Task Planning Algorithm in Hybrid Assembly/Disassembly Process

A. Radaschin*, A. Voda*,*, E. Minca**,*, A. Filipescu***

**Dep. of Automation and Elec. Eng., "Dunarea de Jos" University of Galati, Romania*
(e-mail: radaschinadrian@yahoo.com; alina.voda@ugal.ro;
eugenia.minca@gmail.com; adrian.filipescu@ugal.ro;)
***Dep. of Automation, Computer Science and Elec. Eng., "Valahia" University of Targoviste, Romania*
****GIPSA-lab, University Joseph Fourier Grenoble 1/CNRS, UMR 5216, B.P. 46, F-38402,*
St. Martin d'Heres, France, (e-mail:alina.voda@gipsa-lab.gernoble-inp.fr)

Abstract: A model of a mechatronic assembly/disassembly line served by a robotic manipulator mounted on mobile platform, in order to perform disassembly, is proposed in this paper. The model is a hybrid one in which the mechatroninc line is the discrete system and the wheeled mobile robot (WMR) together with the robotic manipulator (RM) is considered the continuous system. The mobile platform is used only in disassembling operations in order to transport the components from the disassembling locations to the storage locations. The cycle performed by the WMR equipped with RM is the continuous part of the hybrid system. Therefore, a Hybrid Petri Net (HPN) is used in modeling and control. This hybrid system takes into consideration the distribution of the necessary tasks to perform the hybrid disassembly of a component, using robot synchronization with flexible line process. The ultimate goal is to make completely reversible the assembly line, that is to execute full disassembly.

Keywords: mechatronic line; wheeled mobile robot; robotic manipulator; assembly/disassembly.

1. INTRODUCTION

Hybrid systems are currently attracting a lot of attention. The assembly/disassembly plans are composed of parts or subassemblies that are put together (Albus and Meystel, 1998). The integration of design and manufacturing concept essentially is developing plans and procedures that involved in manufacturing a new product. It is envisioned that this type of planning can be done during the design phase so that it may influence the actual product design. Research topics that are particularly relevant include assembly/disassembly representations, work-cell planning, sequence planning, etc.

Off-line task planning is a large area encompassing a diverse set of planning methodologies that are capable of production a detailed operation plan, including planning sensory action, planning manipulator action, planning the trajectory of mobile robot (Gasparetto et al., 2007) rough motion planning, fine motion planning or other planning (Feng and Song, 2008). On-line planning addresses execution and reaction issues such as how to develop plans on-line, how to execute and monitor a plan that was developed off-line, and how to react to various situations that arise during plan execution (Ganget et al., 2005). These issues can be further classified into: plan monitoring, reactive scheduling and behaviour-based action. Traditionally, a product assembly plan is generated by experienced production engineers. The assembly/disassembly planning process involves more complex requirements such as geometric relations, performance measurement and evaluation, resource scheduling, kinematics control, and system planning. It is a difficult task for a complex assembly/disassembly in a concurrent and flexible manufacturing environment. The combination of these factors makes real assembly/disassembly planning more difficult and needs extensive experience and knowledge from the designer and production engineer. Up to now, numerous techniques in task planning, such as use binary matrix, directed graph, establishment condition, precedence relationships, AND/OR graph (Cao and Sanderson, 1998), have been proposed for generation and representation, reasoning, and search of assembly plans in designing intelligent and efficient assembly/disassembly operation, where operators (robot or human) autonomously perform a given task based on certain designated, stored or sensed information. However, in a mobile robotic system with manipulator, a planning strategy oriented to the characteristics of the system is often more effective than techniques derived from domain independent methods. Conventional representation of a system model without constraints may result in a huge search space for feasible plans. A comprehensive knowledge-based approach to disassembly task planning is required, which thoroughly considers the complex interaction and domain knowledge subjected to technical and economical constraints (David and Alla, 2010). The development of knowledge-based on HPN model integrated with a sequence generation algorithm was successfully applied to the modelling and planning of a flexible disassembly process and system at a high level.

However, among autonomous mobile robot with manipulator disassembly planning method and task level planning greatly improves the efficiency of entire process and reduce the cost of disassembly of product. Task specification in low-level

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task planning is in the form of changing models or operation sequences (Hiraishi, 1999). This research is based of some procedures of assembly/disassembly tasks of as mentioned above. In this approach a detailed operations plan could be automatically synthesized and simulated with HPN model which give a high-level description of product to be disassembled. In this paper, the concepts of assembly/disassembly tasks are illustrated in HPN model which respect both aspects: the discrete approach for the elementary tasks and the continuous approach for continuous movement of the robot serving the disassembly tasks. The system of reversible assembly/disassembly line served by robotic manipulators mounted on mobile platforms has a dynamics determined both, by events (events supplied by the control sequences of the automation system) and by the interaction with the WMR, which represent the continuous time component of the system. The considered system is a hybrid one and requires specialized tools for modelling. The hybrid model is elaborated using the dedicated modelling tool, HPN.

2. MECHATRONIC ASEMBLY/DISASSEMBLY LINE

In Fig. 1, the architecture of the mobile robot with manipulator is shown. It is composed of one an autonomous mobile robot, with two independent drive wheels, and an additional caster wheel. The robot has its own odometric system, and an on-board embedded microcontroller is able to read the position information and to send it over a radio communication link, according to a specific protocol and send the data to PLC on manufacturing flexible line. The robot is Pioneer P3-DX, manufactured by Mobile Robots and is equipped with manipulator with 3 articulations and one gripper paddles. The assembly/disassembly manufacturing flexible line is equipped with SIEMENS Simatic S7-300 PLC (Programmable Logic Controller), with 5 distributed modules connected by Profibus DP network for every station.

Flexible line includes five individual workstations with different tasks, carrying and transporting, pneumatic workstations, conveyor belt, sorting unit, test station and warehouse. The work part carrier is used for carrying and transporting the four-piece work part on conveyor belt system. The work part carrier is equipped with 6-Bit identification which provides large number of possible codes, read out by inductive sensors. The four-piece work part enable workflow model such as assemblies, testing, sorting, storage and disassemblies.

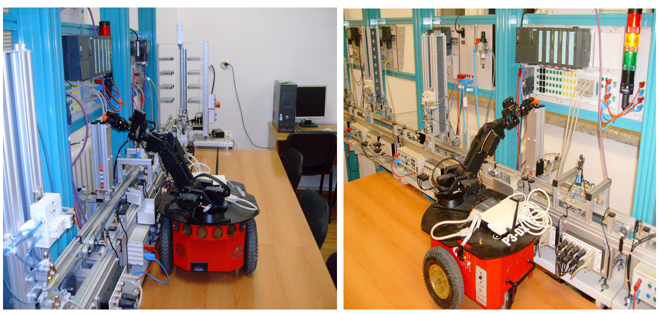

Fig. 1. Assembly/disassembly line served by WMR with RM.

3. ASSEMBLY/DISASSEMBLY PROCESS DESCRIPTION

Before a hybrid disassembly control sequence can be automatically generated, knowledge about the product, its components and their actual condition is needed. For each of the product’s components, a decision has to be made whether to disassemble that specific component. The disassembly level depends on especially the actual condition of a component. For the hybrid disassembly control sequence generation, the following aspects are of relevance:

As different products are allowed to arrive for disassembly all the time, a unique identification of the product to be disassembled is needed. In the case of plastic cylinder component (Fig. 2), the simple identification on product level is sufficient as a database may contain a detailed description of the product and its components;

When the product is unique or when parts of the product have been changed plastic or metal component in our case, more detailed information about the product and its components beyond the simple identification is needed.

The product components are (Fig. 2): work part carrier (base platform) (1), body (2), cover (3), metal cylinder (4) and plastic cylinder (5).

For disassembly operation, the configuration of the product’s components is needed. This includes position and orientation of components and the material it is made, plastic or metal, elements that are relevant for activation the hybrid disassembly operation. Here, disassembly precedence graphs and information about the components like needed disassembly tools are important for hybrid disassembly control sequence generation.

4. DISASSEMBLY TASK PLANNING

A robotic disassembly system consists of many different kind of component such as mobile robot, flexible line, sensors, handling mechanism, and parts. Different task may be assigned to and implemented by the system. All devices must be coordinated to ensure successful completion of a task goal through a sequence of feasible operations. The objective of task sequence planning for an disassembly system is to efficiently represent all feasible and complete task sequences with correct precedence relations and to able to choose among them.

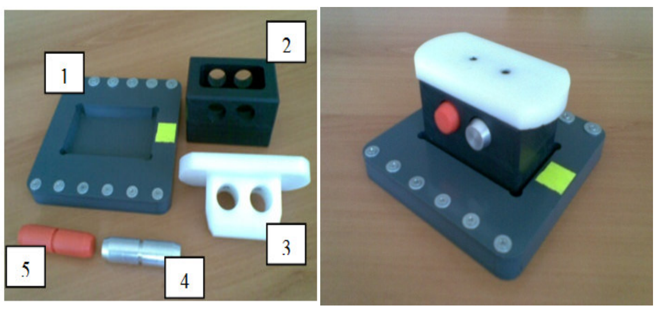

Fig. 2. Components and the assembled product.

4.1 Disassembly task analysis

Based on the characteristics of objects, two types of basic high-level operations are defined: disassembling and internal state transiting. The disassembly operation can be decomposed into a sequence of elementary tasks coupled in parallel with movements of pick-up/dropping /positioning of the robot. The assembly operation can by decompose into a sequence of elementary assembly tasks coupled in parallel with positioning tasks of work-piece along conveyor.

Suppose that an disassembly system consist of n components, $\{C_1,\ C_2,\ \ldots,\ C_n\}$, where C_i represents the i-th component. $s(C_i)$ is used to represent the state of component C_i at a given time, assuming a discrete time representation. Each component may occupy a fixed number, N_i, of feasible state. Define j and k predicate logic relationships for the initial and goal part structure respectively. The initial part structure may be represented by, $S_I = \{L_i(A^*) | i = 1,2,\ldots, j,\ A^* \in A\}$ and the goal part structure by, $S_G = \{L_i(A^*) | i = 1,2,\ldots, j,\ A^* \in A\}$ where $L_i(A^*)$ is a predicate clause, and the element A^* satisfied the relation L_i. Therefore, $S = S_I + S_G$ comprises the input of the assembly system. The states of the object and various kinds of operations can be determined with the function and characteristics of the disassembly. The disassembly task can be modelled based on the definition of specific types of state transitions. During the execution of operations of assembly/disassembly system the system states change with each performing elementary actions:

$$S_j^* = \left(s_j(C_{p1})\quad s_j(C_{p2})\quad \ldots\quad s_j(C_{pr})\right) \tag{1}$$

$$\begin{aligned} S_j^* &= \{s_j(C_{p1}), s_j(C_{p2}),\ldots, s_j(C_{pr})\} \\ &\subseteq \{s_j(C_1), s_j(C_2),\ldots, s_j(C_r)\} \end{aligned} \tag{2}$$

There are generally two kinds of task or operations, that is, disassembly and internal state transition (IST). The disassembly operation refers to when an assembly or a subassembly s separated into a set of components, and can be described as:

$$D(\{C_{j1}, C_{j2},\ldots, C_{jr}\}) = (\{O_{j1}, O_{j2},\ldots, O_{jn}\}) \tag{3}$$

where,

$$O_{jk} = \{C_1^{jk}, C_2^{jk},\ldots, C_{nk}^{jk}\} \tag{4}$$

$$O_{jk} \subseteq \{C_{j1}, C_{j2},\ldots, C_{jr}\}, 1 \le k \le l \tag{5}$$

and

$$O_{jk1} \cap O_{jk2} = \varnothing, 1 \le \{k_1, k_2\} \le l \tag{6}$$

The internal state transition refers to when internal state of a set of component is modified by changing the relative geometric relations of the components, or by modifying a property of a subset component and can be described as IST

$$(\{O_p\}) = (\{O_q\}) \tag{7}$$

where:

$$O_p = \{s(C_{i1}),\ldots, s(C_{is}), s(C_{is+1}),\ldots, s(C_{is+d}),\ldots, s(C_{ir})\}; \tag{8}$$

$$O_q = \{s^*(C_{i1}),\ldots, s^*(C_{is}), s^*(C_{is+1}),\ldots, s^*(C_{ir})\}; \tag{9}$$

$$O_p - O_q = \{s(C_{is}), s(C_{is+1}),\ldots, s(C_{is+d})\}; \tag{10}$$

$$O_p - O_q = \{s^*(C_{is}), s^*(C_{is+1}),\ldots, s^*(C_{is+d})\}; \tag{11}$$

In terms of planning tasks to the sequence, the system must follow intermediary states, ordered in a unique sequence that is determined by the dynamics of the state system vector. Vector representation status for the entire state system is:

$$S_j = \left(s_j(C_1), s_j(C_2),\ldots, s_j(C_n)\right)^T \tag{12}$$

where $0 \le j \le M$ and $M+1$ is the maximum number of all feasible state of system. As an illustration, Fig. 4 shows an example of how the mobile robot take the component and transport to the other station in a disassemble process.

4.2 Representation for disassembly task plans

The hybrid disassembly strategy is based on the hierarchical model proposed in (Kallrath, 2008) and (Radaschin et al., 2011) which uses a graph representation of the product in which the relations among components are expressed by means of arrows. Using that model, the task planner can determine the sequence of components that must be removed to achieve a specific sequence of tasks. If the target consists of the disassembly of a specific component, the task planner can provide the best sequence to reach the specific component (Moore et al. 2001). If the fully assembled product is rebut, the task planner provides the best sequence completely to disassemble the product (Fig.3). For disassembly operation, the configuration of the product's components is needed. Here, disassembly precedence graphs and information about the components like needed disassembly tools are important for hybrid disassembly control sequence generation. Based on the sequence of tasks provided by the task planner, a group of rules are determined. Each task can be divided in one or more rules to disassembly a specific component. The system of reversible assembly/disassembly line served by robotic manipulators mounted on mobile platforms has a dynamics determined both, by events (events supplied by the control sequences of the automation system) and by the interaction with the WMR, which represent the continuous time component of the system.

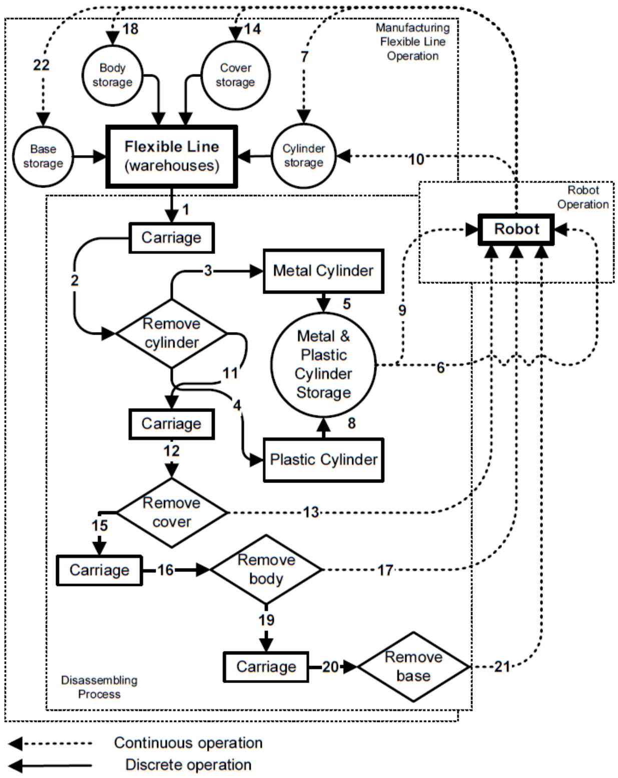

Fig.3. Disassembly task planning.

The considered system is a hybrid one and requires specialized tools for modelling (Rosell, 2002). The hybrid model is elaborated using the dedicated modeling tool, HPN (Ghomri and Alla, 2008):

$$HPN = (P, T, PRE, POST, h, S, V, M_0) \quad (13)$$

The disassembly operations, including disassembly locations, storage warehouses and WMR trajectories for transportation of the components are shown in Fig. 4, where:

$P = \{P^1, \; P^2, \; \ldots, \; P^n\}$ is a finite set of n places;

$$P = P_d \cup P_c \quad (14)$$

where $P_d = \{P_d^1, \; P_d^2, \; \ldots, \; P_d^n\}$ is the set of discrete places

$$P_c = P - P_d \quad (15)$$

is the set of continuous places;

$T = \{T^1, \; T^2, \; \ldots, \; T^m\}$ is a finite set of m transitions;

$$T = T_d \cup T_c \quad (16)$$

where $T_d = \left\{T_d^1, \; T_d^2, \; \ldots, \; T_d^{m'}\right\}$ is a set of m' discrete transitions;

$$T_c = T - T_d \quad (17)$$

is the set of continuous transitions;

$PRE : PxT \rightarrow N$ and $POST : PxT \rightarrow N$ are the backward and forward incidence mappings, respectively

$$\forall (P^i, \; T^j) \in P_d x T_c, PRE(P^i, \; T^j) = POST(P^i, \; T^j) \quad (18)$$

$h : P \cup T \rightarrow \{c, d\}$ defines the set of continuous nodes $(h(X) = c)$ and the set of discrete nodes $(h(X) = d)$;

$S : T_d \rightarrow Q_+$ associates to each d-transition, T_d^j, a duration, d_d^j;

$V : T_c \rightarrow R_+$ associates a maximal firing speed, v_c^j;

M_0 is the initial marking.

Combining the SED model of the analyzed system with the cyclic and continuous time of the robotic manipulator mounted on mobile platform, results a hybrid model, HPN, of the mechatronic assembly/disassembly line. Particularly, to the HPN of the flexible line served by mobile robot equipped with robotic manipulator, the following observations can be made:

Transition times d_d^j are made in relation to the operations of assembly/ disassembly and timings are the durations of an elementary operation assembly/disassembly. The values of timings are chosen a time unit;

Speeds, associated with transitions, are made in relation to the robot move sequences and duration of the robot complete cycle execution. To each robot move cycle, as a continuous time system, is stored in the warehouses, recovered by disassembly.

$P_{da}^i, \quad i = 1, \ldots, 24$ is an assembly discrete place;

$T_{da}^i, \quad i = 1, \ldots, 14$ is an assembly discrete transition;

$P_{dd}^i, \quad i = 1, \ldots, 25$ is a disassembly discrete place;

$T_{dd}^i, \quad i = 1, \ldots, 15$ is a disassembly discrete transition;

$P_{dr}^i, \quad i = 1, \ldots, 17$ is WMR with RM discrete place;

$P_{cr}^i, \quad i = 1, \ldots, 14$ is a WMR with RM continuous place;

$T_{dr}^i, \quad i = 1, \ldots, 21$ is a WMR with RM discrete transition;

$T_{cr}^i, \quad i = 1, \ldots, 10$ is a WMR with RM continuous transition.

The set of external events, $E_1^i, i = 1 \ldots 9$ and $E_2^i, i = 1 \ldots 8$ correspond to the signals provided by the sensors (stop line and disassembly operation for E_1; start line and picking up disassembled component for E_2).

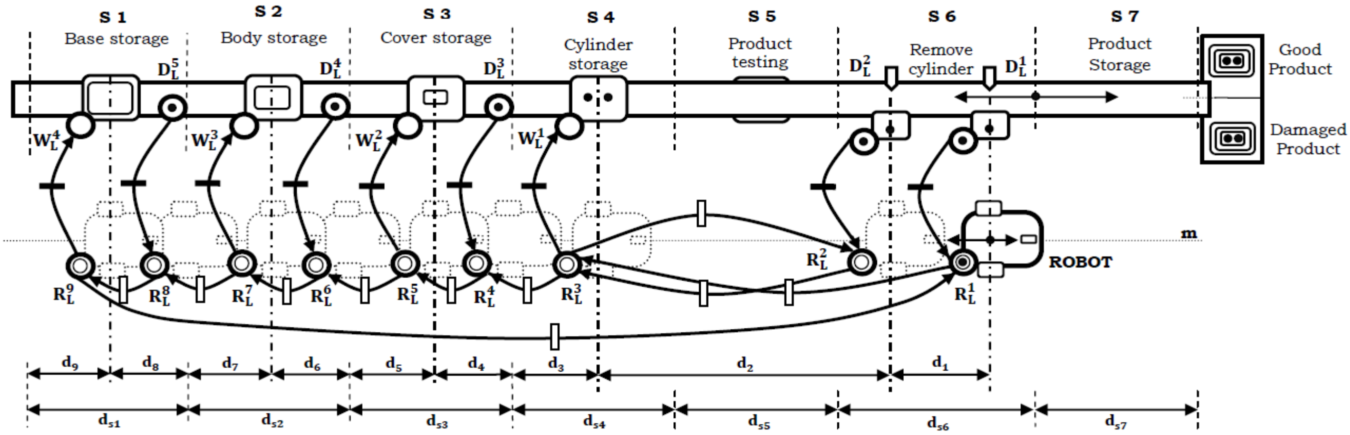

Fig. 4. Hybrid process: disassembly operations and WMR equipped with RM cycle.

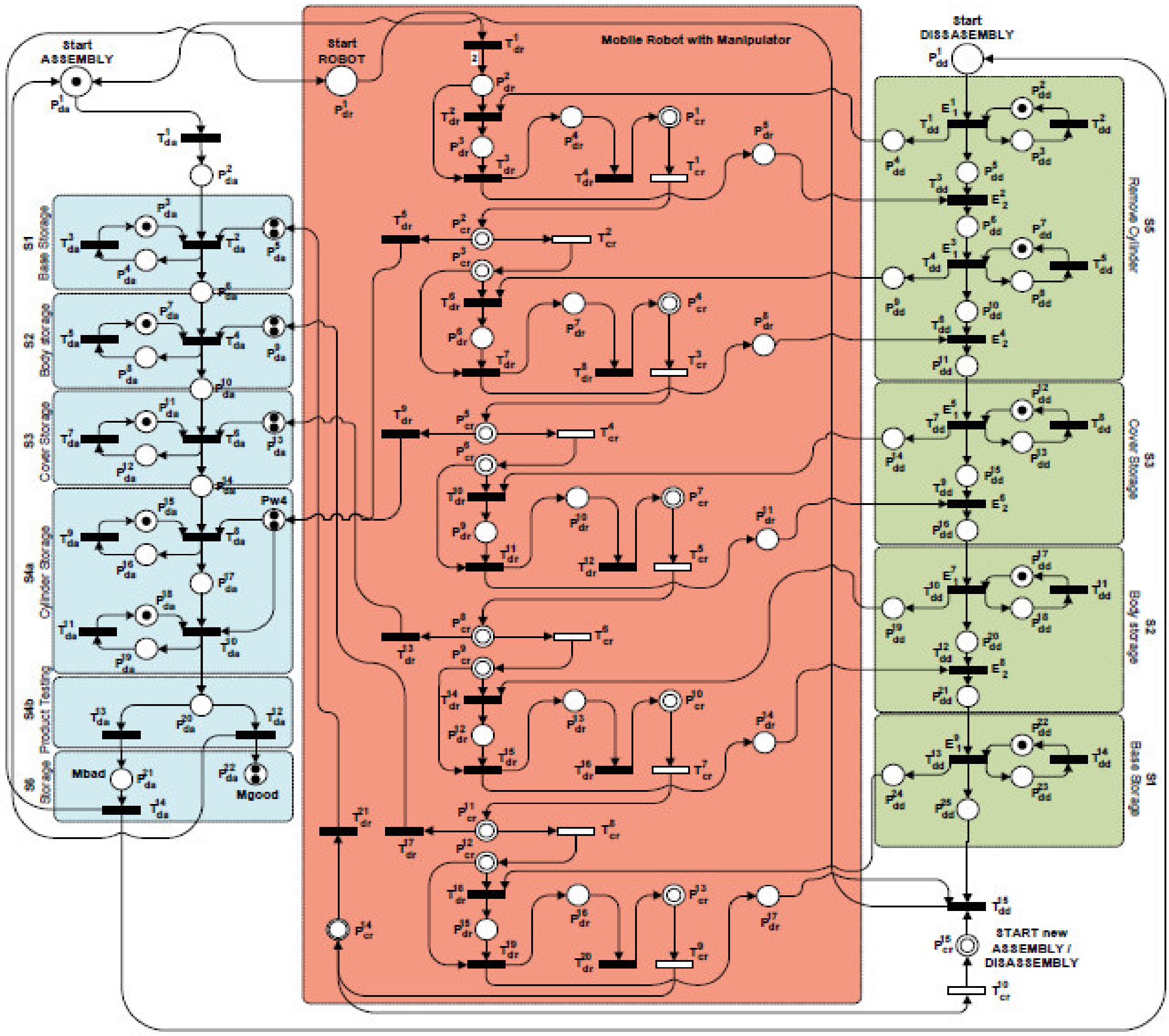

Fig. 5. HPN model of assembly/disassembly line served by WMR equipped with RM.

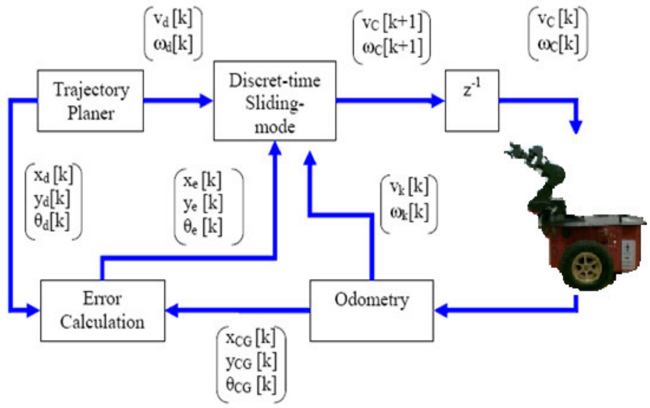

Fig. 6. WMR closed loop control.

5. WMR AND RM CONTROL

Sliding-mode control, in trajectory-tracking, based on kinematic model is used for controlling wheeled mobile robots Pioneer 3-DX (Fig. 6). Pioneer 3-DX is a mobile platform with two driving wheels and one rear wheel. The discrete-time sliding mode controller performs measurements and control signal applications at regular intervals of time and keeps the control signal constant between intervals.

The robotic manipulator, Pioneer 5-DOF Arm, mounted on mobile platform, is controlled in open loop by step by step motors located in each joint. The positioning of the gripper in order to grab the disassembled component and its storage in the warehouse has been made by a visual servoing system.

6. CONCLUSION

A HPN model for control of fully reversible assembly/disassembly manufacturing line is presented in this paper. The HPN model is conditioned on certain state transitions by external signals supplied by the sensors.

In order to perform disassembly, a robotic manipulator mounted on a mobile platform is used. Therefore, the assembly line becomes reversible, i.e. executes automated disassembly. A disassembly process is started when the final product, obtained by assembly, is damaged. The disassembled components are recovered and transported to storage locations, in order to be used again in assembly process.

The conception for the generation of disassembly control sequences has three characteristics, modularity, parameterization and adaptation, in order to meet the high flexibility required for a disassembly system. As a future research direction, different mobile robots equipped with robotic manipulator should be used in order to transport small, medium and heavy weights disassembled components.

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