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Modelling and control of an assembly/disassembly mechatronics line served by mobile robot with manipulator

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ABSTRACT

The aim of this paper is to reverse an assembly line using a mobile platform equipped with a manipulator. By reversibility we mean that the line is able to perform disassembly. For this purpose, an assembly/disassembly line balancing (A/DLB) and a synchronised hybrid Petri nets (SHPN) model will be used to model and control an assembly/disassembly mechatronics line (A/DML), with a fixed number of workstations, served by a wheeled mobile robot (WMR) equipped with a robotic manipulator (RM). The SHPN model is a hybrid type, where A/DML is the discrete part, and WMR with RM is the continuous part. Moreover, the model operates in synchronised mode with signals from sensors. Disassembly starts after the assembly process and after the assembled piece fails the quality test, in order to recover the parts. The WMR with RM is used only during disassembly, to transport the parts from the disassembling locations to the storage locations. Using these models and a LabView platform, a real-time control structure has been designed and implemented, allowing automated assembly and disassembly, where the latter is assisted by a mobile platform equipped with a manipulator.

1. Introduction

The approach proposed in the paper responds to the concepts of planning and control of the processes of assembly/disassembly on mechatronics lines served by mobile platforms equipped with manipulators, with emphasis on the planning of operations.

An assembly line is a flow-oriented production system where the productive units perform operations on workstations, which may be configured as serial, parallel, circular, U-shaped, cellular or two-sided lines. The work pieces visit stations successively as they are moved along the line, usually by some kind of transport system, e.g., a conveyor belt (Choi, Zhang, Ng, & Lau, 1998). Disassembly operations involve separation of the reusable parts from the discarded products. These parts either undergo remanufacturing operations or are sold to suppliers (Kopacek & Kopacek, 1998; Seliger, Grudzien, & Zaidi, 1999). Assembly/disassembly manufacturing systems are real-time and complex control systems, which involve multiple operation conditions and tasks. Hybrid systems are currently the focus of considerable attention. The assembly/disassembly manufacturing lines served by mobile robots have hybrid characteristics, consisting of continuous dynamic behaviours and discrete event behaviours. Hybrid Petri Nets (HPNs) are tools used to model such systems (Ghomri & Alla, 2008; Minca, Filipescu, & Voda, 2012; Voda, Radaschin, Minca, & Filipescu, 2012). The assembly/disassembly plans are made up of parts or subassemblies that are fitted together (Albus & Meystel, 1996). Particularly relevant research topics 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 capable of producing a detailed operation plan, including planning sensory action, planning manipulator action, planning the trajectory of mobile robots (Gasparetto & Zanotto, 2007), rough motion planning, fine motion planning and other planning (Feng & 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 developed off-line, and how to react to various situations that arise during plan execution (Ganget, Hattenberger, & Alami, 2005). These issues can be further classified into: plan monitoring, reactive scheduling, and behaviour-based action. The assembly/disassembly planning process involves more complex requirements such as geometric relationships, performance measurement and evaluation, resource scheduling, kinematics control, and system planning. This is a difficult task for complex assembly/disassembly lines in a concurrent and flexible manufacturing environment. These factors combined make real assembly/disassembly planning more difficult and require extensive experience

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and knowledge on the part of the designer and production engineer. Up to now, numerous techniques in task planning, such as use of binary matrices, directed graphs, establishment conditions, precedence relationships, AND/OR graphs (Cao & Sanderson, 1998), have been proposed for generation and representation, reasoning, and search of assembly plans in designing intelligent and efficient assembly/disassembly operations, 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. Using this 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 disassembling a specific component, the task planner can provide the best sequence for reaching the specific component (Moore, Gungor, & Gupta, 2001). If the fully assembled product fails the quality test, the task planner provides the best sequence for completely disassembling the product. A comprehensive knowledge-based approach to disassembly task planning is required, which considers all aspects of complex interaction and domain knowledge subjected to technical and economic constraints (David & Alla, 2010). Development of knowledge based on a HPN model integrated with a sequence generation algorithm was successfully applied to modelling and planning of a flexible disassembly process and system at a high level. However, the typology of the autonomous mobile robot with manipulator, disassembly planning method, and task level planning, greatly improves the efficiency of the entire process and reduces the cost of product disassembly. Task specification in low-level task planning consists in changing models or operation sequences (Hiraishi, 1999). This paper presents a Synchronised Hybrid Petri Nets (SHPN) model for an Assembly/Disassembly Mechatronics Line (A/DML) served by a Wheeled Mobile Robot (WMR) equipped with a Robotic Manipulator (RM), together with an Assembly/Disassembly Line Balancing (A/DLB) model. Disassembly line balancing is used to find the set of tasks assigned to each workstation for each product to be disassembled. The problem is critical for minimising the use of valuable resources (such as time and money) invested in disassembly, and maximising the level of automation of the disassembly process and the quality of the parts or materials recovered (McGovern & Gupta, 2007). In this thesis, we consider a Disassembly Line Balancing Problem (DLBP) with a fixed number of workstations so as to maximise the value of recovered parts. Lambert (2002) emphasises that a disassembly process does not imply a reverse assembly process. The A/DLB and SHPN models have been customised for an assembly mechatronics line, which assembles a 5-part product. Using the LabView platform, real-time control of A/DML served by WMR with RM is presented, based on A/DLB and SHPN models. These models provide a high-level description of the product to be disassembled. The aim is to assign the tasks to the disassembly line workstations so as to maximise the total value of the recovered parts. The disassembly operations are performed on the same assembly line, consisting of a number of linear configured workstations. The first workstation takes the product to be disassembled, and the parts are disconnected on different workstations. A cycle terminates, i.e. the product leaves the line, whenever all its required parts are disassembled. In this paper, the concepts of assembly/disassembly tasks are illustrated in a SHPN model, which complies with both aspects: the discrete approach for the elementary assembly/disassembly operations, and the continuous approach for displacement of WMR. Thus, the A/DML system becomes reversible and is served, during the disassembling process, by a robotic manipulator mounted on a mobile platform. The A/DML dynamics are determined by events, supplied by the control sequences of the automatic system, and by interaction with the WMR, which represents the continuous time part of the system. The considered system is a hybrid one and requires specialised tools for modelling. The hybrid model is elaborated using the dedicated modelling tool, HPN, described in David and Alla (2010). A SHPN model results from the combination of the SED model of the analysed system with the cyclic and continuous time of the WMR with RM.

The rest of the paper is organised as follows: in Section 2, useful preliminary assumptions are laid out for developing A/DLB and SHPN models; a model with an objective function, useful for optimising A/DBL, is presented in Section 3; the description of the A/DML served by WMR with RM is shown in Section 4; a SHPN model, in generalised and customised form, is elaborated in Section 5. Simulation results are also presented for the customised SHPN model associated with A/DML, served by WMMR equipped with RM; in Section 6, using the LabView platform, real-time control of A/DML is briefly presented, served by WMR equipped with RM, based on A/DLB and SHPN models; some final remarks can be found in Section 7.

2. Preliminary remarks concerning A/DLB and SHPN models

The assembly/disassembly line is served by a WMR equipped with RM during the disassembly phase, Fig. 1. The aim is to make the assembly/disassembly line balanced and reversible. Moreover, the mobile robot is used to carry the disassembled components to a proper storage warehouse.

2.1. Assembly assumptions

Assembly lines are special flow-line production systems, which are typical in industrial production of high quantity standardised commodities. According to Choi et al. (1998), there are several classification schemes for assembly lines, which take into account the nature of the products, operation modes and the nature of operation times. Corresponding to these classifications, the following assumptions hold concerning the assembly of mechatronics systems:

A.1. The A/DML is a single-model line, by the nature of the product, paced line (transfers between the workstations are

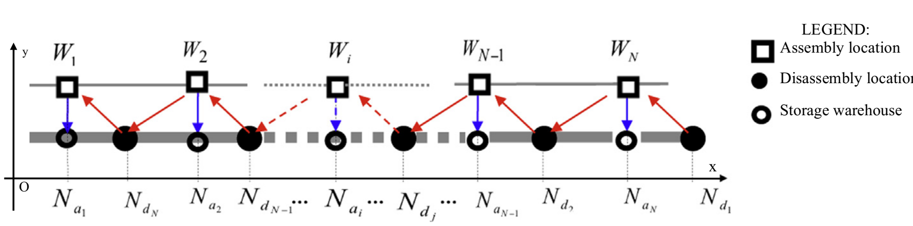

Fig. 1. Assembly/disassembly and storage warehouse locations.