Technique for Synthetic Modeling of the Hardware Architecture in Machining System Reconfiguration

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ABSTRACT

A technique for synthetic modeling of the hardware architecture for reconfigurable machine tools (RMTs) is proposed. The aim is the verification of machine control. The virtual environment proposed allows to simulate RMT working in order to generate a set of kinematically viable reconfigurable machine tools that meet the given design specifications. Moreover the software also builds the layer for communication between modules controllers. The technique proposed in this paper embodied by the new RMT machining system reconfiguration software is presented. This technique allows for the simplification of RMT system development and enhances development ability.

KEYWORDS: machining system reconfiguration, virtual manufacturing, hardware architecture modeling, virtual reality, kinematic model, simulation.

1. Introduction

Manufacturing market becomes increasingly saturated as far as the demands are concerns of the global market due to the rapid development of science and technology. Manufacturing companies need to rapidly change production to new products or new versions of the existing products in order to meet the new global market requirements. A relatively new concept was proposed to meet these requirements namely the Reconfigurable Manufacturing System (RMS) which was considered a solution for the new challenges in manufacturing [4].

The characteristic feature of RMS is that the structure of the system as well as of its machines and controls can be rapidly changed in response to market changes. A major component of RMS is the Reconfigurable Machine Tool (RMT) [1]. RMT allows rapid changes in the machine structure and rapid conversion of the machine by relocating its basic building modules. This also allows building on the same basic machine, of a variety of machining configurations determined by different degree of freedom of the modules [2].

The advantage of the reconfigurable machine is that it permits easy reconfiguration of the structure of the machine and is able to machine a new parts batch belonging to the same part family. The main advantage, however, is represented by no or little capital waste because all machine tool modules are working.

The issues involved in the reconfiguration process are represented by two main phases:

- hardware modules reconfiguration;
- software reconfiguration (both programming and control).

The modeling algorithms of the reconfigurable machine kinematics need to be developed. These algorithms are the basis for the control and simulation of reconfigurable machine tool. By simulation of the hardware and control architecture, it is assured the optimal configuration for the new reconfigured machine.

A significant amount of work has been done for the development of RMT.

Different new concepts as far as it concerns the control paradigm, such as holonic manufacturing, bionic manufacturing [2], fractal companies [1], are studied for the next -generation manufacturing.

Concerning the control concept, it was proposed software architecture based in a combination of object-oriented models and executable formal specifications [13]. The common approach in these researches is the idea of a modular and open architecture to allow fast reconfiguration [13]. In response to the RMT control issue various efforts have been made, such as Open Modular Architecture Controllers (OMAC) [11], Open System Architecture for Controls within Automation Systems (OSACA) [12], Open System Environment for Controllers (OSEC), Hierarchical Open Architecture Multi-processor for CNC (HOAM-CNC) Open Architecture Controller (UMOAC).

The virtual reality concept (hereinafter VR) is applied to a wide area of fields and technologies. The user navigate in an artificial world, and is able to manipulate the information perceived from the environment being so-called virtual environment (VE), designed and created by computer and not the real physical environment.

A virtual reality interface between the human and the computer allows the human to perform activities in the virtual environment in an intuitive manner.

Several scientists considered the VR for manufacturing process, in respect to CAD design [3], rapid prototyping [5][6] and virtual machining [7][8]. One important issue in VR is the input devices [9][10].

The machine tool builders cannot afford the time- and cost-intensive manufacturing and testing of physical prototypes to detect weak spots and optimize the design. Moreover in case of RMT, the testing of physical prototypes, which are in a new configuration, demand using the virtual technology to allow hardware testing and iterative improvements of the physical prototype.

The issue of reconfiguring a new machine using several modules involves great challenges so far that concern the control and software. The time needed for reconfiguring the control needs to be as limited as possible, otherwise the advantage of responsiveness of the RMT concept will vanish.

In our previous research works [14][15] we proposed a new control and hardware architecture to satisfy reconfigurability requirements.

In this paper, a technique for synthetic modeling of the hardware architecture for reconfigurable machine tools is proposed. The virtual environment software described in this paper allows to simulate RMT working in order to generate a set of cinematically viable reconfigurable machine tools that meet the given design specifications. Moreover this will also build the layer for communication between modules controllers.

The virtual environment which acts as a programming language (Fig.2) will be used to build the two technological documents namely, *i*) machine-program, concerning machine reconfiguration phase and *ii*) part-program, concerning the programming of the machine to process a specific part.

In this paper, only the development of the machine-program, will be described according to our proposed RMT control paradigm.

The remainder of the paper is organized as it follows. In Section 2 it is presented the issue of the RMT configuration based on the previously proposed control architecture. In Section 3 it is presented the proposed technique for synthetic modeling. Finally, section 4 gives conclusions of this investigation.

2. Problem Formulation

Further we describe the new proposed control architecture [14][15] and the demands to which the proposed programming language is dedicated to as well as the problems involved in RMT configuration.

Several concepts, previously presented, should be introduced. Our approach considers a bus able to handle communication for all modules.

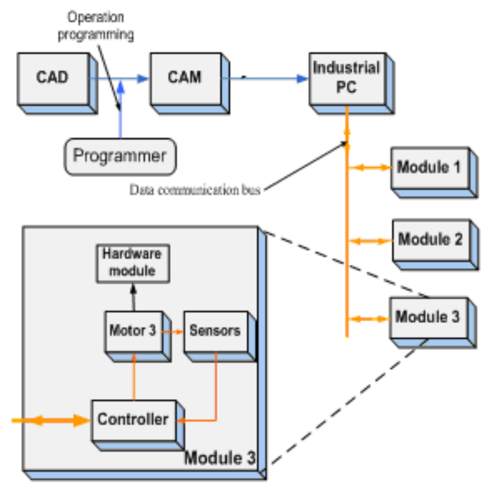

Fig.1. *Proposed control architecture*

Compared to todays fieldbus architecture the hardware modules have close-loops control represented by integrated controller able to communicate with a central industrial computer (Fig.1). The data sent to each module controller are represented by the required position of the hardware module. Any other sensors embedded on module receive/send data via communication bus to the industrial computer.

Machine programming according to the new view is concerned with two distinctive phases of machine operation.

In the building phase, several hardware modules are used to build the machine tool and consequently several kinematics architecture need to be taken into account. Besides the kinematics of the new machine, the modules port assignment is needed in order to be controlled by the industrial computer. Both programs need to be developed in a virtual environment allowing easy and fast programming.

Using solid model in a 3D virtual environment the programmer builds the kinematic model of the machine and than, after a virtual machine is built, the programmer should be able to describe machine tool movement trajectories to process the part.

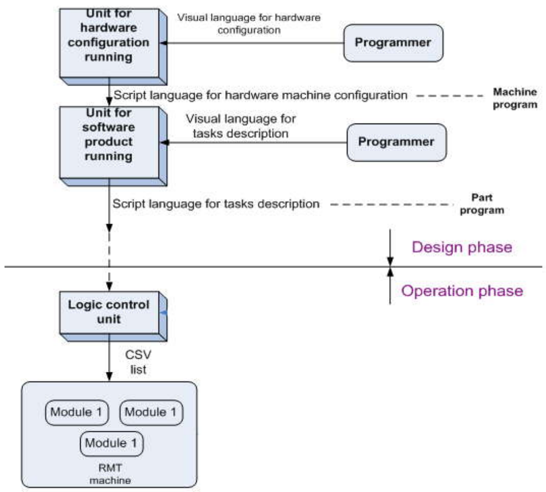

Fig. 2. *RMT programming concept*

3. Problem Solution

Below, it is presented a technique for synthetic modeling of the machine tool. The model should output the appropriate hardware architecture considering the machining tasks to be performed as input. The technique consists in crossing the steps described below:

- Choosing the modules that allow every task accomplishment;
- Simulating movement of the machine modules in order to perform collision tests;
- Recording the modules movement and fixturing in order to build the digital representation of animation for the fixturing process;
- Accepting the port assignment for modules to central industrial PC;
- Building the machine program.

Machine-program comprises several information sets (Fig. 3) as it follows:

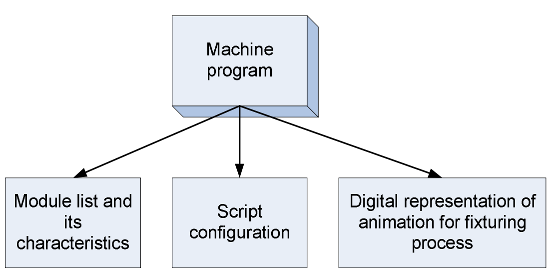

Fig.3. *Machine program information sets*

i) *script program*, which is generated automatically by the software programming environment. The configuration for each module PLC port assignment is attached;

ii) *digital image* of machine hardware configuration, representing information concerning fixturing information for an easy understanding by operators assembling new machine;

iii) *module list* to be used and their characteristics.

Building the part-program implies taking into account the geometric and kinematics characteristics of each module used (maximum feed rate, maximum couple of the motor etc).

The virtual configuration of a machine tool is a computer simulation model of the physical product that analyses and tests like a real machine.

The technique for synthetic modeling is embodied in virtual environment algorithms developed in this research. It consists of generic kinematic model which is composed of each module kinematic model and modules compatibility rules.

Iterative changing of a virtual model by using different modules of the machine tool during the design process of the new configuration allows for fast programming. Also, by exercising design variations until the performance requirements are achieved shall lead to a lower cost of the part machining.

The user can navigate in the virtual workshop using the joystick in order to see the machine tool movement.

In the developed virtual programming environment (Fig. 4) the user is able to select different available modules to build a new machine according to its kinematics and machining characteristics. The modules are generic modules each entitled with one single degree of freedom.

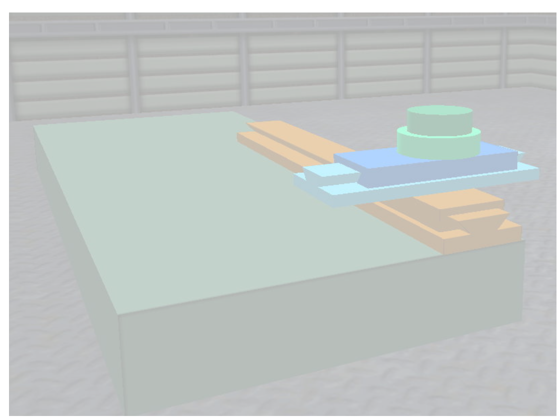

Fig.4. *The virtual environment for RMT testing*

Of course, there are compatibility rules between modules fixturing. For instance, a very heavy translation module cannot be fixed on a low powered module. In case the user selects an incompatible module the software will reject the new module.

The manipulation of modules may cause, in principle, collision between tool, tool holder, machine components, and workpiece. Therefore, collisions test are performed every step in order to assure machine operation.

In order to build the digital representation of the fixturing, the user can select the record option and a film is generate showing the machine design and working for a better understanding for the work team. Also, simulation can generates reports and detailed statistics describing the behavior of the RMT system under study.

Several hardware configurations have been built in the developed software to test the synthetic modeling of the hardware architecture and the application proved to be viable for using in RMT development.

4. Conclusions

The technique proposed in this paper embodied by the new RMT machining system reconfiguration software is presented in this paper to simplify RMT system development and enhance development ability with a previously proposed new control architecture in mind.

The virtual environment described in this paper allows to simulate RMT working simulation and the user is able to generate fast a set of kinematically viable reconfigurable machine tools that meet the given design specifications. Also, based on the simulation in the virtual environment, the physical layouts, equipment selection, operation procedures, resource allocation and utilization can be effectively implemented.

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References

1. *****,** *Engineering Research Center for Reconfigurable Manufacturing Systems*, http://ercrms.engin.unmich.edu/Research.

2. **Stecke, KE**., *Flexibility is the future of reconfigurability, Paradigms of Manufacturing—A Panel, Discussion*, 3rd Conference on Reconfigurable Manufacturing, Ann Arbor, Michigan, USA, 2005

3. **Liu, X., Dodds, G., McCartney, J., Hinds, B.K.**: *Virtual DesignWorks—designing 3D CAD models via haptic interaction,* Comput. Aided Des. 36, 1129–1140, 2004

4. **Mehrabi, M., Ulsoy, A.G., Koren, Y., Heytler, P.**: *Trends and Perspectives in Flexible and Reconfigurable Manufacturing*. Available at: http://www.erc.engin.umich.edu/publications/pub-gen.htm

5. **Choi, SH, Chan, A.M.M.,** *A virtual prototyping system for rapid product development*. Comput Aided Des 36:401–412, 2004

6. **Wang, G.G.,** *Definition and review of virtual prototyping*. J Comput Inf Sci Eng 2(3):232–236, 2002

7. **Wingbun, L., Jianguang, L., Chifai, C.,** *Research on the development of a virtual precision machining system,* Chin J Mech Eng 37(6):68, 2001

8. **Li, J., Yao, Y.,** *Workpiece modeling and representation in virtual manufacturing,* Comput Integr Manuf Syst 6(1):54–59, 2000

9. **Burdea, G.C.,** *Haptic feedback for virtual reality. Special issue on virtual prototyping,* Int J Des Innovat Res 2(1):17–29, 2000

10. **Liu, X., Dodds, G., McCartney, J., Hinds, B.K.,** *Virtual design works-designing 3D CAD models via haptic interaction*, Comput Aided Des 36(12):1129–1140, 2004

11. *****,** *OMAC API Work Group OMAC API set*, http://www.isd.mel.nist.gov/projects/omacapi.

12. *****,** *OSACA Open system architecture controls within automation systems*. Final report. http://www.osaca.org/, 1996.

13. **Wang, S., Shin, K.G.**, *Constructing reconfigurable software for machine control systems,* IEEE Trans Robot Autom 18(4).

14. **Epureanu, Al., Marin, F.B., Marinescu, V., Banu, M., Constantin, I.,** *Manufacturing machines – a holonic approache*, Proceeding ACMOS 08 ISBN:978-960-6766-63-3, ISSN 1790-5117, 2008;

15. **Epureanu, A., Marin, F.B., Marinescu, V., Banu, M., Constantin, I.**, *Optimal feedrate scheduling for a reconfigurable lathe*, Proceeding ACMOS 08 ISBN:978-960-6766-63-3, ISSN 1790-5117, 2008.