Control of Automatic Robot with Guided Manipulator Integrated into Flexible Manufacturing System Using Hybrid Petri Nets*

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

***Abstract*—An analysis of the transportation and handling systems used in assembly/disassembly flexible manufacturing line (A/D-FML) is presented in this paper. Based on the analysis, an approach of the modeling and control a new class of automatic guided vehicles (AGV) is presented, the automatic robot with guided manipulator (ARGM). We propose to use Hybrid Petri Nets (HPN) for modeling the ARGM tasks and for implementing the control strategy of A/D-FML in order to make complete reversible the assembly line, i. e., in order to execute full disassembly.**

I. INTRODUCTION

Processing objects and their transfers between stations of A/D-FML in discrete event systems (DES) represent important problems of the system theory and engineering practice [1]. Their efficient solution need adequate models and control methods. The AGV systems represent subsystems of flexible manufacturing systems (FMS) and consisting of vehicles, robots or carts providing the transport of palettes, work pieces or other components, among FMS stations, or processing centers, or storage device [2],[3]. The transport system performance combined with the task planning scheduling determines the overall efficiency of FMS, but AGV tasks are limited [4]. A problem in practical applications is lack of adequate data required for the overall approach and relatively complicated calculations impossible to be executed in real-time conditions including failures of the system components. The consequence and a way out of the described difficulties is that designers of FMS proceed rather in heuristic ways and they solve the above mentioned problems separately and independently. After the FMS design suitable for the required product class, they usually propose a transportation structure matched and adapted to the particular processing requirements. Consequently, the transportation and manipulation flexibility is limited and the optimal guiding of AGV is restricted just for certain specific production tasks [5],[6]. Another restriction imposed to AGV systems, is the inability to manipulate objects, or parts components by requiring acquisition of FMS stations and transported to other plants or warehouses. Transport and handling operations must be performed with two separate systems, one or more AGV and one or more manipulators to be more efficient [7], but this is a very expensive method. In this paper a new class of AGV is presented, which provides transport and handling of components or objects along the FMS stations [8]. ARGM make two separate operations but presents as a single unit. The main advantage of ARGM from AGV systems is the handling operation with robotic manipulator.

The A/D-FML allows assembly or disassembly component of the products. Disassembly operations are more difficult because some components must carry out in different locations from storage locations where components for assembly are taken. The idea is to use ARGM that carries parts disassembled from the locations where disassembly operations are made, to the storage warehouses. In this paper, to make reversible assembly line, a single ARGM is used. The considered system is a hybrid one and requires specialized tools for modeling [9]. The hybrid model is elaborated using the dedicated modeling tool HPN. This hybrid system takes into consideration the distribution of the necessary tasks to perform the hybrid disassembly of a component, using ARGM synchronization with flexible line process.

This paper is organized as follows: in Section 2, the A/D-FML and ARGM are described; the assembly/disassembly process is presented in Section 3; in Section 4, the ARGM description and control structure are presented; in Section 5 the control policy is presented; HPN model associated to A/D-FML served by ARGM are presented in Section 6; Section 7 is reserved to ARGM control algorithm; some conclusions remarks and future research direction are presented in Section 8.

II. SYSTEM ARCHITECTURE DESCRIPTION

A. Assembly/Disassembly Manufacturing Flexible Line

In Fig. 1, the architecture of the system is shown. The 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. A/D-FML includes five individual workstations with different tasks, carrying and transporting, pneumatic workstations,

*This work was supported by UEFISCDI, project number PN-II-ID-PCE-2011-3-0641.

A. Voda is associate professor with the University Joseph Fourier Grenoble 1/CNRS, Grenoble Image Parole Signal Automatique (GIPSA-lab), UMR 5216, B.P. 46, F-38402 St Martin d'Heres, France (e-mail: alina.voda@gipsa-lab.grenoble-inp.fr) and is senior researcher with the Department of Automation and Electrical Engineering, "Dunarea de Jos" University of Galati, (e-mail: alina.voda@ugal.ro) and.

A. Radaschin is PhD student in Control Systems with the Department of Automation and Electrical Engineering, "Dunarea de Jos" University of Galati (e-mail: radaschinadrian@yahoo.com).

E. Minca is senior researcher with the Department of Automation and Electrical Engineering, "Dunarea de Jos" University of Galati, (e-mail: Eugenia.Minca@gmail.com) and is associate professor with the Department of Automation, Computer Science and Electrical Engineering, "Valahia" University of Targoviste, Unirii, 18, Romania.

A. Filipescu is professor with the Department of Automation and Electrical Engineering, "Dunarea de Jos" University of Galati, Domneasca 47, 800008, Galati, Romania (Corresponding author, Phone: +40724537594; fax: +40 236 460182, e-mail: adrian.filipescu@ugal.ro)..

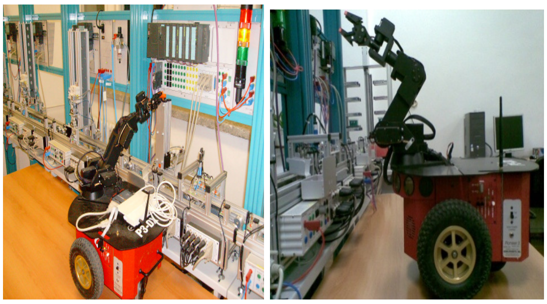

Figure 1. A/D-FML served by ARGM

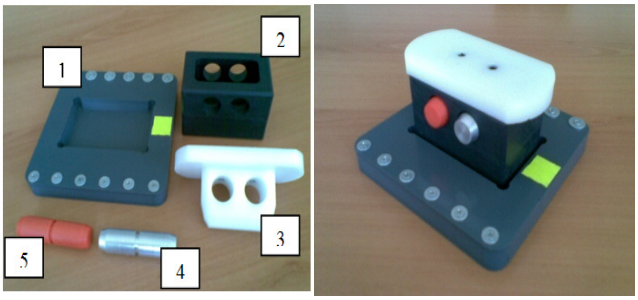

Figure 2. Product components to be assembled or disassembled

conveyor belt, sorting unit, test station and hay bay rack. 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.

B. *Composition of ARGM system*

The A/D-FML is served by ARGM, which is composed of two structures: a mobile robot with two independent drive wheels and an additional rear wheel. The mobile platform has its own odometric system. The on-board embedded microcontroller is able to read the position information and to send it over WI-FI communication link, according to TCP/IP protocol, and send the data to PLC on A/D-FML. The 2DW/1SW mobile platform used is Pioneer P3-DX, manufactured by Mobile Robots. The ARGM is equipped with the Pioneer 5-DOF Arm, having 3 joints and 1-DOF gripper as a second structures.

III. ASSEMBLY/DISASSEMBLY PROCESS DESCRIPTION

Before a product 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 especially depends on the actual condition of a component. For the disassembly control sequence generation, the following aspects are of relevance:

A. *Assembled product and its components*

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.

B. *Configuration of components*

For disassembly operation, the configuration of the product's components has to be presented. This includes position and orientation of components and the material it is made of (plastic or metal) elements that are relevant for activation the disassembly operation.

Here, disassembly precedence graphs and information about the components like needed disassembly tools are important for disassembly control sequence generation. When the product is unique or when parts of the product have been changed (plastic or metal component in our case), more detailed information is needed about the product and its components beyond the simple identification.

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

IV. THE ARGM DESCRIPTION AND CONTROL STRUCTURE

We consider an ARGM layout involving unidirectional guide-paths [10]. The ARGM is divided into several disjoint zones and each zone can represent a workstation of A/D-FML that a vehicle can visit and make some operation, picking up or storage dropping (Fig. 3). The straight unidirectional lanes can be modeled by several zones in order to keep the task simple. Moreover, the ARGM includes a docking station where idle vehicles are parked, and for other stations includes a stop area for handling operations, picking or dropping.

The set of zones of the ARGM is denoted by $Z = \{z_i, i = 1,..., N_z\}$, where z_i for $i = 2,..., N_z$ represents a zone and z_1 denotes the docking station. Each zone, z_i, can accommodate only one ARGM during its corresponding time.

The ARGM, shown in Fig. 3, connects five workstations (see in the figure as S_1, S_2, S_3, S_4, S_5 and S_6 is storage station). Each station has 2 distinct operations (denoted in the figure by $z_1, z_2, z_3, z_4, z_5, z_6, z_7, z_8$ and z_9), z_1 being the docking station. There are five picking zones, $z_1(D_L^1), z_2(D_L^2), z_4(D_L^3), z_6(D_L^4), z_8(D_L^5)$, for disassembly process, located near of the corresponding workstation. There are five additional zones, z_3, z_5, z_7, z_9, for dropping component into corresponding warehouse. $z_1 - z_3, z_2 - z_3, z_4 - z_5, z_6 - z_7$ are the transportation paths and $z_8 - z_9$ is an unidirectional path. ARGM starts a job in zone z_i, after the disassembly operation has been done and reaches the next zone z_{i+1} in order to finish job with dropping of the component in the warehouse. Finally, ARGM goes back through all zones to the docking location

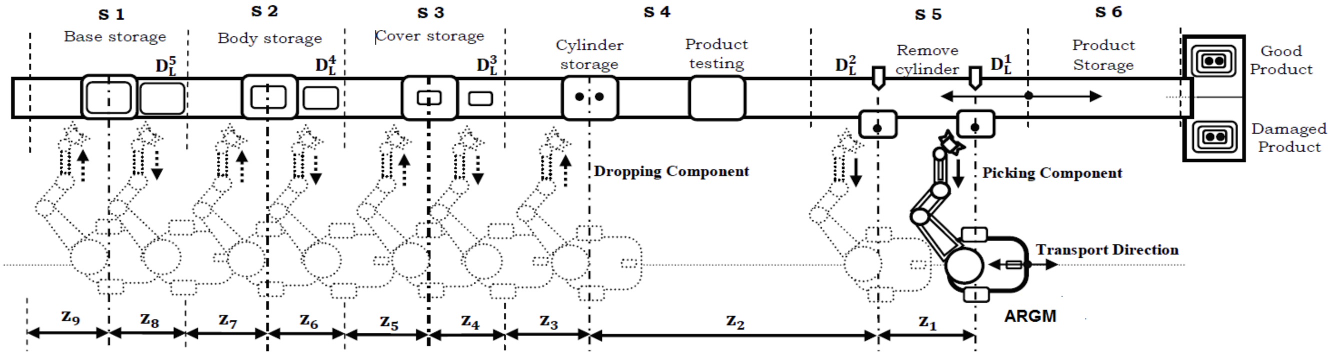

Figure 3. Disassembly operations and components transportation to storage warehouses by ARGV

Hence, we describe the route $r(v)$ assigned to the ARGM $v \in V$ by the zone sequence $r(v) = (z_i ... z_j ... z_k ... z_1)$.

The control structure proposed to manage the ARGM route and handling operation is composed of to levels: the route scheduler and the handling control. The route scheduler determines the routes to assign to ARGM and select the configurations in witch it is necessary to assign another routing to ARGM, for new task of disassembling process. Route planning is one of the main activities of the ARGM management [11] and can be faced by two approaches: static and dynamic planning. Static planning assigns the flow path with the minimum distance to the ARGM trajectory.

On the other hand, dynamic planning takes route decisions at each station of the ARGM component transportation on the basic of the positions at every station and speed. 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 (Fig .4). The handling is controlled in open loop with step by step motors located in each joint. The positioning of the gripper has been made by a visual servoing system, in order to grab the disassembled component and its storage in the warehouse.

V. CONTROL POLICY

The main objective of the control policy is to satisfy demands for transportation and handling as fast as possible and without occurrences of conflicts among ARGM and A/D-FML.

The real-time control policy application is obtained by interfacing HPN model with synchronized signals taken by acquisition of the real process. At the conceptual level, the control platform corresponds to a synchronized HPN model (SHPN) [12],[13].

SHPN model associated to A/D-FML served by ARGM can be made using devoted PN tools, because its dynamics is defined by state variation to events occurrence. Accordingly with definition of synchronized PN, the SHPN corresponding to the A/D-FML can be described by the triple $(HPN, E, Sync)$ where HPN is the hybrid PN represented in Fig.6, E is the set of external events and $Sync$ is the function from the set o transitions associated to the disassembly process, T_{dd}, to E. The set of external events, $E_1^i, i = 1,...,9$ and $E_2^i, i = 1,...,9$ 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;

The joint use of these rules makes ARGM available quickly and hence improves overall system performance. Due to non-deterministic nature of the A/D-FML, on-line scheduling methodology has been used.

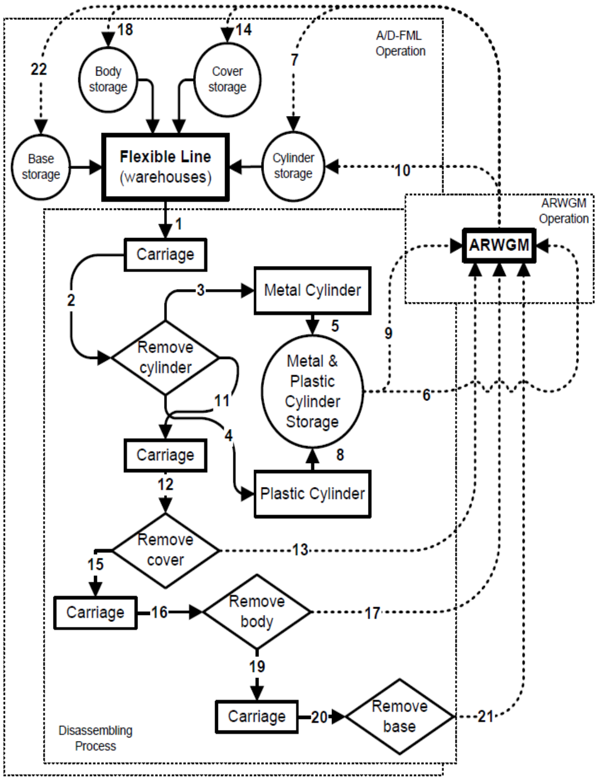

Figure 4. Disassembly task planning

VI. HPN MODEL ASSOCIATED TO A/D-FML SERVED BY ARGM

The system of reversible A/D-FML served by ARGM has a dynamics determined by events (events supplied by the control sequences of the automation system) and by the interaction with the ARGM, which represent the continuous time component of the system (Fig. 6). The considered system is a hybrid one and requires specialized tools for modeling. The hybrid model is elaborated using the dedicated modeling tool, HPN [14],[15]:

$$HPN = \left(P,\ T,\ \mathrm{Pr}\,e,\ Post,\ h,\ S,\ V,\ M_0\right) \quad (1)$$

The disassembly operations, including disassembly locations, storage warehouses and ARMG trajectories for transportation of the components are shown in Fig. 5, where:

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

$$P = P_d \cup P_c \quad (2)$$

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

$$P_c = P - P_d \quad (3)$$

is the set of continuous places;

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

$$T = T_d \cup T_c \quad (4)$$

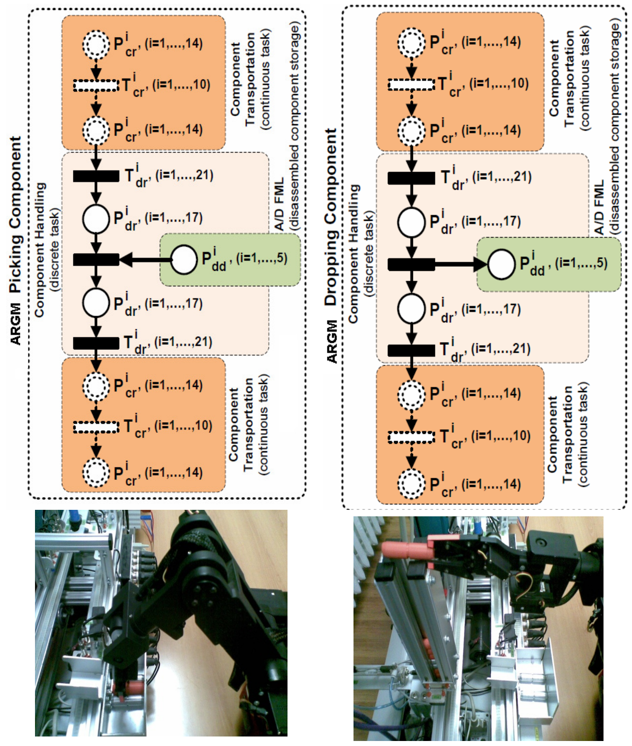

Figure 5. Piking and dropping disassembled component from A/D-FML

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

$$T_c = T - T_d \quad (5)$$

is the set of continuous transitions;

$\mathrm{Pr}\,e : PxT \rightarrow N$ and $Post : PxT \rightarrow N$ are the backward and forward incidence mappings

$$\forall\left(P^i,\ T^j\right) \in P_d x T_c,\ \mathrm{Pr}\,e\left(P^i,\ T^j\right) = Post\left(P^i,\ T^j\right) \quad (6)$$

This means that if an arch connects a d-place P_d^i to a c-transition T_c^j, then exists the arch which connects T_c^j to P_d^i.

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

$S : T_d \rightarrow Q_+$ 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 ARGM results a hybrid model, HPN, of the mechatronic A/D-FML.

Particularly, to the HPN of the A/D-FML served by ARGM the following observations can be made:

- Transition times d_d^j are associated to the transitions with constant execution time. Timed transitions are made in relation with the operations of assembly/ disassembly. The 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 ARGM moving sequences and duration of the complete cycle execution. To each ARGM move cycle, as a continuous time system, is stored in the warehouses, recovered by disassembly

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

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

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

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

P_{dr}^i, $i = 1, \ldots, 17$ is ARGM discrete place;

P_{cr}^{i}, $i = 1,\dots,14$ is a ARGM continuous place; T_{dr}^{i}, $i = 1,\dots,21$ is a ARGM discrete transition;

T_{cr}^{i}, $i = 1,\dots,10$ is a ARGM continuous transition;

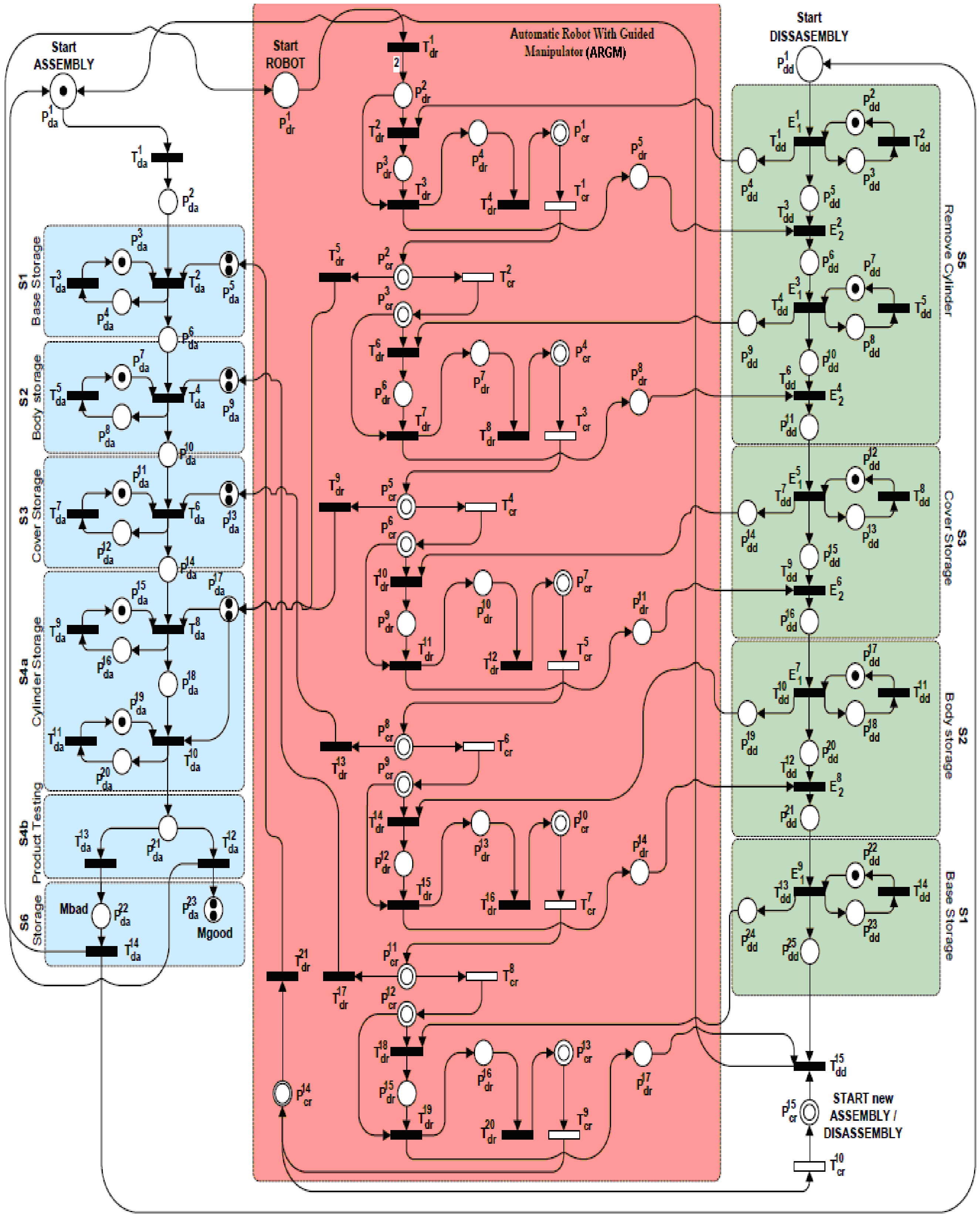

Figure 6. Synchronized HPN of A/D-FML served by ARGM

VII. ARWGM CONTROL ALGORITHM

For trajectory-tracking, sliding mode control method is used to control wheeled ARGM Pioneer 3-DX, based on kinematics model see in Fig.7. ARGM Pioneer 3-DX is a mobile platform with two driving wheels and one rear wheel. The robotic manipulator, Pioneer 5-DOF Arm mounted on ARGM Pioneer 3-DX is driven in open-loop servo motors, the five degrees-of-freedom (5-DOF) Pioneer Arm's end-effector is a gripper whose foam-lined fingers allow for grasp and manipulation of objects from the floor to the back of the robot. All servo-driven joints, except for the gripper fingers, pivot or rotate at least 180 degrees. Mounted to the front of the robot's top plate, the Pioneer Arm has an envelope of operation reaching 50 centimeters from the center of the arm's rotating base to the tip of its closed fingers. The Pioneer Arm's reach, therefore, lets you pick up objects from the floor in front of your ARGM Pioneer 3-DX and place them on its back.

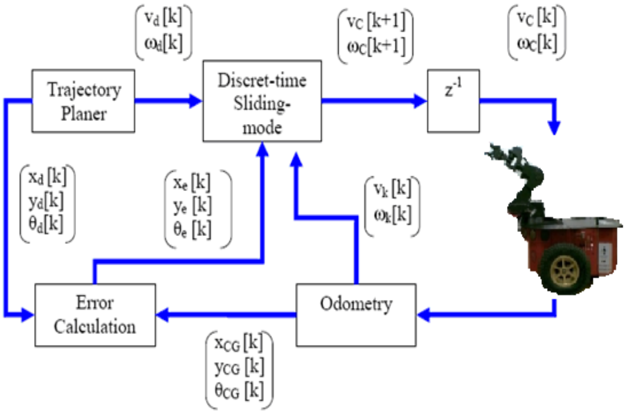

Figure 7. Closed loop control of ARGM

VIII. CONCLUSION

This study has attempted to apply advanced tools of HPN method to model and analyze the practical constraints of an A/D-FML served by ARGM. The transportation and handling component have shown improvement as the ARGM guide path flexibility has been increased. We want to extend this study to analyze other characteristics of ARGM.

Also, the utilization of other resources like A/D-FML cycle time will also be calculated and finally this study will attempt to find best guide path configuration based on A/D-FML performance.

REFERENCES

[1] A.A. Desrochers, and R.Y. Al-Jaar, "Applications of Petri nets in manufacturing Systems: Modeling, Control and performance Analysis", IEEE Press 1995.

[2] G.C. Co, and J.M.A., Tanchoco, "A review of research on AGVS vehicle management". Engineering Costs and Production Economics, 21, 35-42, 1991.

[3] P. J. Egbelu and J. M. A., Tanchoco, "Characterization of automatic guided vehicle dispatching rules". International Journal of Production Research, 22(3), 359-374, 1984.

[4] S., Li, T. Takamori, and S. Tadokoro, , "Scheduling and rescheduling of AGVs for flexible and agile manufacturing, In Petri Nets in Flexible and Agile Automation", M.C. Zhou, (Ed.), Kluwer Academic Pulishers, pp.189-205, 1995.

[5] T. Aized, K. Takahashi, I. Hagiwara, " Hierarchical Control Modeling of Automated Guided Vehicle System (AGVS) using Colored Petri Net" IEICE Technical Report, CST 2005-40 (2006-01), pp. 7-12.

[6] E. L.,Blair, P., Charnsethikul, and A., Vasques, "Optimal routing of driverless vehicles in a flexible material handling system". Material Flow, 4(1+2), 73-83, 1987.

[7] Y., Seo and P. J. Egbelu, "Integrated manufacturing planning for an AGV-based FMS", Int. J. Production Economics, 60-61, 1999, pp. 473-478.

[8] P. J., Egbelu and J. M. A.,Tanchoco, "Potentials for bi-directional guide-path for automated guided vehicle based systems". International Journal of Production Research, 24(5), 1075-1097, 1986.

[9] M. C. Zhou and K. Venkatesh, "Modeling, Simulation, and Control of Flexible Manufacturing Systems", World Scientific, Singapore, 1999.

[10] F. Taghaboni-Dutta, and J. M. A. Tanchoco, "Comparison of dynamic routing techniques for automated guided vehicle system", Int.J. Prod. Res., Vol. 33, No. 10, Oct. 1995, pp. 2653-2669.

[11] G. A., Koff, "Automatic guided vehicle systems: applications, controls, and planning," Material Flow, No 4, 1987, pp. 3-16.

[12] A. Radaschin, A. Filipescu, V. Minzu, E. Minca and A. Filipescu Jr.,"Adaptive disassembly sequence control by using mobile robots and system information", Proceeding of 15th IEEE International Conference in System Theory, Control and Computing, pp: 499-505, 14-16 Oct. 2011, Sinaia, Romania, ISBN: 978-973-621-323-6.

[13] B. Kopacek, P. Kopacek„Robots for disassembly", Proceedings of the 30th International Symposium on Robotics, Tokyo, 1999, pp 207–212.

[14] M. Silva, „Practice of Petri Nets in Manufacturing", ch. Introducing Petri Nets, pp. 1-62. Chapman & Hall, 1993.

[15] R. David and H. Alla (2010). Discrete, Continuous and Hybrid Petri Nets. Springer-Verlag Berlin, ISBN 978-3-642-10668.