SMARTLAM - A Modular, Flexible, Scalable, and Reconfigurable System for Manufacturing of Microsystems

Steffen Scholz*, Tobias Mueller*, Matthias Plasch†, Hannes Limbeck†, Tobias Iseringhausen‡,
Markus Dickerhof*, Andreas Schmidt*§ , and Christian Woegerer†
* Institute for Applied Computer Science
Karlsruhe Institute of Technology
Karlsruhe, Germany
Email: {steffen.scholz, tobias.mueller2, markus.dickerhof, andreas.schmidt}@kit.edu
† Machine Vision Profactor GmbH
Steyr, Austria
Email: {matthias.plasch, hannes.limbeck, christian.woegerer}@profactor.at
‡ Fraunhofer Institute for Manufacturing Engineering and Automation (IPA)
Stuttgart, Germany
Email: tobias.iseringhausen@ipa.fraunhofer.de
§ Department of Computer Science and Business Information Systems,
Karlsruhe University of Applied Sciences
Karlsruhe, Germany

***Abstract*—Digital manufacturing technologies are gaining more and more importance as key enabling technologies in future manufacturing, in particular when flexible and scalable production of small and medium lot sizes of customized parts is demanded. This paper describes a new approach to design manufacturing of complex three-dimensional components building on a combination of digital manufacturing technologies such as laminated objects manufacturing, laser, and e-printing technologies. The manufacturing platform is based on a highly flexible and modular approach, which enables manufacturing of different small-sized batches without tool or mask making within a short time. A number of manufacturing modules can be combined by defined hardware and software interfaces. The control system is designed to integrate all processes as well as the base platform with features far beyond ordinary Programmable Logic Controller (PLC) systems.**

***Keywords*–Additive manufacturing; microsystems; flexible scalable system**

I. Introduction

The development of the markets in micro system technology shows that many new and innovative developments in the field of hybrid microsystems do not achieve a satisfactory success.This can be attributed to the high complexity of micro-technical products and processes, a lack of interdisciplinary knowledge in process development, limited flexibility of the applied manufacturing and assembly systems and the high investment risk due to uncertain forecasts of growth. SMARTLAM (Smart production of Microsystems based on laminated polymer films) addresses these issues by introducing a flexible, modular manufacturing approach similar to the Agile Assembly Architecture by Rizzi et al [1]. It is based on a large collection of mechanically, computationally and algorithmically distributed robotic modules, which enables the user to build a production system out of modules in a Lego block manner. The concept of SMARTLAM also features a highly flexible transport system, which allows a free and multiple access to process stations.

II. SMARTLAM concepts

Digital manufacturing platforms [2] need to meet the challenge of staying competitive with traditional manufacturing systems [3]. Important key factors are extra costs, which emerge from complex hardware and software interfaces, as well as potentially rising idle processing times of single functional modules. A major goal of the SMARTLAM project is to improve competitiveness by designing products in an optimized manner, tailored to the used manufacturing technologies.

In SMARTLAM, each iteration loop can be seen as a workflow consisting of four phases:

- Plan (product specification and design)
- Develop (design support tool)
- Make (process chain selection and process chain configuration)
- Analyze (inspection and process optimization loop)

Figure 1 depicts a scheme of the workflow supported by a 3D-I manufacturing approach, leading from a given product specification to production and product optimization. The corresponding order planning approach is realized through a seamlessly integrated toolchain, which can be sorted along the layer model introduced by the International Standards for Automation (ISA). ISA S95 is an international standard for developing an automated interface between enterprise and control systems as an inherent part of the SMARTLAM project. Four main tools have been realized:

- A capability database, providing information on manufacturing competences (MinaBase),
- a feature-based design tool that enables product design within the systems capabilities,
- a process planning system, which constructs a manufacturing process chain,
- and a configuration tool that enables to set up manufacturing simulation and execution.

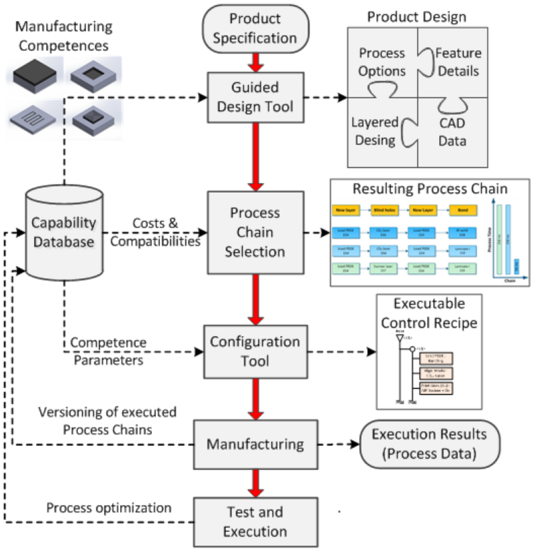

Figure 1. Schematic overview of the 3D-I manufacturing approach

According to Gleadall et al. [4], the feature-based design tool constrains the design engineer in developing a product design that is suitable to be manufactured using integrated SMARTLAM technologies. Therefore, the SMARTLAM 3D-I manufacturing approach supports the development of a microsystem product by using a product concept as the input, which provides a certain degree of flexibility in order to be adaptable to given manufacturing constraints. The manufacturing chain is then developed starting from specifying the technical design of the product design through to configuring and monitoring the actual fabrication process. Also, resulting from its continuously modular design, the system is easily extendable/scalable to cover new manufacturing technologies. Adding a new production technology to the SMARTLAM system requires the following steps to be taken:

- Add a data set of the new manufacturing competence to the database, to make it available to the guided design tool, the process planning system, and the configuration tool.
- Create a component model of the added process module and make it available to the control system. The main controller extracts relevant information, e.g. a protocol and connection description, to establish a link to the new process module.

As the control system's architecture is based on the industrial standard IEC 61499 [3], it is suitable to realize coordination of functional independent modules in order to achieve a given result [5], [6]. Moreover, the openness and interoperability attempts of IEC 61499 reduce development effort that is required for the integration of heterogeneous system components. SMARTLAM supports **seamless data integration**, as its aim is to create an integrated approach to supporting product developers within the scope of the platform in making profound decisions more rapidly. At the core of this is the requirement for a methodology to describe the capabilities and parameters of participating manufacturing technologies and materials. To achieve this, existing knowledge management tools - the Process Capability Database MinaBase - will be adapted and enhanced for storage and retrieval of SMARTLAM-related process parameters based on a SMARTLAM-specific process knowledge ontology. The customers use a design tool, which is developed in the SMARTLAM project, to design their product for manufacture by a SMARTLAM system. The design tool outputs the design to a process chain selection tool, which predicts the key performance indicators (KPIs) for the customer to review. The process capability database plays a central role in this product development process. In detail, the modules for the current application case include:

- Aerosoljet printing module: printing electronics functionality (circuits, interconnects, sensors)
- Laser structuring module: laser milling and surface modification for structuring or changing polymer surface properties
- Laser welding module: bonding of polymer sheets
- Lamination module: positioning and stacking of polymer films
- Inspection module: inspection of top layer of functional elements in-line and at end of the process
- Assembly module: integration of discrete components into sheet stacks

Based on this approach, different modules for the manufacturing of microsystems are currently being developed within SMARTLAM, which will be connected to the manufacturing databases and back-end processes and finally results in a highly sophisticated and flexible digital fabrication cell. Currently, all modules are being prepared for the assembly of the final production cell. A central control unit to operate the overall manufacturing process including all fabrication, assembly, inspection and transportation steps is being set up. Finally, the overall concept of the D-I-approach has been proved on a laboratory scale by producing a demonstrator specimen.

Acknowledgment

SMARTLAM is funded by the European Commission under FP7 Cooperation Program Grant No. 314580.

References

[1] A. Rizzi, J. Gowdy, and R. Hollis, "Agile assembly architecture: an agent based approach to modular precision assembly systems," in Proceedings of the 1997 IEEE International Conference on Robotics and Automation, Albuquerque, USA, April 20-25, 1997, pp. 1511–1516.

[2] G. Chryssolouris, D. Mavrikios, N. Papakostas, G. Michalos, and K. Georgoulias, "Digital manufacturing: history, perspectives, and outlook," Proceedings of the Institution of Mechanical Engineers. Part B, Journal of Engineering Manufacture, vol. 223, no. 5, 2009, pp. 451–462.

[3] "International Standard IEC 61499-1: Function Blocks – Part 1: Architecture, 1st Ed. International Electrotechnical Commission," Geneva, 2005.

[4] Gleadall et al., "A design framework for micro devices manufactured by a modular multi-process platform," in Proceedings of the 9th International Workshop of Microfactories, Honolulu, USA, 2014, pp. 16–222.

[5] D. Ivanova, I. Batchkova, S. Panjaitan, F. Wagner, and G. Frey, "Combining IEC 61499 and ISA S88 for Batch Control," in Proceedings of the 13th IFAC Symposium on Information Control Problems in Manufacturing (INCOM'09), 2009, pp. 187–192.

[6] G. Ebenhofer et al., "A system integration approach for service-oriented robotics," in Proceedings of 2013 IEEE 18th Conference on Emerging Technologies & Factory Automation, ETFA 2013, Cagliari, Italy, September 10-13, 2013, 2013, pp. 1–8.