„Dunărea de Jos" University of Galaţi

Doctoral School of Engineering

Ph. D. Thesis Abstract

CONTRIBUTIONS TO ELECTRIC DRIVE OF THE FLEXIBLE MANUFACTURING LINES AND INTEGRATED ROBOTS

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Abbreviations

A/D-assembly/disassembly;
A/DML-assembly/disassembly mechatronics line;
ALB-assembly line balancing;
A/DLB-assembly/disassembly line balancing;
API-application programming interface;
ARIA-advanced robotic interface for applications;
CAM-computer aided manufacturing;
CAD-computer aided design;
CAE-computer aided engineering;
CAQ-computer aided quality;
CAP-computer aided planning;
CAS-computer aided service;
CNC-computer numerical control;
CT-cycle time;
DES-discrete events system;
DLB-disassembly line balancing;
DOF-degree of freedom;
DV-decision variable;
DW-driving wheel;
ED-electric drive;
FML-flexible manufacturing line;
FMML-flexible manufacturing mechatronics line;
FMC-flexible manufacturing cell;
FW-free wheel;
GUI-graphic user interface;
HPN-hybrid Petri net;
I/O-input/output;
LB-line balancing;
ML-mechatronics line;
MPI-message passing interface;
MPS-mechatronics processing system;
NR-net revenue;
OOP-object oriented programming;
PC-Personal computer;
PLC-programmable logic controller;
PN-Petri net;
P/R-processing/reprocesing;
P/RML-processing/reprocesing mechatronics line;
Profibus DP-professionl field bus descentralized periphery;
Profinet-professional network;
RM-robotic manipulator;
SHPN-sinchronised hybrid Petri net;
SIMATIC-SIEMENS family controllers for automation;
SIMATIC STEP 7-software package for SIEMENS controllers;
SP-strategic planning;
SIPs-server information packets;
SM-sliding-mode;

SMC-sliding-mode control;
SM-TT-sliding mode-trajectory tracking;
TC-task cycle;
TPN-timed Petri net;
THPN-timed hybrid Petri net;
TP-task planning;
TT-trajectory tracking;
WMR-wheeled mobile robot.

Flexible manufacturing lines served by mobile robotic systems

Lately, the industry has faced with new global evolution, driven by the technological progress. This improvement extends to all industrial domains and triggers the evolution of new generations of advanced flexible production systems and new methods of centralized management distributed or supervised. In addition, this involves the evolution of new types of robots and processing machine tools and the need of efficient transport and manipulation systems. The approach proposed in this thesis responds to the concepts of planning and control of the manufacturing of assembly/disassembly, (A/D), and of processing/reprocessing, (A/P), on laboratory systems, mechatronics lines served by mobile platforms equipped with manipulators, with emphasis on the planning of operations. The most eloquent correspondents in the real world are assembly processes in the automotive industry, car body, gearbox and engine block assembly. In most cases, robotic manipulators that have a fixed location serve these assembly and/or processing lines. Through this study, we extended the degree of automation and efficiency of these production lines using mobile robotic systems equipped with manipulators. The assembly lines become reverse, being able to recover and reuse of components and subassemblies, in the event that the final product does not meet quality requirements. The processing lines become able to reprocess components that support this operation, in the event that the final product does not meet quality standards. Assembly and processing mechatronics lines are 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. Disassembly operations involve separation of the reusable parts from the discarded products. Reprocessing involves the return piece on the production line to be subject to the same processing operations, to fit the required parameters. These parts undergo remanufacturing operations or sale to suppliers. Assembly/disassembly and processing/reprocessing, manufacturing systems are real-time and complex control systems, which involve multiple operation conditions and tasks.

State of Art. Hybrid approach

Hybrid systems are currently the focus of considerable attention. A/D and P/R 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. A/D plans are made up of parts or subassemblies that are fitted together. P/R plans are operation sequences (drilling, reaming, extrusion, bending, etc.), executed in serial or parallel so that the product meets the quality requirements. Particularly relevant research topics include A/D and P/R 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, rough motion planning, fine motion planning and other planning. 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. These issues can be further classified into: plan monitoring, reactive scheduling, and behaviour-based action. A/D and P/R planning processes involve complex requirements such as geometric relationships, performance measurement, evaluation, resource scheduling, kinematics control, and system planning. This is a difficult task for complex A/D and P/R lines in a concurrent and flexible manufacturing environment. These factors combined make real A/D and P/R planning more difficult and require extensive experience 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, have proposed for generation and representation. Have to search assembly or processing plans to design intelligent and efficient A/D or P/R, where operators (robot or human) autonomously perform a given task based on certain designated, stored or sensed information. However, mobile robotic systems with manipulators and planning strategies oriented to the characteristics of the system is often more effective than techniques derived from domain-independent methods. Conventional representation of the system models without constraints may result in a huge search space for feasible plans. Using these models, the task planners can determine the sequence of parts that must remove or the sequence of reprocessed operations to achieve specific sequences of tasks. If the target consists of disassembling a specific part or performing a specific operation, the task planner can provide the best sequence for reaching it. If the fully assembled or processed product fails the quality test, the task planner provides the best sequence for completely disassembling or reprocessing. A comprehensive knowledge-based approach to disassembly or reprocessing task planning is required, which considers all aspects of complex interaction and domain knowledge subjected to technical and economic constraints. 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.

Flexible manufacturing mechatronics line served by mobile robotic systems

The research performed in the framework of thesis also includes getting of generalised Synchronised Hybrid Petri Nets (SHPN) models for two mechatronics lines: Assembly/Disassembly Mechatronics Line (A/DML) and Processing/Reprocessing Mechatronics Line (P/RML) served by Wheeled Mobile Robots (WMRs) equipped with Robotic Manipulators (RMs). SHPN models have customised for an assembly mechatronics line, HERA&HORSTMANN, which assembles a 5-part product and a mechatronics line, FESTO MPS-200, of 4-workstations, respectively. To A/DML, two cases have considered: first, A/DML is served by a WMR equipped with RM; second, A/DML is served by two WMRs, parallel working, one is equipped with RM, used for manipulation and the other used for transport. Using the LabView or Visual C++ platform, real-time control of A/DML served by one or two WMRs based on SHPN models is presented. 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 thesis, the concepts of A/D tasks are caught in SHPN models which comply with both aspects: the discrete approach for the elementary A/D operations, and the continuous approach for displacement and handling operations executed by the robotic systems. Also, a SHPN model for P/RML, served by the WMR equipped with RM is presented. The problem is critical for minimizing the use of valuable resources (such as time and money) invested in reprocessing, and maximizing the level of automation of the process. The aim is to assign the tasks to the processing line workstations to reprocess the pieces that fail the quality test. The reprocessing operations are performed on the same line. Using the MATLAB platform real-time control of P/RML served by one WMR based on SHPN models is presented. A/DML and P/RML dynamics are triggered by events, supplied by the control sequences of the automatic system, and by interaction with the WMRs, which represent the continuous time part of the system. The considered systems are hybrid ones and requires specialised tools for modelling. The hybrid models are elaborated using the dedicated modelling tool, HPN. A SHPN model results from the combination of the SED model of the analysed systems with the cyclic and continuous time of the WMRs with RM. The proposed models, have been tested, analysed and verified through simulation package Sirphyco.

Thesis objectives

- Modelling, acting and control of WMRs equipped with RMs:
- Task planning, balancing (optimising), hybrid modelling, simulation and control of A/DML served by a WMR equipped with RM. General case. Customization

to A/DML, HERA&HORSTMANN, served by one WMR, Pioneer 3-DX, equipped with RM, Pioneer 5-DOF Arm;

- Flexible manufacturing hybrid technology fully automatic, on A/DML, HERA&HORSTMANN, served by one WMR with RM, tested in laboratory;
- Task planning, balancing, hybrid modelling, simulation and control of A/DML served by two WMRs equipped with RM. General case. Customization to A/DML, HERA&HORSTMANN, served by two collaborative WMRs one of them equipped with RM, Pioneer 3-DX, equipped with RM, Pioneer 6-DOF Arm, used for manipulation, and the other, PatrolBot, used for transport. Testing in laboratory;
- Task planning, hybrid modelling, simulation and control of P/RML, FESTO MPS-200 served by one WMR, Pioneer 3-DX, equipped with RM, Pioneer 5-DOF Arm;
- Flexible manufacturing hybrid technology, based on visual servoing systems, fully automatic, on P/RML, FESTO MPS-200, served by one WMR with RM, tested and validated in laboratory.

Chapters' content

In Chapter 1, kinematic modelling, electric drive and control of WMRs with two driving wheels and one or two free wheels (2DW/1FW, 2DW/2FW) are presented. Also, Modelling, electric drive and control of WMRs: 2DW/1FW Pioneer 3-DX and 2DW/2FW PatrolBot are presented.

Structure, functionality, electric drive and control of flexible manufacturing lines served by robotic systems with customization to A/DML, HERA&HORSTMANN, and P/RML, FESTO MPS-200 are presented in Chapter 2.

In Chapter 3, useful preliminary assumption, hardware, task planning and balancing are laid out for WMRs integrated into A/DML and P/RML.

SHPN model and its simulation in Sirphyco of the A/DML served by one WMR with RM in generalised and customised form, is shown in Chapter 4. Also, SHPN model and its simulation in Sirphyco of two WMRs integrated into A/DML, are presented in Chapter 4. Also, in Chapter 4, it is presented SHPN model and its simulation of the P/RML served by a one WMR with RM.

Using LabView, Visual C++ and MATLAB platforms, real-time control of WMRs servicing A/DML and P/RML based on SHPN models, are presented in Chapter 5.

Final remarks, contributions, future research directions and dissemination of results can be found in Chapter 6.