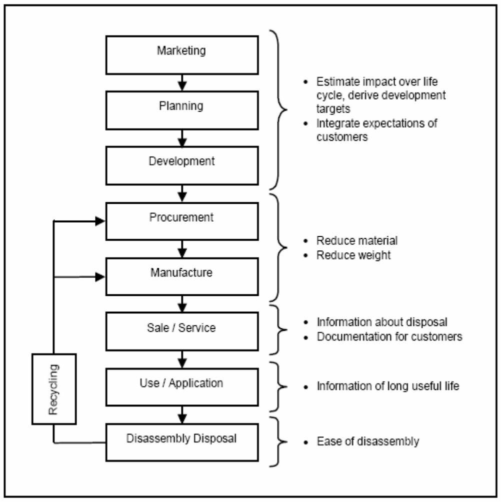

Fig. 1. Input of rules into development phase

The main reasons for disassembling the products are ecological, and/or economical (Güngör & Gupta, 2001; Thomas Hirth, 2005). The ecological reasons are based on the conservation of the environment. When companies apply a disassembly process the ecosystem is being taken care of, because toxic substances can be separated; and treated separately, to avoid contamination. The economical causes based on the fact that products disassembly allow companies to recover materials to make new product, with the consequent saving in raw materials. Also, pieces that are in good state can be reused directly. Thus completely eliminates the cost of manufacturing these pieces (Feldmann et al., 1998; Eckterth et al., 1998). In Figure 2 the cost/benefit relationship in recycling is shown. It is observed that they are inversely proportional.

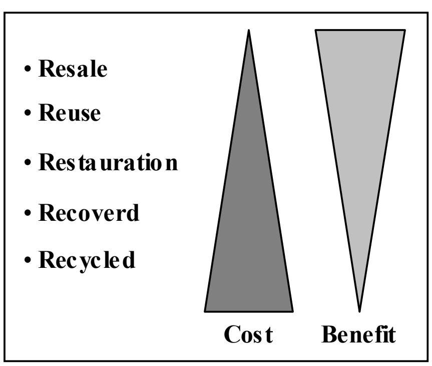

Fig. 2. Cost/Benefit relationship.

Including two or more robotic manipulators working in a cooperative way increases the performance of the disassembly system, this is because of the synergy that produces a group of units working jointly as a team. The value of a group of entities collaborating among them, working in group as a team has been proven many times in many domains. For example, in nature a group of animals working cooperatively as a team can manage to hunt a stronger and bigger animal, or in the military service a group of men with limited resources and specific abilities are united to create groups with an incredible capacity. These examples illustrate that a group of entities with similar or different abilities joined to work in a team, can produces a work with abilities and capacities greater than the sum of its parts (Navarro-Serment et al., 2002).

Work in a coordinated way has been growing continuously due to the advantages that this gives, for example:

- *The increase the flexibility of the system*: because two or more robotic manipulator working together as a team can perform a greater quantity of task than one manipulator working alone, without doing an adaptation of all the cell
- *The increase the productivity:* the existence of many manipulators working in the same cell carry out that many task can do in a short period of time due to the synergy that produce work in a cooperative way
- *The increase of the load capacity:* working with two or more robotic manipulator allow handling bigger and heavier objects

Other advantages that can mentioned sharing are, information and resources, a more failure tolerance, and assistance between robots.

In the field, cooperative works with manipulators, can distinguish two groups:

- Two or more robots collaborating on the same tasks (Yokoyama et al., 2003; Tinós et al., 2002; Fonseca & Tenreiro, 2003).
- Cooperative tasks between robotics manipulators and humans (Pramila et al., 2004; Kumar et al., 2000; Hägele et al., 2002; Woern & Laengle, 2000).

The remarkable difference that defines these two groups is that when cooperative tasks between robotics and man are used the system must consider external and internal sensors in order to avoid the person suffering physical damage. This article considers an example of cooperative tasks between two manipulators, the intervention of the human in a disassemble cell is considered like a future possibility.

Working in a cooperative way has been growing continuously given the advantages that these offer, some of those advantages are: make tasks that a single robot cannot do. For example, a single robot can not transport a beam that exceeds its lifting capacity, but two manipulators working in a cooperative way can. Other advantages are, share information and resources; greater tolerance to failures; and attend between manipulators for different tasks. Working in a coordinated way also provides the system a faster and an effective disassembly; this would bring a consequent saving of money to the industries that apply it.

Disassembly is defined like the process of separating pieces that compose an object; automatic implies the intervention of robotic manipulators. In this process is very useful to consider the advantages of cooperative tasks, in which two or more robots take part, or tasks in which the intervention of a human being is required. In this article only the first way is considered: two or more manipulators working together in a coordinated way.

This article is organized as follows: after the introduction in Section 2 the working cell is described. In Section 3, the process' architecture is shown, and in sub-section 3.1 the cooperative task planner is developed. In Section 4 an application example is explained. And finally conclusions and future projects are presented.

2. Working Cell

The automatic disassembly robotic cell is composed of the following elements, described in Figures 3, 4 and 5:

- Robotic Manipulator Mitsubishi® PA-10.
- Robotic Manipulator Intelitek® SCORBOT ER-IX.
- Work table.
- Deposits.
- Tool Changer.

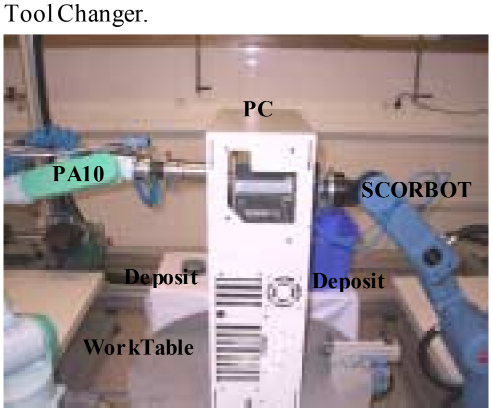

Fig. 3. Work Cell.

The worktable is a rotating table (360º) equipped with four pneumatic pistons which hold the product for disassembling; in this example these product is a computer (Fig. 3 and Fig. 4). The work table increases the flexibility of the system because it allows the different manipulators to access the areas which are outside of its workspace. In addition, the work table permits to make the necessary rotations to place the object in a comfortable position to be manipulated by the robots. The work cell also contains a tool changer that allows the use of different tools according to the task to execute (Fig. 5) For example in the practical example described in this paper the PA-10 holds an electrical screw driver, and the Scorbot uses a pneumatic clamp, as shows in Fig. 6 and Fig. 7.

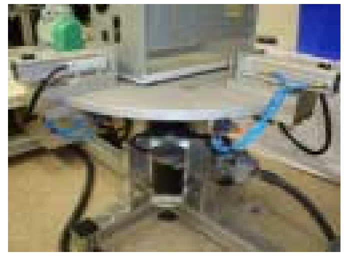

Fig. 4. Rotating table.

Fig. 5. Tools Changer.

Fig. 6. PA-10 with an electrical screwdriver.

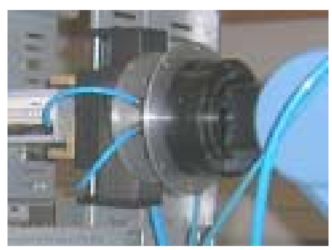

Fig. 7. Scorbot with a pneumatic clamp.

3. Process' Architecture

Cooperative disassembly process' architecture used is shown in Figure 8. In this scheme the Data Base contains the list of tasks for disassembling a product.

The Task Planner determines which task corresponds to each manipulator and in their precise moment. Then a Position and a Vision control are aplied to avoid collisions in real time between robots and also collisions of the manipulators with the environment. This grants the system the possibility of doing on line corrections.
In tasks that needs cooperation between two or more robots working on the same object it is very important to consider the layout and coordinate the movements that each manipulator perform, in order to avoid collisions. The Task Planner is the one in charge to obtain a free shock path. Those give the necessary information to the system and the steps to be followed by each manipulator, to obtain an optimal disassembly. The Task Planner should consider: the location of each manipulator, try to reduce the tool changes, and other considerations, in order to achieve decreasing times in products disassembles.

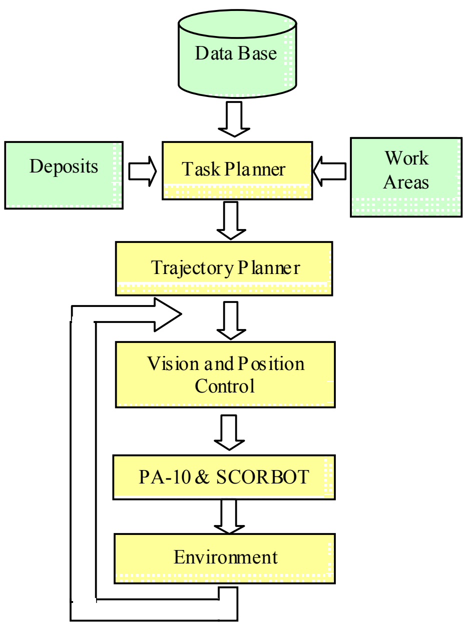

Fig. 8. Process' Architecture.

3.1 The Task Planner.

The method proposed in this paper develops the Task Planner which is based on a hierarchical graph model proposed in (Puente et al., 2001; Torres et al., 2003). Here a product representation technique is set out. Using this technique a graph model is obtained. This graph contains all the actions to disassemble a product (Fig. 9). In the application example, this product corresponds with a computer (PC). This graph model gives useful information, like the precedence and the parallelism between tasks. Crossing this graph the rules that specify the sequence to disassemble a product is obtained.

In this case the rules to disassemble a PC are:

- Rule 1= Remove Screw → Separate external case
- Rule 2 = Remove Screw → Separate Card 1
- Rule 2 = Remove Screw → Separate Card 2
- Rule 3 = Remove Screw → Separate CD Drive
- Rule 4 = Remove Screw → Separate energy source

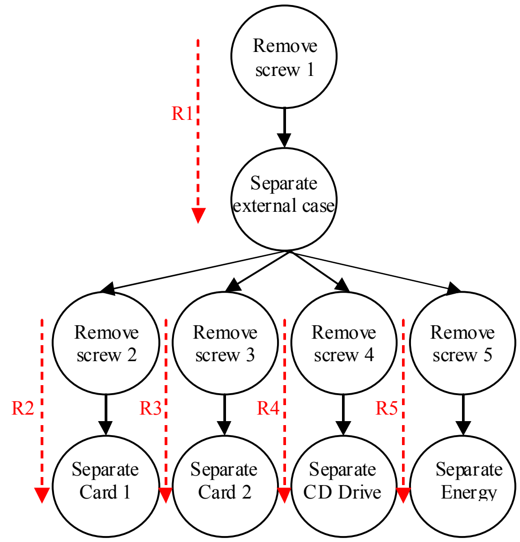

Fig. 9. Graph Model to disassemble a PC.

The Task Planner proposed in this paper distribute these tasks between manipulators to obtain a cooperative and a successfully disassemble of a product. This one uses these rules to construct a decision tree that allows the system to establish a right sequence to carry out the different tasks that consist in the disassembly process of a product.

From the hierarchical graph the different rules are obtained. These rules are divided into actions **A**, for each action correspond a tool **T**, and each action is divided into sub-actions, if it is possible.

Inside a cooperative environment two different types of tasks are considered:

- Common Tasks: those where it is required two or more manipulators working simultaneously on the same object. For example in the disassembly of a PC the extraction of the CD player.

- Parallel Tasks: those in which each manipulator executes a different task; they need to share the same work-space however each robot engage in a different objective. For example in the disassembly of a PC, the extraction of a Card Slot.

To construct the decision trees and to model the system, the following sets are defined:

Number of Robots $=\left[R_1, R_2, ..., R_i, ..., R_j\right]$

Task's Type = $[Tc, Tp]$

where: *Tc:* Common Task.
Tp: Parallel Task.

Rules = Task = $[Ts_1, Ts_2, ..., Ts_m]$

each task is divide into actions.

Actions = $[A_1, A_2, ..., A_n]$

and each action is divided into sub-actions ⇒

$$A_1 = \left[A_{11}, A_{12}, ..., A_{1p}\right]$$
$$A_2 = \left[A_{21}, A_{22}, ..., A_{2q}\right]$$
$$\vdots$$
$$A_r = \left[A_{r1}, A_{r2}, ..., A_{rs}\right]$$

Beside two special actions are considered. These actions are:
- Tool change = *AChange*.
- Rotate the work-table = *ARotate.*

For each action exist a respective tool. In other words the same number of action as tools exist

Tools = $[T_1, T_2, ..., T_n]$

3.1.1 The Work Area.

When cooperative work is executing, it is very important to take into account the work areas of each manipulator and their respective intersection, in order to avoid collision between them and with the environment. A general diagram is shown in Fig. 10.

It is necessary to consider the layout of the *j* robots and the tool's availability in order to establish which robot is the most suitable to execute the first action A_1. To determine this robot, the decision trees shown in Fig. 11 and Fig. 12 are constructed each one for each type of task (*Tp* and *Tc* respectively).

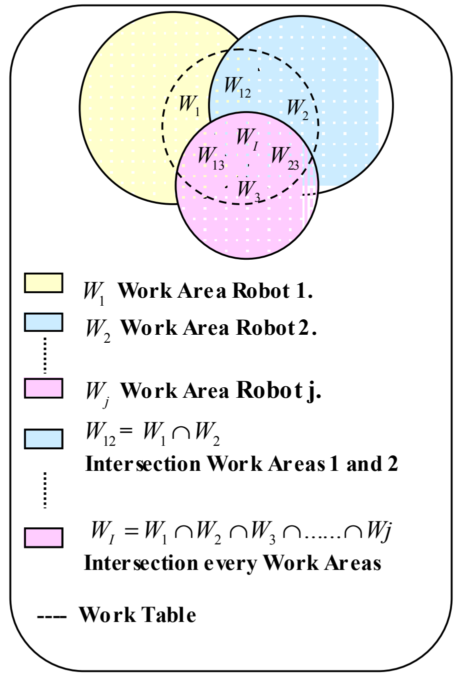

Fig. 10. Work Areas diagram.

3.1.2 The Decision Trees.

A decision tree algorithm based on the optimal path was developed. For each action there is an information gain assigned. Shown in Table 1

Table 1
Assigned Information Gain

Action	Gain.
Ask Robot.	*x*
ARotate.	*5x*
AChange.	*10x*

The gains are assigned according to the cost of each action. The Table 1 represents that the action rotating the table has a greater cost than asking for a robot, and the action of changing a tool is the most expensive because it requires more time to be executed. These costs are assigned according to the characteristics of each action. In this work time is the most important characteristic considered.

Several paths have the same minimum total cost, because it is assuming that each manipulator has similar characteristics. In that case any path is randomly chosen.

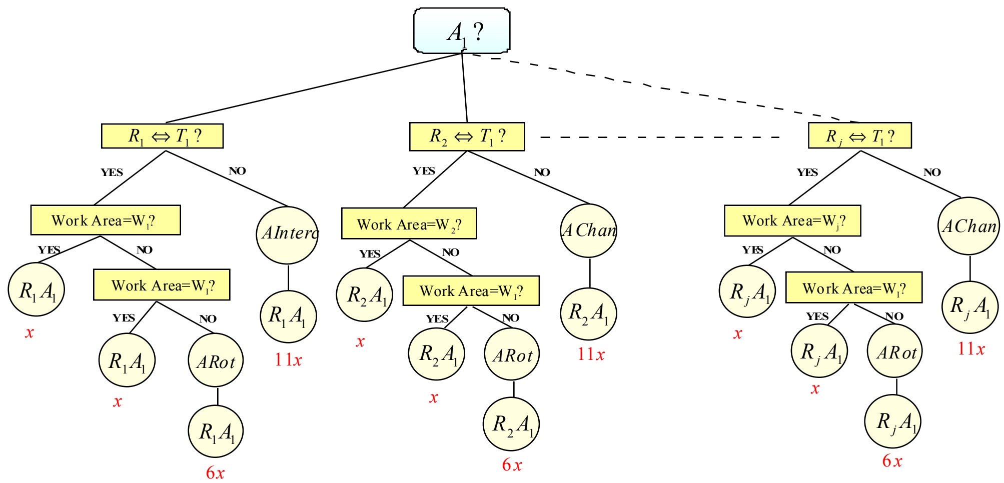

Fig. 11. Decision Tree, *Tp*

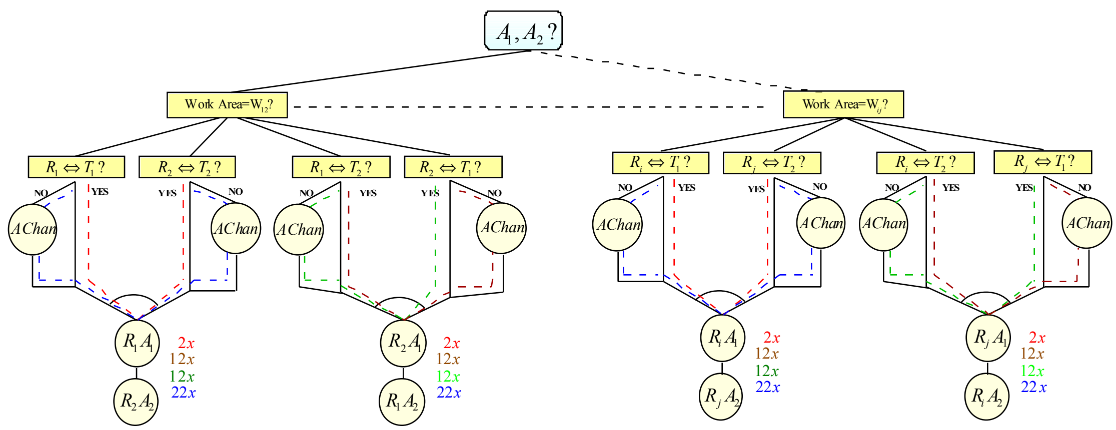

Fig. 12. Decision Tree, *Tc*.

In the Fig. 11 the decision tree is developed to determine which manipulator is the most suitable to execute the first action. In the case that the task is a parallel type (*Tp*), it can be observed that first it is asked which of the *j* manipulators is equipped with the tool that corresponds to do the first action. The table rotate according to the work area where the product to be disassembles is located. Depending on this information, the table's rotation and the tool's changes are determined. In this figure it is observed the total cost of choosing each path, following the path with least cost, the most suitable robot to execute the first action is obtained.

For common type tasks (*Tc*) the tree diagram of the Fig. 12 is constructed. Assuming that only two robots are required to realize this common task, (in a cell that counts with *j* manipulators) it must be asked if they are available and ready, equipped with the corresponding tool, to execute the first (A_1) and the second (A_2) action simultaneously. In this figure, it is observed that if the work area is the intersection between two robots: $W_{12} = W_1 \cap W_2$ or $W_{13} = W_1 \cap W_3$ or.. $W_{ij} = W_i \cap W_j$ then there will exists eight possible paths. Two paths corresponding with the minimum cost (*2x*), in which one robot (R_i) is equipped with tool one (H_1) to perform the first action (A_1), and the other robot (R_j) has the tool number two (H_2) in its end effectors, to execute the following action (A_2) or vice versa. Other possible paths occurs when one of the two robots needs a tool's change to realize the first or the second action. These paths have a greater cost (*12x*).

Finally the paths that have the greatest cost (*22x*) are those in which the two robots have to change their tools to carry out the first and the second actions. If the task to do this is a common type task, and it needs the intervention of every manipulator available in the work cell, the product to disassemble must be located in the intersection of every work area

($W_I = W_1 \cap W_2 \cap W_2 \cap ...... \cap Wj$), to allow every robot gain access to the product in question. It is observed that the action for a tool's change is the most expensive, therefore is important to try to find an alternative path to carry out the different actions.

To determine what manipulator is the most suitable to execute the rest of the action, decision trees like Fig. 11 or Fig. 12 (depending of the type task) have been constructed, until the last action have been assigned.

Once the assignation of every action with their correspondent manipulator is done, the construction of the decision tree to plan the cooperative tasks is done. In general for a working cell with j robots, and n tools available, the obtained decision tree is shown in Fig. 13.

In Fig. 13 represents the general criteria to construct the scheme that allows the system to plan the different tasks. There are some actions (A_{1p} - A_{21}) that can be divided into sub-actions in order to obtain more parallelism. These bring the system a minimization of the disassembly's time. It involves an important advantage to the industrial application. Other actions can not be executed in a parallel way because of the precedence between them. For example, action A_n can not be started until the previous action has finished.

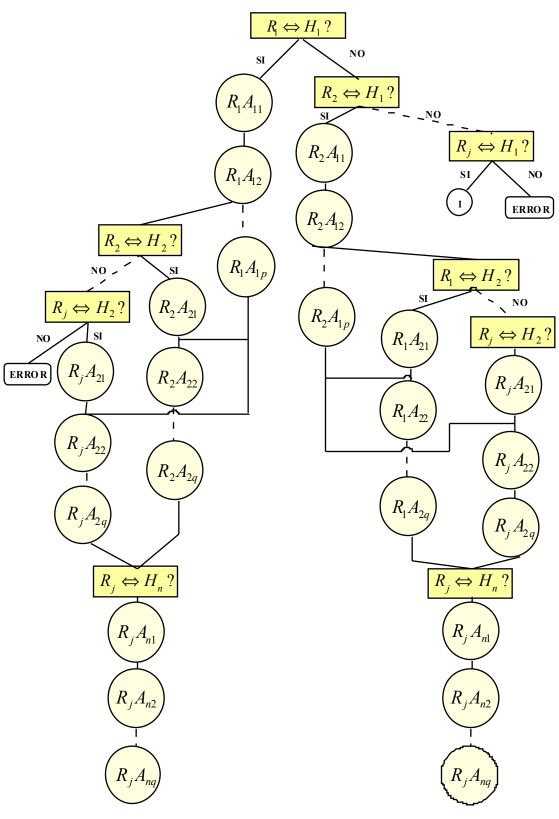

Fig. 13. Task Planner, decision tree.

4. Application Example

The system architecture introduces two manipulators working together because of the advantages that are present to solve certain problems. An example of this advantage is observed when a CD player is disassembled. With a single manipulator the CD player would fall down when all the screws to separate the CD of the main box are removed. Including a second manipulator, a simple solution to this kind of problem, is obtained. Modelling the system for Rule 3:

Rule 3 = Remove the CD Player:

Remove the screws $\rightarrow$ Separate the CD

$\Rightarrow$ A_1 = Unsecrew (Screwdriver)

A_2 = Separate CD (Gripper)

It is important to take into account the initial condition of the work cell, which is shown in Fig. 14 First to determine which robots perform the first A_1 and the second A_2 action, the decision tree of Fig. 15 is constructed.

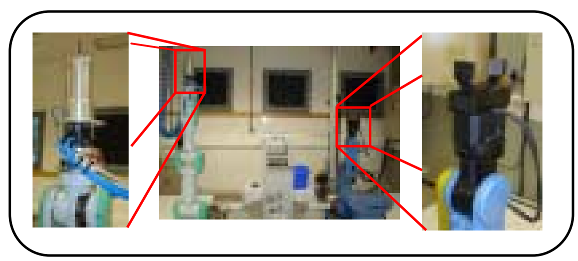

Fig. 14. Initial conditions of the work cell.

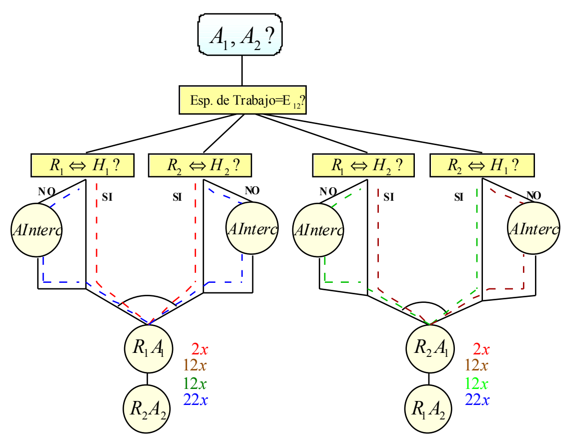

Fig. 15. Task Planner, Decision Tree.

Like the initial position of the system shown in Fig. 14, following the scheme of the Fig. 15 is determined that the robot R_1, PA-10, carries out the first action that corresponds to the unscrew. And the R_2, SCORBOT, execute the second action A_2, separate the CD Player from the main box and deposit.

Then, the first action A_1, is sub-divided in nine actions:

$$A_1 = A_{11} \rightarrow A_{12} \rightarrow A_{13} \rightarrow A_{14} \rightarrow A_{15}$$
$$\rightarrow A_{16} \rightarrow A_{17} \rightarrow A_{18} \rightarrow A_{19}$$

$$\begin{aligned} where: A_{11} &= Unscrew\ Screw\ 1. \\ A_{12} &= Deposit\ Screw\ 1. \\ A_{13} &= Unscrew\ Screw\ 2. \\ A_{14} &= Deposit\ Screw\ 2. \\ A_{15} &= Rotate\ table\ 180^{\circ}. \\ A_{16} &= Unscrew\ Screw\ 3. \\ A_{17} &= Deposit\ Screw\ 3. \\ A_{18} &= Unscrew\ Screw\ 4. \\ A_{19} &= Deposit\ Screw\ 4. \end{aligned}$$

and A_2 is sub-divided in two actions:

$$A_2 = A_{21} \rightarrow A_{22}$$

$$\begin{aligned} where: A_{21} &= Pick\ \text{CD}. \\ A_{22} &= Deposit\ \text{CD}. \end{aligned}$$

The decision tree is constructed and shown in Fig. 16. Previously in Fig. 15 there was the development of the scheme to determine the assignation of each action. But in order to provide the system more reliability, the tool availability is cheeked in each moment.

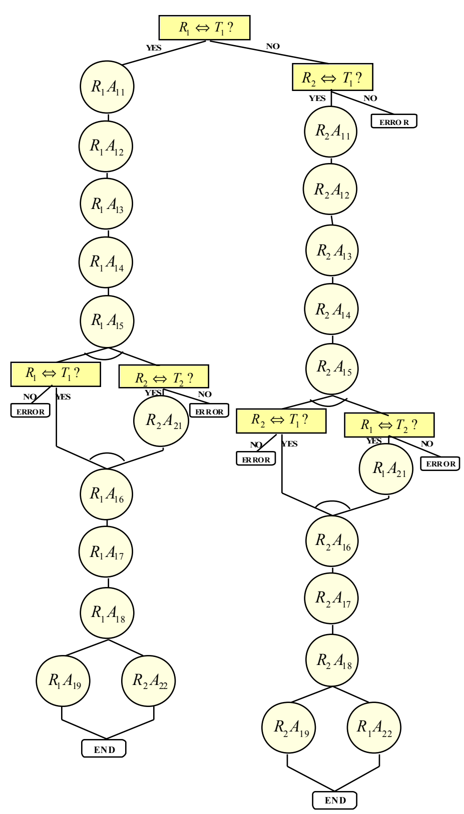

Fig 16. Decision Tree, Rule 4.

Fig. 17 shows the real sequence of the two cooperative manipulators executing this common task. It is observed that the corresponding robot doing the first action to unscrew and deposit the two first screw ($A_{11}, A_{12}, A_{13}, A_{14}$, Fig. 17.a and Fig 17.b), then the work table rotate 180^o (A_{15}, Fig. 17.c), to allow the robot gain access to the rest of the screw. The robot assigned holds the CD player (A_{21}, Fig. 17. d) to avoid its fall when the rest of the screws have been removed (A_{16}, A_{17}, A_{18}). While the last screw is deposited (A_{19}), the CD is removed and then deposited (A_{22}) to finish the task (Fig. 17.e and Fig. 17.f).

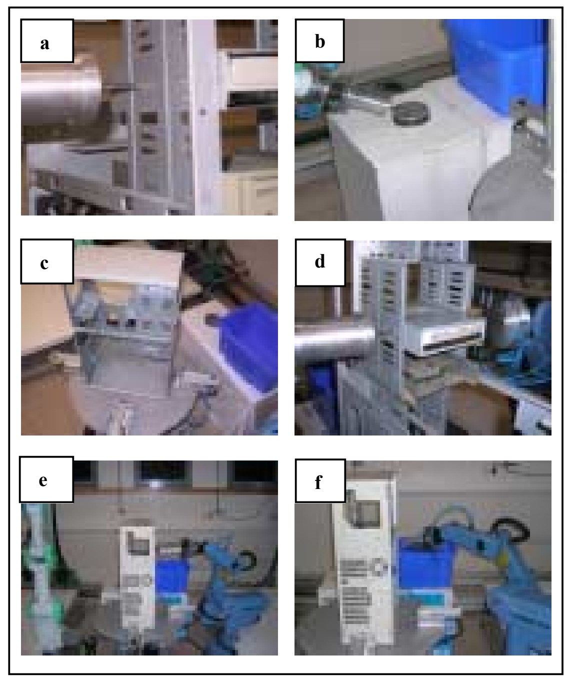

Fig. 17: Disassembly real sequence.

5. Conclusions

Including cooperative control techniques to work in an automatic disassembly system give many advantages. The experimental results shown, working in a coordinated way allows the system to reduce the total disassembling time. This implies important improvements to industrial applications that include cooperative work in their disassembling process. Also working in a cooperative way to disassembly implies saving time and a consequent saving of money, that otherwise would take many companies to use these techniques. Taking advantages of the disassembly process while they are taking care of the environment, reusing and recycling materials.

Also in this article a cooperative Task Planner is presented. In order to obtain a generic algorithm that permits to work with *j* robotics manipulators. It is important to highlight the Task Planner proposed in this article gives a simple solution to a complicated problem that is sharing the same working area. The task planner proposed here allows the systems to avoid collisions between robots, because each one has assigned a specific task in a specific time.

A future proposal is obtain a task planner to work in a cooperative way between robots and humans, in the same disassemble cell. This could become a promising way to reach greater productivity for the industry, since robots can become intelligent assistants that collaborate with humans.

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