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A Theoretical Approach of the Time Cycle Optimisation Based Control of a Mechatronics Line Served by Mobile Robot

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Abstract. In this paper a theoretical approach of the generalized hybrid model and time cycle optimization of a mechatronics line served by mobile robot with manipulator is presented. Thus, the considered global model is a hybrid one as it is based on the dynamics of discrete and continuous components which interact on a basic level. The generalized Synchronized Hybrid Petri Nets (SHPN) model describes this hybrid system with N degree of repetitive tasks. The advantage of this generalized approach consists in the optimization of the process parameters. Consequently, a time cycle optimization which is based on the minimization of temporal duration events is proposed. The proposal is exemplified by the assembly/disassembly process of a mechatronics line (A/DML), served by a wheeled mobile robot (WMR) equipped with a robotic manipulator (RM).

Introduction

This paper proposes a generalized Synchronized Hybrid Petri Nets (SHPN) dedicated for hybrid repetitive process model. The hybrid system properties are identified only at the level of the disassembly process which is served by the mobile platform with the robotic manipulator as the continuous system. Within the defined system, the assembly is a conventional process and has a specific typology of discrete system events (DES). At the same time, this hybrid system takes into consideration the distribution of the tasks necessary to perform the hybrid disassembly of the components, using robot synchronization with A/DML. The tool SHPN is dedicated to model the control of hybrid systems, composed of repetitive tasks series. These repetitive components we define as the elementary operations. The proposal will be tested for a reversible assembly/disassembly manufacturing line (A/DML) served by wheeled mobile robot (WMR) equipped with robotic manipulator (RM).

Description of the generalized hybrid system

The considered system is a hybrid one and requires specialized tools for modeling, as in [3].The hybrid model is elaborated using the dedicated modeling tool, HPN, described in [9] and [10]. General approach will customize to an A/DML, didactic mechatronics line, HERA&Horstmann, shown in Fig.1a and 1b, which makes assembling a piece of five components, shown in Fig.1c and Fig. 1d. The assembly/disassembly operations can by decomposed into a sequence of elementary assembly tasks coupled in parallel with positioning tasks of work-piece along conveyor, as in [1], [2], and [4].

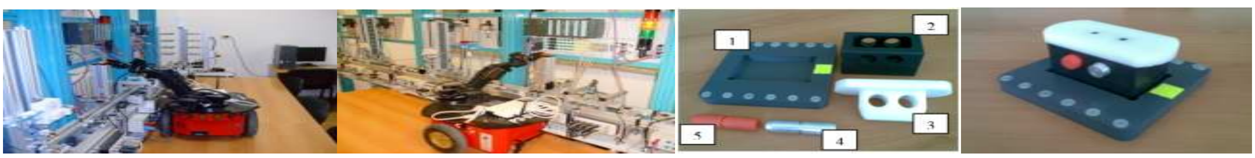

Fig 1. a) and b) assembly line, Hera, served by WMR, Pioneer 3-DX, equipped with RM, Pioneer 5-DOF Arm; c) parts; d) assembled product

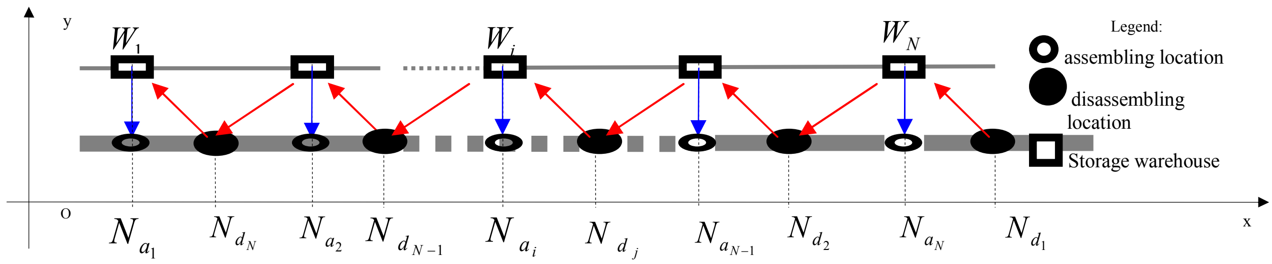

Fig 2. Assembly/Disassembly and storage warehouse locations

The hybrid disassembly strategy is based on the hierarchical model proposed in [5], [6], [7] and [8] which uses the general representation from Fig. 2. SHPN structure from Fig. 3 is obtained by modeling of assembly/disassembly and continuous service assistance, for disassembly operations, performed by mobile platform equipped with manipulator. The entire model is SHPN type because it is interfaced with external events for synchronization in an approach of modeling/simulation, useful in real-time control. SHPN morphology results by integration three PN models. 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).

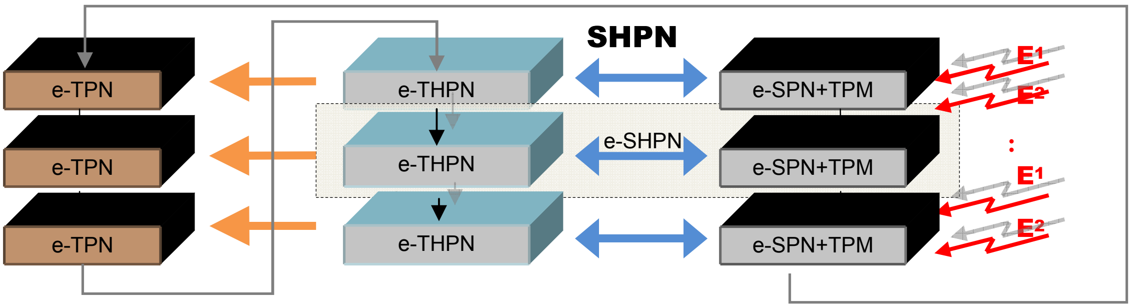

Fig 3. The SHPN representation by blocks with elementary modules:e-TPN for assembly, e-THPN for WMR with RM, e-SPN+TPN for disassembly and e-SHPN for disassembly served by WMR with RM.

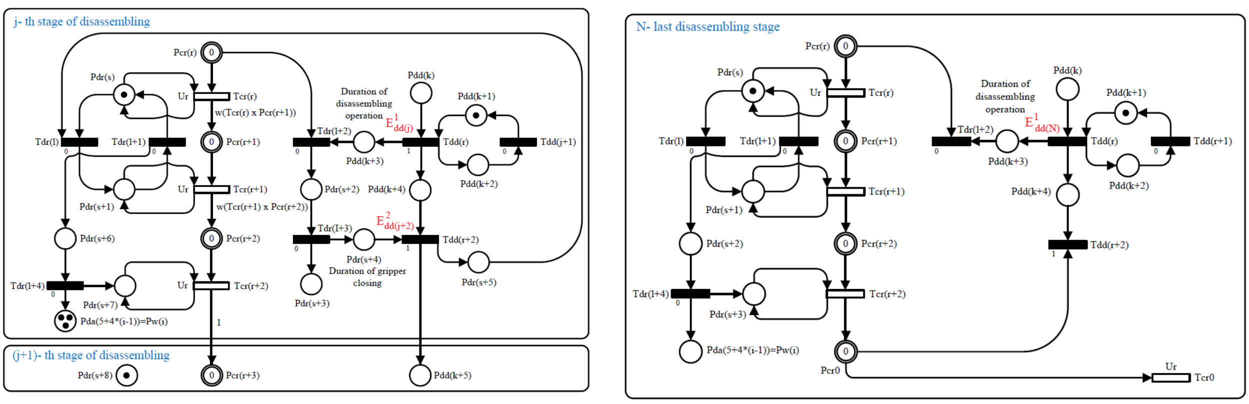

Fig 4. a) e-SHPN model of j-th elementary disassembly operation; b) SHPN model of the last disassembly operation, $j = N$

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, as is represented in Fig. 4.a). Because after the last disassembly operation is no longer necessary line starting to a next disassembly, the SHPN model is different from others and is shown in Fig. 4.b).

Let us consider the following notations:

- $r = 1 + (j-1)\cdot 3$- indexes a continuous place of the robot states, Pcr; a continuous transition of the robot, Tcr and a discrete transition of disassembly process Tdd.
- $k = 1 + (j-1)\cdot 5$- indexes a discrete place of disassembly process, Pdd.
- $l = 1 + (j-1)\cdot 4$ - indexes a discrete place of the robot states, Tdr.

Optimization of the Time Cycle corresponding to the control of repetitive processes

The weights of the arcs $w(r), w(r+1)\big|_{r=1+3\cdot(j-1)_{j=\overline{1,N}}}$ in e_SHPN network (Fig.2) are:

$$\begin{cases} w_r = w\left(T_{cr_r}, P_{cr_{r+1}}\right)\big|_{r=1+3\cdot(j-1)_{j=\overline{1,N}}} \\ w_{r+1} = w\left(T_{cr_{r+1}}, P_{cr_{r+2}}\right)\big|_{r=1+3\cdot(j-1)_{j=\overline{1,N}}} \end{cases} = \begin{cases} w_r = D\left(W_{N+1-j}, N_{d_{j+1}}\right)/D\left(n_{d_j}, N_{N+1-j}\right)\big|_{r=1+3\cdot(j-1)_{j=\overline{1,N}}} \\ w_{r+1} = D\left(N_{d_{j+1}}, W_{N-j}\right)/D\left(W_{N+1-j}, N_{d_{j+1}}\right)\big|_{r=1+3\cdot(j-1)_{j=\overline{1,N}}} \end{cases} \tag{1}$$

The duration of the mobile robot's elementary cycle – the time cycle, consists of the constant speed times travel between the warehouse-work post distances and to the robot's stationary durations: • the duration of the elementary disassembly operation corresponding to "j" stage of disassembly (d_{dd_r}); • the travel duration of the mobile robot between the operations: stationary in the working point - storage warehouse $D\left(N_{d_j}, W_{N+1-j}\right)/Vr$; storage warehouse - moving to the next work point $D\left(W_{N+1-j}, N_{d_{j+1}}\right)/Vr$; • the picking up and dropping down durations for a disassembled component, followed by gripper closing (d_{dr_l}).

For the "j" stage of disassembling within the SHPN model, the value of this variables are defined by the temporal marking evolution ($m_{cr_{r+1}}$) of the $P_{cr_{r+1}}$ places (Fig.2). In this case the duration of the elementary cycle (T_{EC}) for the mobile robot are:

$$T_{EC} = D\left(N_{d_j}, W_{N+1-j}\right)/V_r + d_{dd_r} + d_{dr_l} + D\left(W_{N+1-j}, N_{d_{j+1}}\right)/V_r \tag{2}$$

or:

$$T_{EC} = m_{cr_{r+1}}/Vr = m_{cr_r}/Vr + d_{dd_r} + d_{dr_l} + m_{cr_{r+2}}/V_r\Big|_{\substack{r=1+3\cdot(j-1)_{j=\overline{1,N}};\\ l=4+5\cdot(k-2)_{k=\overline{2,N}};\\ j=\overline{1,N}}} \tag{3}$$

where:

$$m_{cr_r} = D\left(N_{d_j}, W_{N+1-j}\right),\ m_{cr_{r+2}} = m_{cr_r}\cdot w_r \cdot w_{r+1} = D\left(W_{N+1-j}, N_{d_{j+1}}\right) \tag{4}$$

The optimization of entire robot cycle T_{robot_cycle} implies the minimization of duration disassembly operations (if possible) and the minimization of the manipulation durations. The temporal synchronization restriction envisaging the robot's and the piece's travel on the conveyer results from the blockage avoidance condition within the SHPN network (27):

$$T_{robot\_cycle} = \sum_{j=1}^{N} D\left(N_{d_j}, W_{N+1-j}\right)/V_r\Big|_{j=\overline{1,N}} + \min\left(\sum_r d_{dd_r} + \sum_l d_{dr_l}\right)\Big|_{\substack{r=1+3\cdot(k-1)_{k=\overline{1,N}}\\ l=4+5\cdot(k-2)_{k=\overline{2,N}}}} + \sum_{j=1}^{N} D\left(W_{N+1-j}, N_{d_{j+1}}\right)/V_r\Big|_{j=\overline{1,N}} \tag{5}$$

$$\begin{cases} T_{robot\_cycle} = \sum_{j=1}^{N} D\left(N_{d_j}, W_{N+1-j}\right)/V_r + \min\left(\sum_r d_{dd_r} + \sum_l d_{dr_l}\right)\Big|_{\substack{r=1+3\cdot(k-1)_{k=\overline{1,N}}\\ l=4+5\cdot(k-2)_{k=\overline{2,N}}}} + \sum_{j=1}^{N} D\left(W_{N+1-j}, N_{d_{j+1}}\right)/V_r \\ \min\left(d_{dd_r} + d_{dr_l}\right) \le D\left(W_{N+1-j}, N_{d_{j+1}}\right)/V_r \end{cases} \tag{6}$$

Conclusions

A theoretical approach of the generalized hybrid model and time cycle optimization of a mechatronics line served by mobile robot with manipulator is presented in this paper. The SHPN model is conditioned on certain state transitions by external events representing signals supplied by sensors. The A/DML is served by a WMR equipped with RM which is used only in disassembling in order to transport the disassembled components to the storage warehouses. Therefore, the assembly line becomes reversible, i.e. executes automated disassembly. Consequently this modeling theoretical approach, a time cycle optimization which is based on the minimization of temporal duration events is proposed. The SHPN model has been tested via simulation and used in real-time control for testing the theoretical approaches.

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