RAPID RECONFIGURATION OF MACHINE-TOOLS FOR HOLONIC MANUFACTURING SYSTEMS

Thomas Strasser * **Kurt Fessl** *
Alexander Hämmerle * **Martin Ankerl** *

* *PROFACTOR Research,*
Im Stadtgut A2, 4407 Steyr-Gleink, Austria
{*thomas.strasser,kurt.fessl,*
alexander.haemmerle,martin.ankerl}*@profactor.at*

Abstract: In the automotive industry SME suppliers are forced to keep the innovative pace with OEMs, resulting in the key requirement for economic production of small lot-sizes. State of the art technology in manufacturing systems is inadequate to meet this requirement. Current production equipment is either tailored towards a specific product or is flexible, but at the expense of expensive machinery; preventing it from extensive deployment in small and medium enterprises. The innovations proposed in this paper are based on the idea of Reconfigurable Manufacturing Systems, combining the required features of high throughput and high flexibility but avoiding high investment costs for expensive machinery.
In this paper we propose an approach for an engineering support for reconfigurable manufacturing systems - especially for reconfigurable machine-tools based on the holonic paradigm.

Keywords: Virtual Mechatronic Components, Holonic Systems, Mechatronic Systems, Embedded Control, Reconfigurable Manufacturing Systems

1. INTRODUCTION

1.1 Background and Motivation

In the automotive industry suppliers are forced to keep the innovative pace with Original Equipment Manufacturers (OEMs). Reduction of model life cycles and increases in product variety are major challenges for automotive suppliers, resulting in the key requirement for economic production of small lot-sizes.

Current available production and manufacturing systems based on state of the art technology is inadequate to meet the above requirement, given the fact that the supply market in the automotive industry is dominated by Small and Medium Enterprises (SMEs) with limited financial resources (Kurek, 2004).

1.2 State of the Art Technology and Limitations of Manufacturing Systems

Currently SME suppliers use a portfolio of Dedicated Manufacturing Systems (DMS) and Flexible Manufacturing Systems (FMS) in production. DMS are characterized by high throughput, but poor flexibility. The manufacturing system is tailored towards a specific product and can not be adapted to new products. Thus a DMS has to be disposed when the corresponding product reaches the end of its life-cycle. A FMS is characterized by high flexibility, but also by high costs due to expensive machinery, preventing it from extensive deployment in SMEs (Cole, 2004).

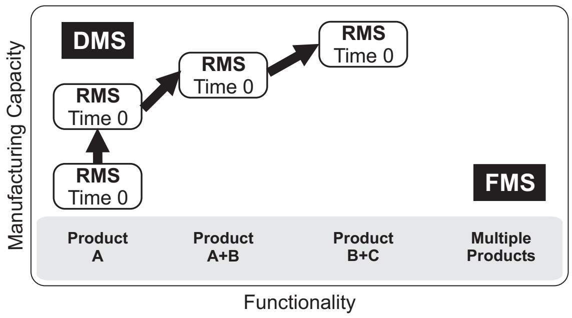

Fig. 1. Comparison of DMS and FMS (Koren *et al.*, 1999)

To save and enlarge the leading position of SME suppliers a novel manufacturing concept is required (FUTMAN, 2003), (ManuFuture, 2003), (MANTYS, 2003). This concept combines the high throughput of DMS (for economic production) with the flexibility of FMS (for low time-to-market) for new products with minimal planning, engineering and set-up costs of the manufacturing system. This new manufacturing concept enables a supplier to react on changes requested by an automotive OEM quickly and efficiently. For deployment in SMEs the concept avoids high investment costs due to expensive machinery (Koren *et al.*, 1999).

A Reconfigurable Manufacturing System (RMS) combines the required features of high throughput and high flexibility, but avoids high investment costs for expensive machinery (see fig. 2).

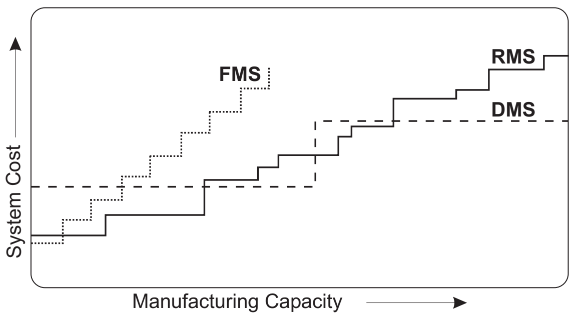

Fig. 2. Comparison of DMS, FMS and RMS costs over production capacity (Koren *et al.*, 1999)

RMS are designed at the outset for rapid change in structure, as well in hardware and in software components. This allows rapid adjustment of production capacity and functionality. Today first academic approaches are based on the notion of Reconfigurable Manufacturing Systems (Koren *et al.*, 1999).

From a technological point of view an RMS is based upon Reconfigurable Machine-Tools (RMT). An RMT is characterized by a modular configuration with replaceable components, resulting in high reconfigurability. The major advantage of such systems is that they provide exactly the functionality and capacity needed, exactly when it is needed. Advantages for machine manufacturers therefore are:

- enlargement of product portfolio and
- simplified and faster configuration/ reconfiguration & set-up of machine-tools.

The industrial usability of the RMS-concept requires enabling technologies also for the area of machine-tools. The mechatronic concept with replaceable components is a promising candidate for an enabler technology (Larses and Adamsson, 2004). However, current mechatronic approaches are lacking technologies and methodologies for significantly improving the reconfiguration flexibility of complex machine tools while simultaneously speeding up the set-up time (Reinhart, 2002). The main limitations are:

- Insufficient engineering methodologies for RMS & reliability check methods.
- Interoperability limitations of mechatronic components controller from different vendors.

Key characteristics of a Holonic Manufacturing System (HMS) are the recursive structure of its constituents and their cooperative abilities (Bussmann, 1998), (Bussmann and McFarlane, 1999), (Tharumarajah *et al.*, 1996). A RMT (being a cooperative constituent of an RMS) composed of mechatronic components (the cooperative constituents of a RMT) thus clearly adds to the technological realisation of a HMS (the cooperative features of the mechatronic components will become clear in section 3.2).

1.3 State of the Art Technology and Limitations of Functional/Mechatronic Engineering

Solutions for the hardware level (machine), see (*METEOR - Mehr Technologie Orientierte Rekonfigurierbare Werkzeugmaschine*, 2004) are available but current engineering approaches and methods do not support the reconfiguration aspect sufficiently. Fig. 3 shows the concept of RMS for a machine-tool example using the composition of standardized mechatronic components on different levels.

This paper is organized as follows: chapter 2 describes the virtual representation of mechatronic components as basic reconfiguration elements. The necessarily of a virtual market place for such components will also be explained in this section. In chapter 3 the reconfiguration of a manufacturing system (e.g machine-tools . . .) with mechatronic components will be described. Finally conclusions are presented in section 4.

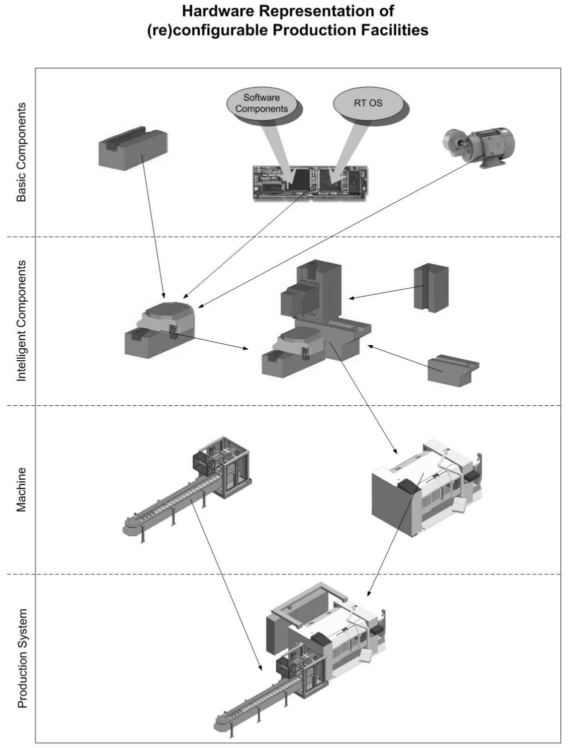

Fig. 3. Hardware Representation of Reconfigurable Production Facilities

2. MECHATRONIC COMPONENTS AS BASIC RECONFIGURATION ELEMENTS

2.1 Virtual Representation of mechatronic components

As mentioned in the last section the goals of reconfigurable manufacturing systems are

- Minimization of the engineering-complexity of the construction process for application-specific machines or systems that increase quality.
- Reduction of product cycle times.

Machines or systems are plugged together out of standardized mechatronic modules as well as physical and virtual mechatronic modules. This leads to the functional engineering and reconfiguration of customized manufacturing equipment.

The flexibility of an RMS/RMT can only be achieved if engineering methodologies are also flexible enough. This flexibility can be reached with the virtual description of mechatronic components. The abstraction and encapsulation of mechatronic components into software modules is denoted as Virtual Mechatronic Component (VMC) which represents different views such as (Vollrath, 2004):

- Mechanical,
- Electrical,
- Component control,
- Documentation,
- Simulation and
- their interaction semantic.

Each VMC also contains information about usage of the corresponding hardware component. A VMC is therefore a compound of different engineering views (i.e. descriptions) of one mechatronic component. The information of these different views is encapsulated within the VMC. Only the necessary interfaces are provided for interaction with other VMCs (see fig. 4).

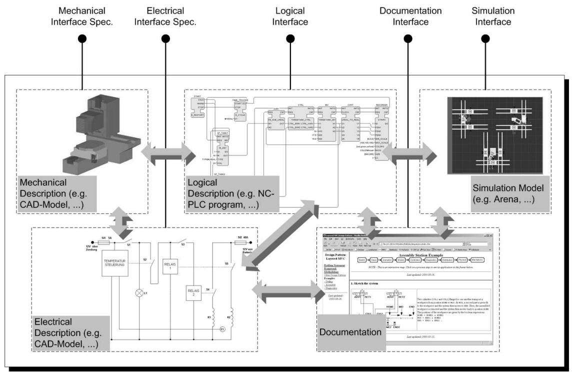

Fig. 4. Interface and elements of a virtual mechatronic component

Therefore, from an engineering point-of-view V-MCs from different vendors are plugged together by a so-called "system engineer". Additionally, VMCs support engineering from the system's point-of-view rather than performing discipline-oriented engineering in the typical waterfall manner. Fig. 5 shows the composition of a virtual machine-tool using VMCs.

Modeling languages such as Mechatronic UML (Burmester, 2004) or component based engineering (Pesch, 2004) are used for a model based development of such mechatronic systems (Larses and Adamsson, 2004).

2.2 Creation of virtual market place for mechatronic components

To support system engineers in rapidly and seamlessly assembling the VMCs, adaptive, collaborative and self-organizing software tools are an important part of the overall manufacturing equipment (as depicted in fig. 6).

The administration of VMCs will be performed in distributed repositories by their manufacturers forming a virtual market place. The infrastructure to store, discover, and access VMCs will use common technologies like Universal Description,

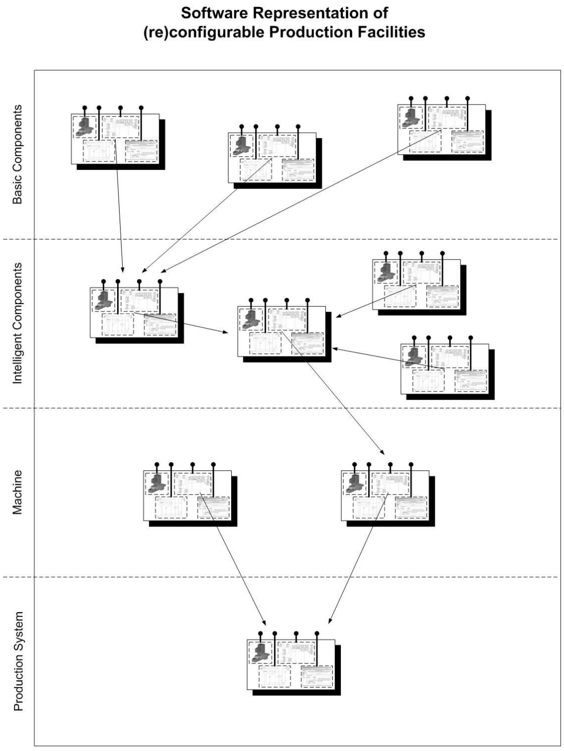

Fig. 5. Software Representation of Reconfigurable Production Facilities

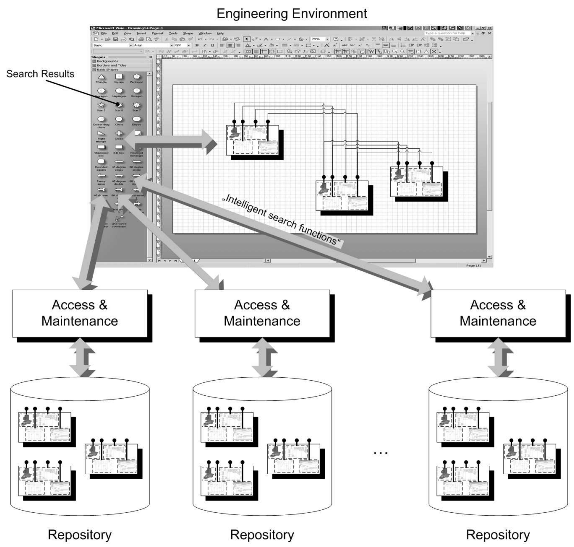

Fig. 6. Discovery of mechatronic components using agent technology

Discovery and Integration (UDDI) [1] and Semantic Web. Machine designers are able to use VMCs from different vendors forming a new machine or reconfigure an existing. As a result the virtual market place provides a construction kit of VMCs representing mechatronic modules.

For the creation of the market place for VMCs it is necessary that all VMC vendors provide their VMCs in standardized way. Currently there are some attempts for the creation of a VMC standard:

- OOONEIDA (OOONEIDA, 2004) is a new IMS CCI initiative to enable the flexible, open integration and reconfiguration of embedded intelligence in industrial automation systems. The goal of OOONEIDA is the creation of the technological infrastructure for a new, open knowledge economy for automation components, products and systems.
- The Ad Hoc Group 2 of the International Electrotechnical Commission proposed a draft paper for Automation Objects which are a kind of VMCs (IEC Ad Hoc Group 2, 2002).

3. RECONFIGURATION OF HOLONIC MANUFACTURING SYSTEMS

The development (design) and operation of a Holonic Manufacturing System are two different steps. In the following subsections we describe how a Holonic Manufacturing System is designed or reconfigured using VMCs and how it will perform operation using holonic control.

3.1 (Re)Engineering of a Holonic Manufacturing System using VMCs

The modeling framework supports a designer / engineer in the planning and engineering process for a specific Holonic Manufacturing System in a fast and intuitive way. Key enabler for this framework is the virtual representation of such systems using VMCs from several vendors. The configuration is automatically generated based on input from product & production development process using agent based technology to handle the big complexity in the modeling procedure (Hämmerle *et al.*, 2002), (Bellifemine *et al.*, 2004). The designer/engineer only has to make final enhancements to the system configuration (depicted in fig. 7). This approach drastically decreases the design time of reconfigurable manufacturing equipment.

3.2 (Re)Configuration and Operation of a Holonic Manufacturing System

Running complex mechatronic systems (RMTs) from different vendors also requires a flexible ar-

[1] The Universal Description, Discovery and Integration (UDDI) protocol is one of the major building blocks required for successful Web services. UDDI creates a standard interoperable platform that enables companies and applications to quickly, easily, and dynamically find and use Web services over the Internet. UDDI also allows operational registries to be maintained for different purposes in different contexts. UDDI is a cross-industry effort driven by major platform and software providers, as well as marketplace operators and e-business leaders within the OASIS standards consortium (http://www.uddi.org).

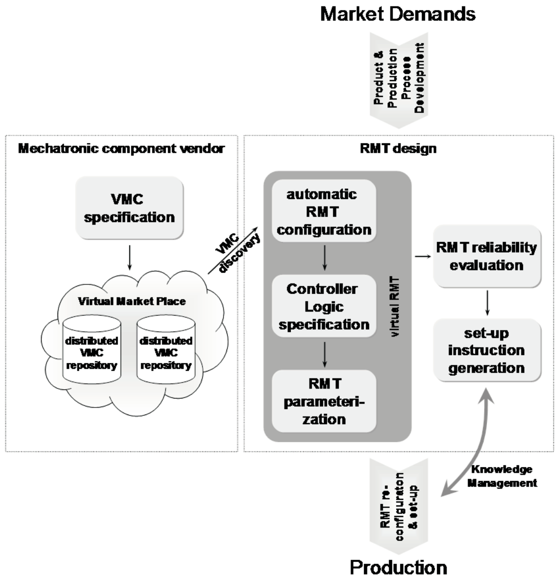

Fig. 7. Fast & flexible (re)design of reconfigurable machine-tools

chitecture for the control of embedded mechatronic components. Current approaches like holonic control, that can be applied, only act at the higher control levels. A problem is that low-level real-time device control (nowadays Programmable Logic Controller or PLC level) does not sufficiently support distribution and scalability and ignores reconfigurability up to now. For a real breakthrough of agile concepts also the low-level control has to support reconfigurability, scalability and distribution into functional complete modules - at low level even in real-time!

The holonic control architecture presented by (Christensen, 2000) is convenient to meet these requirements because it includes both

- Low-level (LLC) control and
- High-level (HLC) control.

LLC refers to normal automation functions, while HLC refers to software agent technology.

LLC can be characterized as follows according to (Christensen, 2000): *Real-time inter-controller communication based on very small amounts of transported data is handled via IEC61499 mechanisms.* HLC has according to (Christensen, 2000) the following characteristics: *Less time constraint communication for more complex inter-controller interaction based on bigger amounts of data is handled by FIPA/JADE mechanisms.*

Examples when to apply LLC and HLC

- Low level control:
  - · *Operation of machines / production systems*: While in operation a machine or whole production system uses this machine-intimate mechanism.
  - · *LLC architecture*: addresses the functions associated with the domain of real-time control, including control and automation of physical equipment, real-time communications and input/output (I/O) associated with industrial processes, machines and their human operators, designers, installers and maintainers.
- High level control:
  - · *Parameter adjustment*: After mechatronic building blocks (hardware parts equipped with controllers) are put together, their pre-configured parameters have to be adapted/fine-tuned to guarantee interoperability. Negotiating this parameter adjustments can be handled by the FIPA/JADE layer.
  - · *Data feedback*: While in operation a machine or whole production system may deliver sensor/machine data back to higher-level systems, not for control purposes but for data collection to enhance follow-up simulations of the overall system.
  - · *Condition monitoring, failure diagnosis*: for cases where no real-time constraints have to be met.
  - · *Distributed start-up of machines and productions systems*: necessary for LLC and HLC domain

According to this approach IEC 61499 can be used for the low level control part. A detailed investigation of this IEC standard results in the fact that IEC 61499 is in principle not real-time capable. To overcome this fact an IEC 61499 standard's based execution environment providing support for real-time reconfiguration shall be used (according to (Zoitl *et al.*, 2004)).

4. SUMMARY AND CONCLUSION

In this paper we have introduced the basic ideas of a flexible and efficient engineering support for reconfigurable manufacturing systems. The approach is based on the creation of a virtual market place for mechatronic software components as an abstraction of mechatronic components. The engineering for such RMS is done using the automatic formation of reconfigurable manufacturing equipment with virtual mechatronic components. A central role in this approach plays the control of the networked mechatronic components. The controller architecture is based on a real-time part and a non real-time part using agent technology. A broad spectrum for reconfigurable production equipment of different implementations is made possible using this approach.

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