Simulated Hybrid Model of an Autonomous Robotic System Integrated into Assembly/Disassembly Mechatronics Line

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Abstract: The new idea presented in the paper is to reverse of an assembly line in order to allow complete disassembly. A generalised Synchronised Hybrid Petri Nets (*SHPN*) model based control of an assembly/disassembly mechatronics line (*A/DML*) served by a wheeled mobile robot (*WMR*) equipped with robotic manipulator (*RM*) is presented. The approach is a hybrid one, the assembly/disassembly line being the discrete part whilst the *WMR* with *RM* is the continuous part. The mobile platform is used only in disassembly operations, in order to transport the components from the disassembly locations to the storage locations. Therefore, *SHPN* approach is used to model and control. This hybrid system takes into consideration the distribution of the necessary tasks to perform hybrid disassembly, using robot synchronisation with *A/DML*. Using *SHPN* model and a LabView platform, a real-time control structure has been designed and implemented, allowing automated assembly and disassembly where the last one is assisted by a mobile platform equipped with a manipulator.

1. INTRODUCTION

As a main contribution of this paper, is a new approach for modelling and controlling of the assembly/disassembly production flows, by aggregation of continuous and discrete events systems, into a hybrid system. Consequently, it is proposed a generalised Synchronised Hybrid Petri Nets (*SHPN*) model for a reversible assembly/disassembly mechatronics line (*A/DML*) served by wheeled mobile robot (WMR) equipped with robotic manipulator (*RM*). Generalised model will be customised for an assembly mechatronics line of a five parts work piece. *SHPN* model based real-time control of *A/DML* served by *WMR* with *RM* is also presented. This model gives a high-level description of the work piece to be disassembled. In this paper, as a premier, the concepts of assembly/disassembly tasks are illustrated in *SHPN* model respecting both approaches: the discrete approach for the elementary assembly/disassembly operations and the continuous approach for displacement of *WMR*. The reversible *A/DML* served by robotic manipulators mounted on mobile platforms has a dynamics determined both, by events (events supplied by the control sequences of the automatic system) and by the interaction with the *WMR*, which represent the continuous time part of the system. The considered system is a hybrid one and requires specialised tools for modelling. The assembly/disassembly operation can by decomposed into a sequence of elementary assembly tasks coupled in parallel with positioning tasks of the work piece along conveyor, as in Baldwin et al. (1991), Choi et al.(1998), Rosell (2002) and Ganget et al. (2005). The hybrid disassembly strategy is based on the hierarchical model proposed in Seliger et al. (1999), David and Alla (2010), Radaschin et all (2012), Minca et al (2013a) and Minca et al.(2013b).

The rest of the paper is organized as follows: the description of *A/DML* served by *WMR* and *RM* is presented in Section 2; structure of the generalised *SHPN* model is presented in Section 3; generalised and customised *SHPN* formalisms together model simulation results are presented in Section 4; Section 5 is reserved to real-time control of *A/DML* served by *WMR* and *RM* based on *SHPN* model; some final remarks can be found in Section 6.

2. *A/DML* SERVED BY *WMR* EQUIPPED WITH *RM*

A robotic assembly/disassembly system consists of different kinds of components such as mobile robot, robotic manipulator, assembly/disassembly line, sensors, conveyors, storage warehouses, data acquisition cards and *PLC* (Programmable Logic Controller). The *A/DML* is served by a *WMR* equipped with *RM* during of disassembly phase (Kopacek B. & Kopacek 1999). The objective is to make the assembly line reversible, i.e. to allow disassembly. Moreover, the mobile robot is used to carry the disassembled part to an appropriate storage warehouse. General approach will customise to an *A/DML*, *HERA&Horstmann*, shown in Fig.1a and 1b, which makes assembly of five parts, shown in Fig.1c and Fig. 1d. The *WMR*, *Pioneer3-DX*, has an odometric system, two driving wheels, and one rear free wheel. An on-board embedded microcontroller is able to read position information and send it, via a WI-FI link, to a remote *PC* according to a specific protocol. The remote *PC* computes control input and sends it to *WMR*. Also, the remote PC sends the data to the assembly line *PLC*. The *A/DML* is equipped with *SIEMENS SIMATIC S7-300 PLC*), with five distributed modules connected by Profibus. *A/DML* includes five individual work stations. The components to be assembled (Fig. 1c and 1d) are: work part carrier (base platform) (1), body (2), cover (3), metal cylinder (4) and plastic cylinder (5). The general representation of assembly and disassembly is shown in Fig. 2. In Fig. 3, is presented the particular case of an assembly/disassembly of a product consists of 5 parts, served by *WMR* with *RM*. *WMR* carries the component from the place where disassembly occurs to the appropriate storage warehouse.
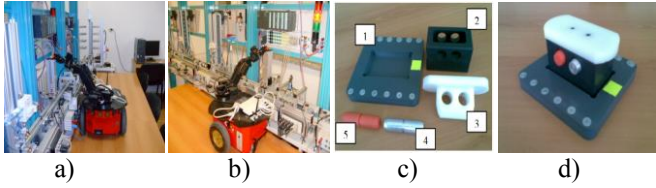
a)	b)	c)	d)

Fig. 1. a)&b) assembly line, *Hera&Horstmann*, served by *WMR, Pioneer 3-DX*, equipped with *RM, Pioneer 5-DOF Arm;* c) parts; b) assembled piece.
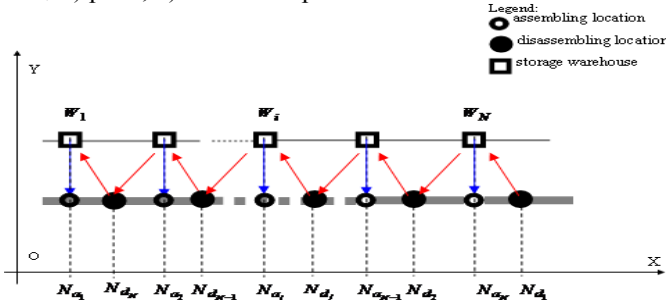

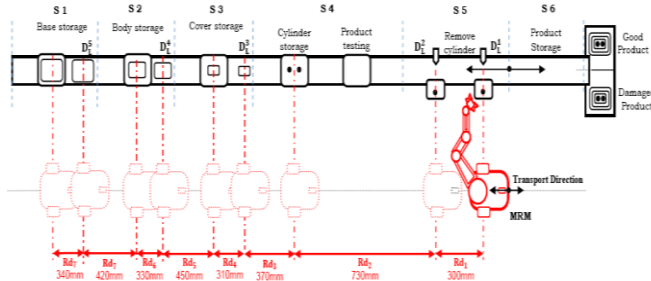Fig. 2. The places of the warehouses, assembly and disassembly stations

Fig. 3. The distances covered by *WMR* equipped with *RM*

3. STRUCTURE OF THE *SHPN* MODEL

The following assumption hold: A.1. The disassembly process starts immediately after the assembly process and final piece fails the quality test; A.2. Storage warehouses places are identical to positions where assembly occurs; A.3. In an assembly/disassembly operation is assembled/disassembled only one piece; A.4. By convention it is assumed that the end product fails the quality test if it contains cylinders of different materials; A.5. After the last remaining piece of disassembly process is transported to the storage warehouse starts a new assembly process.

Let N be the number of parts to be assembled. For $N = 5$ gets the customized case. Let $N_{a_i}, i = \overline{1,N}$ be the assembly locations on the positive sense of Ox axis. Let $N_{d_j}, j = \overline{1,N}$ be the disassembly locations on the inverse sense of Ox axis. Obviously, $i = N - j + 1$. Let $W_i, i = \overline{1,N}$ be the warehouse locations, which are identically with the assembly locations. Obviously, $W_{N+1-j} \equiv W_i, j = \overline{1,N}$. Let $D(N_{d_j}, W_{N+1-j})$ be the distance between disassembly location N_{d_j} and the corresponding storage warehouse W_{N+1-j}. Let $D(W_{N+1-j}, N_{d_{j+1}})$ be the distance between last storage warehouse W_{N+1-j} and the next disassembly location $N_{d_{j+1}}$.

Let $D_{r_j} = D(N_{d_j}, W_{N+1-j}) + D(W_{N+1-j}, N_{d_{j+1}})$ be the distance travelled by the mobile robot in the j-stage of disassembly. Variable $s = 1 + (j-1) \cdot 8$ indexes a *RM* discrete place, Pdr. Variable $r = 1 + (j-1) \cdot 3$ indexes: a *WMR* continuous place of the robot, Pcr; a *WMR* continuous transition, Tcr, and a disassembly discrete transition, Tdd. Variable $k = 1 + (j-1) \cdot 5$ indexes a disassembly discrete place, Pdd. Variable $l = 1 + (j-1) \cdot 4$ indexes a RM discrete transition, Tdr.

The hybrid aspect of the model is given by the variables related to distances travelled by the robot. These are distances between the locations where disassembly occurs and storage warehouses locations. These variables vary according to whether speed is constant or variable. Variation is based on the mobile platform speed between *A/DML* locations. To develop a global model of assembly and/or disassembly, will consider hybrid aspect of the entire process served by the mobile platform. For modelling, it will use Timed Hybrid Petri Nets (*THPN*), as in David and Alla (2010), Minca et al. (2013a), Minca et al. (2013b). *THPN* integrates the discrete appearance of the assembly/disassembly process with the continuous appearance of the WMR displacement and handling of parts by the RM. The entire model is *SHPN* type, because is interfaced with external events for synchronisation, useful in real-time control. Therefore, the system becomes of a reversible *A/DML* that is served, during disassembly, by robotic manipulator mounted on mobile platform. The system has a dynamics determined by events (events supplied by the control sequences of the automatic system) and by the interaction with the WMR. The hybrid model is elaborated using the dedicated modelling tool, *HPN*, described in [9]. Combining *SED* model of the analyzed system with the *WMR* continuous time cycle, results a *SHPN* model. *SHPN* model, shown in Fig. 4, is obtained by modelling assembly/disassembly and continuous service assistance of *WMR* equipped with *RM*. *SHPN* morphology results by integration three *PN* models. Each of these models has a specific typology: *TPN* (Timed *PN*), *SPN* (Synchronised *PN*) and *THPN* (Timed Hybrid *PN*). These models describe the following automatic operations: assembling/storage in warehouses (*TPN* typology); disassembling of damaged product (*SPN* and *TPN* typologies); service assistance, during disassembling process, performed by the mobile robot equipped with manipulator (*THPN* typology). In Fig. 5 is shown the generalised *TPN* model corresponding to N-parts assembly, where the last one includes a sequence associated to quality test for the end product (work-piece). During disassembly process, can identify a repetitive sequence associated to a single disassembly operation and service assistance of *WMR* equipped with *RM*. All of these can be modelled with a *SHPN*, called elementary *SHPN* (e-SHPN). In Fig. 6, is shown the model corresponding to the first disassembly part. $E^1_{dd(j)}$ and $E^2_{dd(j+2)}$ are external events from the sensors used for line synchronisation with the *WMR* equipped with *RM*.

$E_{dd(j)}^1$ is an external synchronisation signal, corresponding to *STOPPING* line and *STARTING* disassembly. $E_{dd(j+2)}^2$ is an external synchronisation signals, corresponding to *PICKING UP* of disassembled component and *START* line.
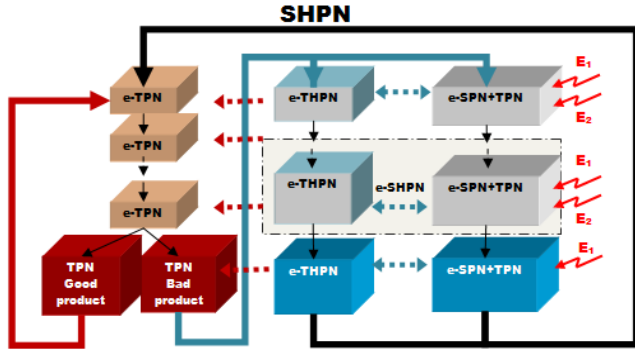

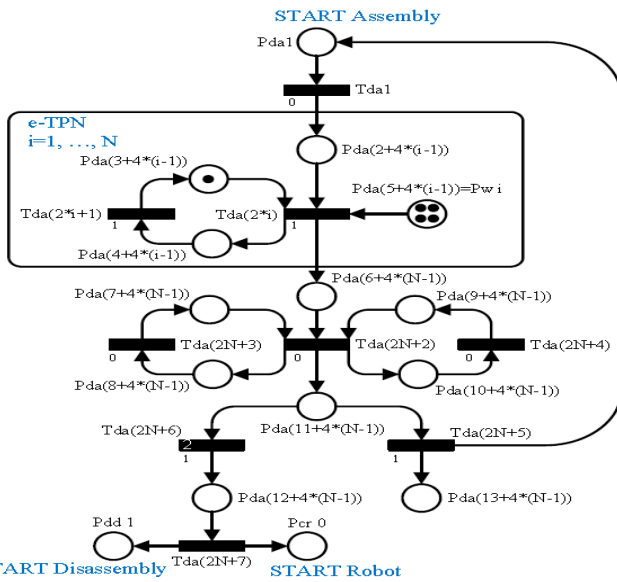Fig. 4.The *SHPN* representation by blocks with elementary *THPN* modules, *e-THPN*.

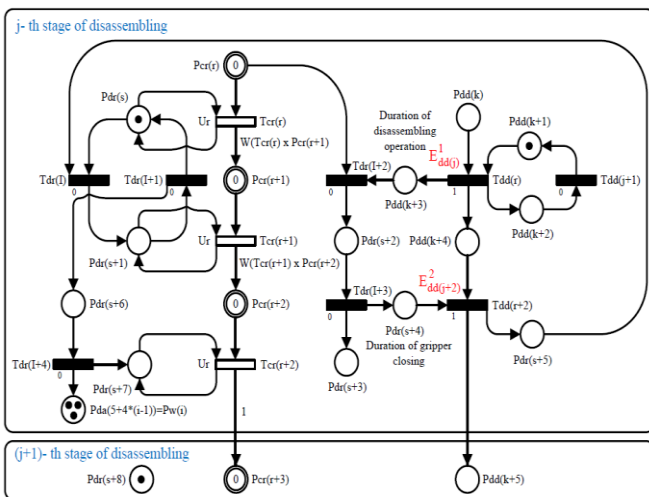Fig. 5. Generalised *TPN* model for the assembly process of *N* components

Fig. 6. *e-SHPN* model of the jth disassembly stage.

4. GENERALISED AND CUSTOMISED *SHPN* MODEL

The *SHPN* model associated to the assembly/disassembly is a triplet,

$$SHPN = \langle THPN, \quad E, \quad Sync \rangle \qquad (1)$$

where: *THPN* is a septuplet

$$THPN = \langle P, T, Pre, Post, m_0, h, tempo \rangle \qquad (2)$$

E is a set of external events

$$E = \left\{ Edd_i^1, Edd_j^2 \right\} \cup \{e\}, i = 1 + 3(k-1), j = 3(k-1), k = \overline{1,N} \quad (3)$$

$\left\{ Edd_i^1 \right\}$ is the set of external synchronization signals, supplied by the sensors, corresponding to STOPPING line and *STARTING* disassembling;

$\left\{ Edd_j^2 \right\}$ is the set of external synchronization signals, supplied by the sensors, corresponding to *PICKING UP* of disassembled component and *STARTING* line;

Sync is a function from the set of the discrete disassembly transitions to the set of external events

$$Sync : T \to \left\{ E^1, E^2 \right\} \cup \{e\} \qquad (4)$$

where e is the always occurring event (it is the neutral element of the monoid E^*) and

$$Sync : \left\{ Tdd_r \right\}_{r=1+3 \cdot (k-1)_{\overline{k=1,N}}} \to \left\{ E^1, E^2 \right\}$$

$$Sync : \left\{ Tdd_i \right\}_{i=3 \cdot (k-1)_{\overline{k=2,N}}} \to \left\{ Edd_i^2 \right\}_{i=3 \cdot (k-1)_{\overline{k=2,N}}}$$

$$Sync : T \setminus \left\{ Tdd_r \right\}_{r=\overline{1,3+3(N-1)}} \cup \left\{ Tdr_l \right\}_{l=\overline{1,4+5(N-1)}} \cup \left\{ Tcr_r \right\}_{r=\overline{1,3+3(N-1)}} \to e$$

$$P = \left\{ P_1, P_2, \dots P_n \right\} = P^D \cup P^C \qquad (5)$$

is a finite, not empty, set of places with P^D the set of discrete places

$$P^D = \left\{ Pda_i \right\}_{i=\overline{1,13+4(N-1)}} \cup \left\{ Pdd_r \right\}_{r=\overline{1,5+5(N-1)}}$$
$$\cup \left\{ Pdr_s \right\}_{s=\overline{1,4+8(N-1)}} \qquad (6)$$

and P^C the set of continuous places

$$P^C = \left\{ Pcr_k \right\}_{k=\overline{0,3+3(N-1)}} \qquad (7)$$

For $N = 5$ (*A/DML Hera&Horstmann*), (6) and (7) become:

$$P^D = \left\{ Pda_i \right\}_{i=\overline{1,29}} \cup \left\{ Pdd_j \right\}_{j=\overline{1,25}} \cup \left\{ Pdr_k \right\}_{k=\overline{1,41}}.$$

$P^C = \left\{ Pcr_k \right\}_{k=\overline{0,15}}$; where, $\left\{ Pda_i \right\}_{i=\overline{1,29}}$ is the set of discrete places for assembly process; $\left\{ Pdd_j \right\}_{j=\overline{1,25}}$ is the set of discrete places for disassembly process; $\left\{ Pdr_k \right\}_{k=\overline{1,41}}$ is the set of discrete places for the states of mobile robot while serving disassembly process; $\left\{ Pcr_k \right\}_{k=\overline{1,15}}$ is the set of continuous places associated to the distances performing by the mobile robot for each disassembly operation in order to transport the disassembled component from the disassembled location to the storage location.

$$T = \left\{ T_1, T_2, \dots T_m \right\} = T^D \cup T^C \qquad (8)$$

is a finite, not empty, set of transitions with T^D the set of discrete transitions

$$T^D = \{Tda_i\}_{i=\overline{1,7+2N}} \cup \{Tdd_r\}_{r=\overline{1,3+3(N-1)}}$$

$$\cup \{Tdr_l\}_{l=\overline{1,4+5(N-1)}} \tag{9}$$

and T^C the set of continuous transitions

$$T^C = \{Tcr_r\}_{r=\overline{1,3+3\cdot(N-1)}}$$

For $N = 5$, (8) and (9) become

$$T^D = \{Tda_i\}_{i=\overline{1,17}} \cup \{Tdd_j\}_{j=\overline{1,15}} \cup \{Tdr_k\}_{k=\overline{1,24}} \tag{10}$$

$$T^C = \{Tcr_k\}_{k=\overline{1,15}}$$

where: $\{Tda_i\}_{i=\overline{1,17}}$ is the set of discrete transitions for assembly operations model; $\{Tdd_j\}_{j=\overline{1,15}}$ is the set of discrete transitions for disassembly operations model; $\{Tdr_k\}_{k=\overline{1,24}}$ is the set of discrete transitions for states of mobile robot while serving disassembly operations; $\{Tcr_k\}_{k=\overline{1,15}}$ is the set of continuous transitions associated to distances performing by the mobile robot for each disassembly operation. To these transitions is associated the maximum linear speed of the *WMR*.

Remark 1: Sets P and T are disjointed, $P \cap T = \varnothing$;

$Pre : P \times T \to Q_+$ or N is the input incidence application;
$Post : P \times T \to Q_+$ or N is the output incidence application;
$m_0 : P \to R_+$ or N is the initial marking;

Remark 2: In the definitions of Pre, $Post$ and m_0, N corresponds to the case when $P_i \in P^D$, and Q_+ or R_+ corresponds to the case when $P_i \in P^C$.

$$h : P \cup T \to \{D, C\} \tag{11}$$

called "hybrid function", indicates for every node whether it is a discrete node (sets P^D and T^D) or a continuous one (sets P^C and T^C),

$$h : P^D \cup T^D \to \{D\}, h : P^C \cup T^C \to \{C\} \tag{12}$$

tempo is a function from the set T of transitions to the set of positive or zero rational numbers,

$$tempo : T \to Q_+ \cup \{0\} \tag{13}$$

If $T_j \in T^D$, then $d_j = tempo(T_j)$ is timing associated to T_j.

For each discrete assembly transition of the set

$$T_a^D = \{Tda_i\}_{i=2\cdot k_{k=\overline{1,N}}} \cup \{Tda_{2\cdot(N+1)}\} \tag{14}$$

$$tempo(Tda_i) = d_{da_i} \tag{15}$$

where d_{da_i} represents the duration (in seconds) associated to the corresponding assembly operation.

For each discrete disassembly transition of the set

$$T_d^D = \{Tdd_r\}_{r=1+3\cdot(k-1)_{k=\overline{1,N}}}, \tag{16}$$

d_{dd_r} is the duration of the corresponding disassembly.

For each discrete *WMR* transition of the set

$$T_r^D = \{Tdr_l\}_{l=4+5\cdot(k-2)_{k=\overline{2,N}}}, \tag{17}$$

d_{dr_l} is the duration of *RM* positioning in picking up and dropping down of a disassembled component.

For $N = 5$, (14), (15), (16) and (17) become

$$T_a^D = \{Tda_i\}_{i=\{2,4,6,8,10\}} \cup \{Tda_{12}\},$$

$$tempo(Tda_i)_{i=\{2,4,6,8,10,12\}} = \{9.5, 9.3, 8.5, 0.5, 4.75, 27.2\}, \text{where}$$

d_{da_i} represents the duration of the current assembly operation together with the transport time to the next assembly location, for $i \in \{2,4,6,8,10\}$, and the duration of the quality test together with the transport time to the elevator of end products warehouse, for $i \in \{1, 2\}$;
$T_d^D = \{Tdd_r\}_{r=\{1,4,7,10,13\}}$, $d_{dd_{r=\{1,4,7,10,13\}}} = 1$, where d_{ddr} is the duration of the current disassembly operation
$T_r^D = \{Tdr_l\}_{l=\{4,9,14,19\}}$, $d_{dr_l} \in \{5.1, 21.2, 8.9, 7.8\}$, where d_{dd_l} is the duration of *RM* positioning in picking up and dropping of a disassembled component. If $Tcr \in T^C$, then

$$U_r = 1/tempo(T_{cr}) \tag{18}$$

is flow rate associated to T_{cr}. If $T^C = \{Tcr_r\}_{r=3+3\cdot(k-1)_{k=\overline{1,N}}}$, then $U_{cr_r} = U_r; U_{r\max} = V_r$ where U_{cr} is the variable flow of mobile robot displacement between disassembly stations. Consider the average speed of motion of *WMR*, $V_r = 94mm/s$.

Definition 1: The *ED-enabling degree* of a C-transition T_j for a marking, m, denoted by $ED(T_j, m)$, is the enabling degree of T_j after all the arcs, from a *C*-place to a *C*-transition, have been deleted:

$$ED(T_j, m) = \min_{P_i \in {}^0 T_j \cap P^D} \lfloor m_i / Pre(P_i, T_j) \rfloor \tag{19}$$

Definition 2: The *maximal firing speed* of transition T_{cr_r} is the product of its flow rate U_r by its *ED* -enabling degree.

Suitable definitions 1 and 2, for the general case, it can write:

$$ED(T_{cr_j}, m_{cr(j+1)}) = \{0,1\}, \tag{20}$$

$$m_{cr(j+1)} = V_j \cdot w(Tcr_j \times Pcr_{(j+1)}), \tag{21}$$

$$w(Tcr_r \times Pcr_{r+1}) = D(W_{N+1-j}, N_{d_{j+1}}) / D(N_{d_j}, W_{N+1-j}), \tag{22}$$

where, $m_{cr(j+1)}$ is the mark associated to a continuous place and $w(Tcr_{(r)} \times Pcr_{(r+1)})$ is the weight of the arc from a continuous transition to a continuous place of the *WMR*.
For $N = 5$ the arches $(P_i \times T_j)$, where $P_i = \{ROBOT\ state1,\ ROBOT\ state2\} \in {}^o \{Tcr_k\}_{k=\overline{1,10}} \cap P^D$, have the weight equal to one. Therefore, $Vcr_k = Ucr_k = 2|_{k=\overline{1,10}}$.

Remark 3: for a synchronized *PN* a transition is enabled when each of its input places contains enough tokens. If it is enabled, it is firable on occurrence of the event associated with it.

Sync function, from (4), can be expressed for the customised form as follow:

$$Sync : \{Tdd_j\}_{j=\{1,3,4,6,7,9,12,13\}} \rightarrow \{Edd^1, Edd^2\} \quad (23)$$

$$Sync : \{Tdd_i\}_{i=\{1,4,7,13\}} \rightarrow \{Edd_i^1\}_{i=\{1,4,7,13\}} \quad (24)$$

$$Sync : \{Tdd_i\}_{i=\{3,6,9,12\}} \rightarrow \{Edd_i^2\}_{i=\{3,6,9,12\}} \quad (25)$$

$$Sync : \{Tdd_j\}_{j=\overline{1,16}} \cup \{Tdr_k\}_{k=\overline{1,21}} \cup \{Tcr_k\}_{k=\overline{1,10}} \rightarrow e \quad (26)$$

Analysis of the *SHPN* model is relevant at basic level according to an elementary *THPN* module, denoted *e-THPN*. *SHPN* model is obtained by recurrent assembling of these elementary *e-THPN* modules (corresponding to each basic disassembly served by *WMR* with RM). The *SHPN* global model is an exclusive relationship between *TPNs* associated with the assembly process, elementary *THPN* modules associated with *WMR* service assistance, and *SPN* with *TPNs* associated with the disassembly process.

In Fig. 7, is the simulated response of the hybrid model shown in Fig. 6. The simulation model was developed in *Sirphyco*. The *WMR* markings of the continuous places, before and after simulation, match the distances shown in Fig.3. In Fig.7, the evolution of the *WMR* continuous and discrete place markings corresponding to $j = 1$ is shown as following: $Mcr(r)$ – the temporal variation of the travelled distance by the robot between stage 1 of disassembly and warehouse 5 (1031mm according to Fig.3); $Mcr(r+1), Mcr(r+2), Mcr(r+3)$ – the variation of the distance to be travelled by the robot in the following stage (730mm according to Fig. 3) correlated to the synchronisation of the events Edd_1^1 and Edd_3^2. $Mdr(s)$, $Mdr(s+1)$, $Mdr(s+2)$, $Mdr(s+6)$, $Mdr(s+7)$ represent the temporisations associated with the discrete actions of the *WMR* (piece gripping and dropping, gripper closure, repositioning to the next disassembly work-station).
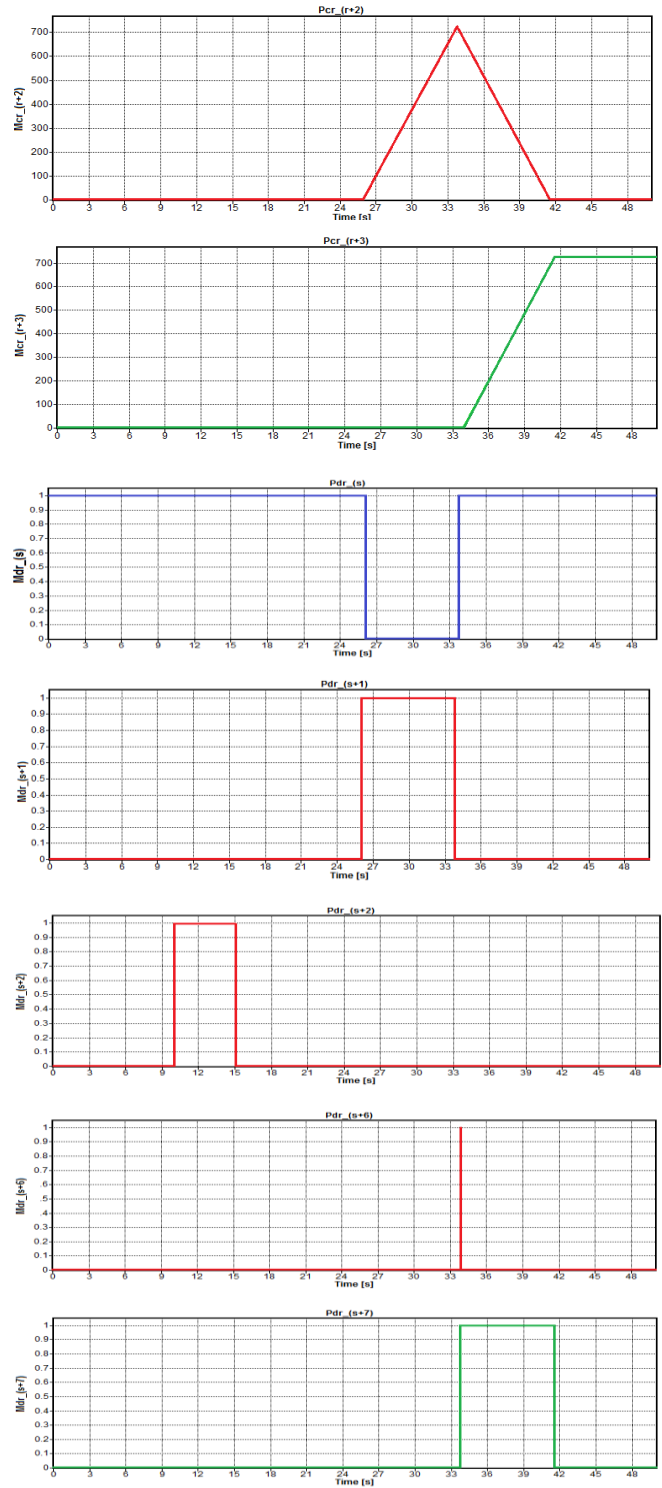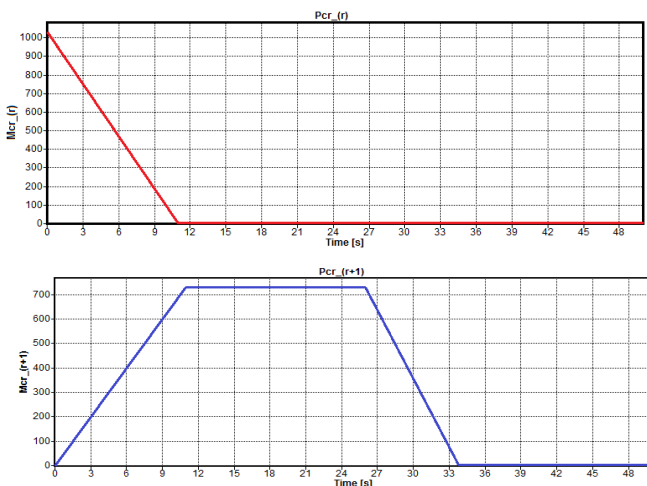

Fig. 7. Variation of the continuous and discrete places associated to displacements of *WMR* and RM corresponding to the first stage of disassembling.

5. *SHPN* MODEL BASED REAL-TIME CONTROL

The SHPN model is transposed, via LabView platform, in a real-time application, obtained by interfacing *HPN* model with synchronised signals taken by acquisition from the real process. At the conceptual level, the control platform corresponds to a synchronised *HPN* model (*SHPN*). The real-

time application is synchronised with the controlled process by the positioning signals of the work piece along the conveyor taken by acquisition card NI USB-6008. The synchronisation signals, used in the LabView real-time control, validate certain transitions into the *SHPN* model. These transitions are conditioned by the associated signals of the position work piece on the conveyor track. The synchronization will lead to initialize robot and to monitoring/controlling assembly/disassembly of *WMR* with *RM*. Discrete time, sliding-mode control, in trajectory-tracking, based on kinematic model is used to control *WMR* (Radaschin et al. 2012). In this way both the robot and flexible line are controlled, in order to achieve a smallest assembly and disassembly cycle time. The robot is initialised by a signal transmitted via a wireless access point mounted on the mobile platform, received by the LabView application. Via the acquisition board, the state signals are transmitted to the flexible line to control the position of the work piece along the conveyor and to synchronise the robot with the flexible line. The LabView I/O module transmits the signals to the *A/DML*'s *PLC* (*SIMATIC S7-300*) via the acquisition board. The positioning of the gripper in order to grab the disassembled component and its storage into warehouse has been made by a visual servoing system.

6. CONCLUSIONS

A *SHPN* model based real-time control of fully reversible *A/DML* served by a *WMR* equipped with *RM*, is the main contribution of this paper. The SHPN model is conditioned on certain state transitions by external events representing signals supplied by sensors. The *A/DML* is assisted by *WMR* equipped with *RM* during disassembling in order to transport the disassembled components from the disassembly locations to the storage warehouse locations. Therefore, the assembly line becomes reversible, i.e. executes automated disassembly. A disassembly process is started when the final work piece, obtained by assembly, is damaged and fails quality test. The disassembled components are recovered and transported to the storage locations, in order to be reused in assembly process.
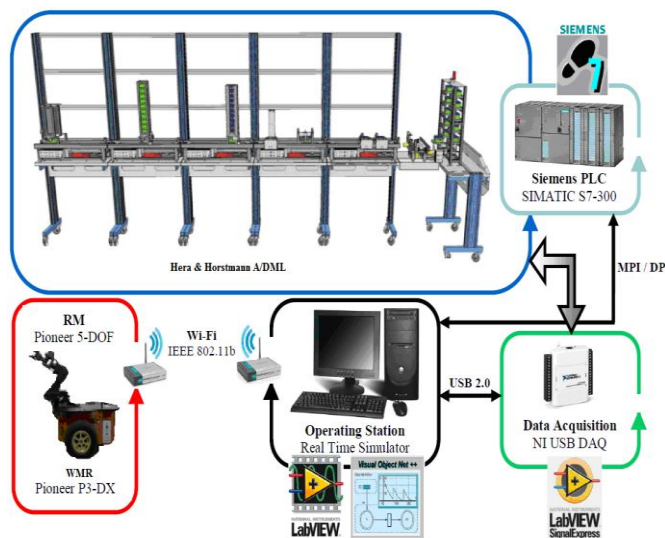

Fig. 8. Control structure of *A/DML* served by *WMR* with *RM*

The entire structure of the *A/DML* real-time control served by *WMR* is shown in Fig. 8. The *SHPN* model has been tested via simulation. and used in real-time control. The likeness with the real manufacturing/production/assembly line is evident.

REFERENCES

Baldwin, D. F., T. E. Abell, C. M. Lui, T. L. De Fazio, and D. E. Whitney, (1991) An integrated computer aid for generation and evaluation assembly sequences for mechanical products, *IEEE Transactions on Robotics until Automation*, , pp. 78-94.

Choi, C. K. X. F. Zhang., T. L. Ng, and W. S. Lau, (1998) On the generation of product assembly sequences, *International Journal of Production Research*, pp. 617-633.

David, R. and H. Alla, (2010) *Discrete, Continuous and Hybrid Petri Nets*, ISBN 978-3-642-10668-2, Springer-Verlag Berlin Heidelberg.

Minca, E., Voda, A., A. Filipescu and A. Filipescu, Jr., Hybrid Model Based Control of a Mechatronics Line Served by Mobile Robot with Manipulator, In Proceedings of the *8th IEEE International Conference on Industrial and Electronic Application (ICIEA2013)*, pp. 1296-1301, ISBN: 978-1-4673-6322-8, 19-21, June, 2013, Melbourne, Australia.

Minca, E., A. Filipescu and A. Voda, Processes, In Proceedings of the *9th Asia Control Conference (ASCC2013)*, ISBN:978-1-4673-5769-2, 23-26 June, 2013, Istanbul, Turkey.

Ganget, J., G. Hattenberger and R. Alami (2005) Task planning and control for multi-UAV system:architecture and algotithms, *IEEE Intl. Conf. On Intelligent Robot and System*, Vol.18, 758-768.

Kopacek, B. and P. Kopacek (1999), Robots for disassembly, *Proceedings of the 30th International Symposium on Robotics*, Tokyo, pp 207–212.

Radaschin, A., Voda, A., E. Minca and A. Filipescu, (2012) Task Planning Algorithm in Hybrid Assembly/Disassembly Process, *14th IFAC Symposium on Information Control Problems in Manufacturing*, May 23-25, 2012, Bucharest, ISSN: 1474-6670; ISBN: 978-3-902661-98-2, pp. 571-576.

Rosell, J. (2002) Assembly and task planning using Petri nets: A survey and a roadmap towards autonomous robotic assembly systems, *Technical report IOC-DT-P-2002-13*, Univ. Politecnica de Catalunya.

Seliger, G. W. Grudzien and H. Zaidi (1999) New methods of product data provision for a simplified disassembly, Proceedings of the *6th International Seminar on Life Cycle Engineering*, Kingston, Canada, June 21–23, pp. 250–259.