TASK PLANNER FOR A COOPERATIVE DISASSEMBLY ROBOTIC SYSTEM

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Abstract: this paper proposes a task planner for a disassembly robotic system. In which two or more manipulators work in a cooperative way to solve the disassemble tasks. This method is based on the construction of decision trees schemes that allows the system to determine a general method to planner all the disassembly actions in a cooperative and coordinated way. In a cell composed for j robotic manipulators. *Copyright © 2006 IFAC*

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1. INTRODUCTION

Environmental considerations in industrial activities have been growing continuously, thus the government proposes regulation on these aspects in different industrial areas. In 1998, the European Community introduced a report that contains regulation and norms to treat waste production in electrical and electronics devices. These regulation is still in effect (Waste Electrical and Electronic Equipment; Directive 2003/108/EC). These norms have implication in the development of the products. The environmental considerations must be taken into account in all the cycle of production. They must be involved in all the product life period, 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.

Including two or more robotic manipulators working in a cooperative way increases the performance of the disassembly system because 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 unit with abilities and capacities greater than the sum of its parts (Navarro-Serment, *et al.*, 2002)

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 (Adams and Skubic, 2005). In this article only the first way is considered: two or more manipulators working together in a coordinated way. The second option, cooperation between human and robot is considered for future works.

This article is organized as follows: after the introduction in Section 2 the working cell is described. Then, in Section 3, the system architecture is shown, and the task planner is developed. In Section 4 an application example is explained. And finally conclusions and future works are presented.

2. WORKING CELL

The automatic disassembly robotic cell is composed of the elements described in Fig. 1:

- Robotic Manipulator Mitsubishi® PA-10.

Fig. 1. Work Cell.

- Robotic Manipulator Intelitek® SCORBOT.
- Work table.
- Deposits.
- Tool Changer.

The work table is a rotating table (360°) equipped with four pneumatic pistons which hold the product to be disassembled, in this example this product is a computer. The work table increases the flexibility of the system because it allows the different manipulators to gain access to areas which are outside of its workspace. In addition, the work table allows 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 be executed.

3. PROCESS' ARCHITECTURE

Cooperative disassembly process' architecture used is shown in Fig. 2. In this scheme the Data Base contains a list of tasks for disassemble a product. The Task Planner determines the task that corresponds to each manipulator and their precise moment. Then a position and a vision control are applied 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 all tasks that need a 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 Trajectory and the Task Planner are on charge to obtain a free shocks 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 and try to reduce the tools changes and other more consideration in order to achieve decreasing times in product's disassembled.

Fig. 2. Process' Architecture.

3.1 The Task Planner.

The method proposed in this paper develops the Task Planner which is based on the relational model graph proposed in (Torres, *et al.*, 2003). Here a products representation technique is set out. Using this technique a graph model is obtained. This graph contains all the actions to disassemble a product (Fig. 3). In the application example, this product corresponds with a computer (PC). This graph model gives much useful information, like the precedence and the parallelism between tasks. Crossing this graph the rules that specify the sequence to disassemble a product are 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 3 = Remove Screw ➔ Separate Card 2
- Rule 4 = Remove Screw ➔ Separate CDdrive
- Rule 5 = Remove Screw ➔ Separate energy source.

The Task Planner proposed in this paper allocates these tasks between manipulators to obtain a cooperative and a successfully disassembly 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.

Fig. 3. Directed Graph for disassembling a PC.

Of the relational graph obtains the different rules. These rules are divided into actions **A**, for each action corresponds a tool **T**, and each action is divided in sub-action if it is possible.

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

- Common Tasks: are those in which is required two or more manipulators working in the same object. For example in the disassembly of a PC the extraction of the CD player.
- Parallel Tasks: those in which each manipulator do a specific task, it is required the presence of only one manipulator. Can be executed in simultaneous way. 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:

$$\text{Number of Robots} = [R_1, R_2, \dots, R_i, \dots, R_j]$$

$$\text{Task's Type} = [Tc, Tp]$$

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

$$\text{Rules} = \text{Task} = [Ts_1, Ts_2, \dots, Ts_m]$$

each task is divided in actions.

$$\text{Actions} = [A_1, A_2, \dots, A_n]$$

and each action is divided into sub-actions

$$\Rightarrow A_1 = [A_{11}, A_{12}, \dots, A_{1p}]$$

$$A_2 = [A_{21}, A_{22}, \dots, A_{2q}]$$

$$\vdots$$

$$A_r = [A_{r1}, A_{r2}, \dots, A_{rs}]$$

Beside two special actions are considered. These actions are:

- Tool change = *AChange*.
- Rotate the work-table = *ARotate*.

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

$$\text{Tools} = [T_1, T_2, \dots, T_n]$$

3.1.1 The Work Area.

When cooperative work is executed, 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. 4.

Fig. 4. Work Areas diagram.

It is necessary to consider the layout of the *j* robots and the tool's availability in order to establish what robot is the most suitable to execute the first action *A*₁. The decision trees shown in Fig. 5 and Fig. 6 are constructed each one for each task type (*Tp* and *Tc* respectively) to determine this robot.

3.1.2 The Decision Trees.

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

Table 1 Assigned Information Gain

Action	Gain.
Ask Robot.	<i>x</i>
<i>ARotate</i> .	<i>5x</i>
<i>AChange</i> .	<i>10x</i>

The gain is empirically assigned to the cost of each action. The Table 1 represents that the action of 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 done. These costs are assigned according to the characteristics of each action. Time is the most important characteristic in this application.

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

In the Fig. 5 the decision tree is developed to determine what manipulator is the most suitable to execute the first action. In case that the task is parallel type (Tp), it can be observed that first is asked which of the j manipulators is equipped with the tool that corresponds to execute the first action. The table rotation is according to the work area where the product to be disassembled is put. Depending of this information, the table's rotation and the tool's changes are determined.

In Fig. 5 it is possible to observe the total cost of choosing each path. Following the least cost path, the most suitable robot to execute the first action is obtained.

For common type tasks (Tc) the tree diagram of the Fig. 6 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 is observed that if the work area is the intersection between two robots:

$$W_{12} = W_1 \cap W_2 \text{ or } W_{13} = W_1 \cap W_3 \text{ or.. } W_{ij} = W_i \cap W_j$$

then, eight possible paths exist. 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 effector, to execute the following action (A_2) or vice versa.

Fig. 5. Decision Tree, Tp .

Fig. 6. Decision Tree, Tc .

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 is a common type task, and it needs the intervention of every manipulator available in the work cell, the product to disassemble must be in the intersection of every work areas ($W_I = W_1 \cap W_2 \cap W_2 \cap \dots \cap W_j$), to allow every robots have access the product in question. It is observed that the action for a tool's change is the most expensive, because it is important to try to find an alternative path to realize the different actions.

To determine what manipulator is the most suitable to realize the rest of the action, decision trees like Fig. 5 or Fig. 6 (depending of the type task) have been constructed, until the last action has been assigned. Once the assignation of every actions with their correspondent manipulator is done, the construction of the decision tree to planner the cooperative tasks is proceeded. In general for a working cell with j robots, and n tools available, the decision tree is shown in Fig. 7.

Fig. 7. Task Planner, Decision Tree.

In Fig. 7 it is represented the general criteria to construct the scheme that allows the system to planner the different tasks. Exist some actions (A_{1p} - A_{21}) that can be divided into sub-actions in order to obtain more parallelism. These will bring the system a minimization of the disassembly's time. It involves an important advantage to 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.

3 APPLICATION EXAMPLE

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

Rule 4 = Remove the CD Player:

Remove the screws $\rightarrow$ Separate the CD

$\Rightarrow A_1 = \text{Unsecrew (Screwdriver)}$

$A_2 = \text{Separate CD (Clamp)}$

A_1 is sub-divided in nine actions:

$A_1 = A_{11} \rightarrow A_{12} \rightarrow A_{13} \rightarrow A_{14} \rightarrow$

$A_{15} \rightarrow A_{16} \rightarrow A_{17} \rightarrow A_{18} \rightarrow A_{19}$

where : $A_{11} = \text{Unsecrew Screw 1.}$

$A_{12} = \text{Deposit Screw 1.}$

$A_{13} = \text{Unsecrew Screw 2.}$

$A_{14} = \text{Deposit Screw 2.}$

$A_{15} = \text{Rotate table } 180^\circ.$

$A_{16} = \text{Unsecrew Screw 3.}$

$A_{17} = \text{Deposit Screw 3.}$

$A_{18} = \text{Unsecrew Screw 4.}$

$A_{19} = \text{Deposit Screw 4.}$

A_2 is sub-divided in two actions:

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

where : $A_{21} = \text{Pick CD.}$

$A_{22} = \text{Deposit CD.}$

The decision tree is constructed and shown in Fig. 8. The tool availability is checked in each moment to do the system more reliable. Fig. 9 shows the real sequence of the two cooperative manipulators executing this task.

Fig 8. Decision Tree, Rule 4.

In Fig. 8 and in Fig 9 is observed the corresponding robot doing the first action to unscrew and deposit the two first screws ($A_{11}, A_{12}, A_{13}, A_{14}$, Fig. 9.a and Fig 9.b), then the work table rotate 180° (A_{15} , Fig. 9.c), to allow the robot to gain access to the rest of the screw. The robot assigned holds the CD player (A_{21} , Fig. 9. 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. 9.e and Fig. 9.f).

4 CONCLUSION

In this paper a cooperative Task Planner is presented, in order to obtain a generic algorithm that permit to work with j robotic manipulators. It is important to highlight the Task Planner proposed in this paper gives a simple solution to a complicated problem that is sharing the same working area.

This could become in a promising way to reach greater productivity at the industry, since robots can become intelligent assistants that collaborate with humans. Working in a cooperative way to disassemble, implies saving time and a consequent saving of money that would take many companies to use cooperative disassembly.

Fig. 9: Disassembly real sequence.

A future proposal is to obtain a task planner to work in a cooperative way between robots and humans, in the same disassembly cell.

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