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SPECIAL ISSUE ON RECENT ADVANCES IN FLEXIBLE AUTOMATION

Xun Xu[1], Kazuo Mori[2] and Jun Ni[3]

[1]Department of Mechanical Engineering
University of Auckland
Private Bag 92019, Auckland, New Zealand
x.xu@auckland.ac.nz

[2]Industrial Technology Research Centre
Tochigi Prefectural Government
367-1 Karinuma-machi, Utsunomiya, Tochigi 321-3224, Japan
mori.k@aist.go.jp

[3]Department of Mechanical Engineering
College of Engineering
University of Michigan
1023 HH Dow, Ann Arbor, MI 48109 -2136, USA
junni@umich.edu

Abstract. *Flexible Automation as a topic of research has been around for at least a half century. In the late 70's, flexible manufacturing cell/systems (MFC/MFS) started playing pivotal roles in modern industry, in particular automobile industry. However, the journey of going from a theory or vision to an art or reality did not end there and then. In the last two decades, flexible automation has taken on many new concepts, technologies and practices. This evolution process has resulted in numerous new terminology in replacement (or sometimes in favor) of flexible automation. Nonetheless, the ultimate goal remains - empowering the modern industry with different "versions" of automation technologies in order to meet the ever-diverse and ever-changing market. It is the time that we go back to the "basics", i.e. flexible automation by embracing a raft of new technologies that are evolved from the basic concept of flexible automation. This is the main aim of this special issue, which is made possible due to a timely international conference named "International Symposium on Flexible Automation (ISFA 2006)", held in July 10-12, 2006, in Osaka, Japan. Most of the articles are selected from, and expanded based on, the presentations at the conference. There are twelve articles included in this special issue. They can be grouped into four categories, (1) New Advances at the CNC Front, (2) Advancement in Automation Hardware, (3) Intelligent Scheduling in FMS, and (4) IT Issues in a Manufacturing System.*

1. **New Advances at the CNC Front.** Over the years, most of the flexible automation systems have Computer Numerically Controlled (CNC) machine tools as the principal manufacturing equipment. G-codes (ISO 6983, RS 274 as known in the USA, or DIN 66025 as known in part of Europe) have been extensively used by the CNC machine tools for part programming and are now considered as a bottleneck for developing next generation CNC machines. A new standard for STEP-compliant Computer Numerical Controllers, informally known as STEP-NC, is being developed as the data model for a new breed of CNCs. This data model represents a common standard specifically aimed at the intelligent CNC manufacturing workstation, making the goal of a standardized CNC controller and NC data generation facility a reality.

There are two papers in this special issue reporting on some of the pioneering work. The paper titled, "A Design-by-Feature Approach to STEP-Compliant NC Programming" by Liu, Zhang, Zhang and Wang, takes advantage of STEP-NC's high-level data structure that enables a comprehensive description of a machined part together with technological information to be passed in a well-organized structure down to the CNC machine. In order to automate and streamline the generation process of such rich-information programs, this paper proposed usage of the STEP-NC manufacturing features right at the modeling stage, and suggested an integrated framework for part modeling, process planning and part program generation through direct use of the manufacturing features and the adoption of the STEP-NC data model.

The paper by Wang, Xu, Sun, Li and Wang, titled "Development of an NC Controller for Next Generation CNCs", is another article on STEP-NC research. The purpose of this research is to investigate an intelligent STEP-NC controller, which involves a STEP-NC Parser and a Motion Controller. The STEP-NC Parser is programmed in VC++ in conjunction with the STIX library. All STEP-NC entities such as Workplan, Workingsteps, Machining Features, Operations and Machining Strategy, can be extracted by the Parser. The motion controller consists of a Digital Signal Processor (DSP) and a Complex Programmable Logic Device (CPLD). The DSP is responsible for tool path programming and servo controls whereas CPLD controls the positions of the axes as well as other interfaced devices. This STEP-NC controller has the advantages of being modular, open, simple in structure, bi-directional in data flow and feature-based.

The third article titled "Tool Path Generation Technique of NC Lathe Machines in FTL Development by GA" by Ramli and Yamamoto, addresses numerical control from within a Flexible Transfer Line (FTL). FTLs have been used by many manufacturers as their strategies to improve their production efficiencies. A typical FTL is established by having both machining centers and CNC lathes in the production line. It is therefore difficult and also critical to work out the optimal tool paths in an FTL because of its short machining cycle time. In this paper, Genetic Algorithms (GA) has been used to automatically decide the part reverse point and to generate the tool paths when a workpiece is machined by a CNC lathe in the FTL. The GA approach adopts the moving points of a tool path as an individual, and two original individual expressions are proposed. The first expression is defined by adopting an absolute value of the tool path as Absolute Expression and the second is defined by adopting the incremental value of the tool path as an Incremental Expression.

2. **Advancement in Automation Hardware.** Hardware development for automation systems has not stopped and will perhaps never. There are three papers in this issue discussing some of the advancements related to automation hardware, e.g., Automatic Guided Vehicles (AGVs), Master Slave Manipulator and flexible machining of non-cylinder piston pinhole. Yamamoto and Ramli's paper, titled "Real-Time AGV Actions Control by Dialogue to Realize Autonomous Decentralized FMS", focuses on an autonomous decentralized FMS. This type of FMS aims at high production efficiency by self-controlling or decentralizing the plan, design and operation of a FMS. This paper discusses the realization of an autonomous decentralized FMS with AGVs and machining centers. A real-time production control method has been developed that can manage current production situations as well as predict the future ones. The research has demonstrated that a multi-production scenario that keeps the target production ratio is also possible even though neither AGV actions' plans nor parts input schedules are given beforehand.

Robot manipulators are commonly used equipment for flexible automation, tele-operation system, power assisting systems and haptic devices. For conventional tele-operation systems, sense of force acting on robot manipulator cannot be exactly transferred to human operators. It is expected to realize a sense of force between the control element and the robot manipulator for master slave manipulation systems. The paper titled "Force Display for Master Slave Manipulator with Different Configurations" by Ikegami, Nishi and Konishi, presents a new type of interactive master slave manipulation system for tele-operation. The system consists of a master and a slave subsystem with different structure. These two subsystems are governed by a bilateral control scheme. For master slave manipulation systems, nonlinear interferences may deteriorate the performance in a bilateral control system. To capture a sense of force, the bilateral control scheme together with a decoupling control for slave is introduced to the master manipulator with different configurations.

Zhai, Zhang, Hu, Chen, Wang and Yu reported in their paper titled "Flexible Machining for Non-Cylinder Piston Pinhole Based on GMM" a machining system that housed a novel mechanism based on Giant Magnetostrictive Materials (GMM) for improved precision machining of a non-cylinder piston pinhole. In order to bear more loads for heavy truck pistons, the shape of a heavy truck piston pinhole is often designed in a non-cylinder form. Hence precisely machining it is a challenge. New models have been established for the servo mechanism, GMM and magnetizing force of the control solenoid to characterize the relationship between the control current of the solenoid and the displacement of the Giant Magnetostrictive Actuator.

3. **Intelligent Scheduling in FMS.** Scheduling in FMS and transportation routing for AGV has been widely studied in the past. In spite of this, it is almost impossible to obtain near optimal solution by the dispatching heuristics. In this study, a decentralized optimization method for production scheduling, transportation routing for AGVs and motion planning for material handling robots has been developed. The system consists of a process agent that creates production schedule, AGV agents to generate collision-free routing for multiple AGVs, and a handling agent that determines motion planning for material handling system. Each agent repeats the information exchange and re-plans until a feasible solution is found. This research is reported in the paper, "Distributed Optimization Method for Simultaneous Production Scheduling and Transportation Routing in Semiconductor Fabrication Bays" by Furusho, Nishi and Konishi.

Scheduling problem is also found in other type of production systems and have a lot to do with material handling. Hirashima, in his paper titled "A Q-Learning System for Container Transfer Scheduling Based on Shipping Order at Container Terminals", looks at the material handling problem at a marine container-yard terminal in order to reduce the ship waiting time. A Q-Learning algorithm based on the number of container-movements for the material handling in the container-yard terminal is proposed. Each container has several desired positions based on its shipping order, so that the learning performance can be improved.

4. **IT Issues in a Manufacturing System.** Dealing with information at the shop-floor is not a new task for any manufacturing system. Only has the information become more and more diverse, complicated, inter-related and needing prompt attention in a modern manufacturing system. The information may be concerned with product design or the entire product lifecycle. IT tools are also needed for better managing supply chain planning and global information integration.

Setchi and Lagos in their paper "Adaptive, Responsive and Reconfigurable Product Support for Future Manufacturing", described their strategy of moving towards reconfigurable manufacturing by providing manufacturing industry and research with an integrated approach to developing highly customized and responsive product support for new product development. The paper presents the key features of the proposed approach, its enabling technologies, architecture and development phases, such as development of training materials and their integration with the automation system, integration of the training materials with the diagnostic modules, and provision of context-aware training.

Haapala, Rivera and Sutherland in their paper titled "Application of Life Cycle Assessment Tools to Sustainable Product Design and Manufacturing" examined how designers and planners can address key sustainable manufacturing measures such as energy use, resource consumption, waste production and occupational health. As an illustration, the functional and life cycle performance of several alternatives for a steel component are analyzed. A sensitivity analysis is performed to identify the product and process variables with the greatest effect on the entire life-cycle impact. Finally, the analysis considers how changes in the product/process design may impact production economics and measures of sustainable performance.

In the paper "Effects of Inventory Control on Bullwhip in Supply Chain Planning for Multiple Companies" by Tominaga, Nishi and Konishi, the influence of safety parameters for inventory control method on bullwhip effects is studied for supply chain planning in multiple companies with uncertain demands. A production planning model has been developed to represent actual planning environments where demand variances in the future periods are gradually available with respect to the progress of time steps.

In order to resolve data quality problems occurring in global value chains, the concept of Master Data Management (MDM) is proposed by Luh, Pan and Wei in their paper titled "An Innovative Design Methodology for the Metadata in Master Data Management System". The concept of MDM is that the management rights of Master Data (MD) be isolated from enterprise systems. This concept can be applied to resolve issues over global management, such as global flexible automation. The design methodology has four phases: MD Dimensions, MD Views, MD Classifications and MD Definitions.

The above twelve papers are not to be considered as inclusive as far as flexible automation research is concerned. Instead, it should provide a snapshot of some of the advancements and new trends in the field. The Guest Editors would like to thank all the authors for their contributions. Many thanks go to Professor Peng Shi, the Editor-in-Chief, for his great support and help. The editors are also grateful to the numerous reviewers who have helped shape the papers to an elevated level.