Development of a Robot System for Advanced High Quality Manufacturing Processes

B. Kuhlenkoetter

Grinding and polishing are standard operations in material processing which are nowadays automated with the help of industrial robots in order to relieve human labour and optimize the profitability of production. However, it is expensive to adapt present systems to the production of other part geometries and operation cycles, and therefore adaptations are economically applicable only for large batch sizes.
This project develops an "intelligent" robot system that obtains sensory skills due to the linkage of innovative robot technology and image processing systems via new software. With this system even the smallest error on highly-polished, mirror-like surfaces can be detected objectively and reproducibly. In addition, the system will be capable of establishing an optimum error compensation strategy dependent on the error data, as well as generating and realizing operating programmes. For this purpose it is given a manual-learning skill. A new offline-programming and simulating system for exacting operation processes makes it easier to set up, change and optimize robot programmes, thus making it useful for the operator.

Keywords: flexible manufacturing systems, materials handling and robotics, quality systems.

Selected paper from the 4th International Conference on Advanced Engineering Design (AED 2004), which was held in Glasgow from 5 to 8 September 2004.

1 Grinding and polishing processes as part of the manufacturing chain

The aim of grinding and polishing processes is to provide greater forming and dimensional accuracy as well as better surface finishing. Both processes play an important role, as they are at the end of the net product chain, and processing errors lead to high rates of rejection.

In the sanitary fitting industry of today, complex, freely formed work pieces are manufactured by casting. Through subsequent grinding and polishing a high-quality shiny surface is produced with the dimensional accuracy of the

1. 2. 3. 4. 5.

Fig. 1: Manufacturing steps in the manufacture of fittings – 1. casting, 2. grinding, 3. polishing, 4. galvanizing and 5. the end product

Fig. 2: The manual grinding process

workpiece playing only a secondary role. (Fig. 1). The casting process, however, is characterized by high resulting dimensional and form tolerances as well as quality fluctuations such as blowholes and pores. These greatly varying starting conditions lead to unprofitable rejection rates and a very costly manual testing procedure in automated grinding and polishing processing. What is even more difficult for the realization of an automated solution is that errors are only detectable after a part of the fine processing has been done and that sensitive and very shiny surfaces are hard to establish by measuring methods. In addition, visual inspection can strain the operator's eyesight.

2 The use of robots in grinding and polishing processes

The use of modern handling/robot systems for belt grinding and polishing is intended to relieve human workers from physically hard, monotonous and dangerous work (Fig. 2) and, on the other hand, to minimize costs while optimizing quality.

The robot-aided automated solutions known at present in the fields of grinding and polishing are especially and successfully used in the sanitary fitting industry (Fig. 3). Whereas in the past these systems were profitable despite high wage costs, they are now challenged by competition from cheaper manual grinding and polishing processes in low-wage countries, due to advancing globalization of the markets. The threat of grinding and polishing processes moving abroad is compounded by the medium-term danger that the subsequent steps of manufacturing will also be shifted abroad.

The high time and cost requirements for programming and optimizing have a particularly negative effect on the profitability of industrial robot-aided grinding and polishing cells [4]. Compared to conventional robot tasks, these high requirements result from the clearly more complex, comprehensive and more accurate motion programs and the use of "trial and error" in optimizing the process. These requirements have of an even more negative influence if new programming or adaptions frequently become necessary [2]. The two main reasons for this can be an unfavourable ratio of batch size to the variety of modifications,, and also the occurrence of fluctuations in the process due to workpiece tolerances, as well as other errors in the upstream manufacturing process. The general aim of the intended R&D cooperation between SMEs oriented to automation and development, research institutes and manufacturing users is therefore to develop of manual, partly or fully automated procedures based on efficient program optimization of robot-aided grinding and polishing processes ("epo").

The required degree of automation of the procedures depends on how often optimizing work is needed. While manual intervention is sufficient for the initial programming and for occasional process malfunction, more frequent occur-

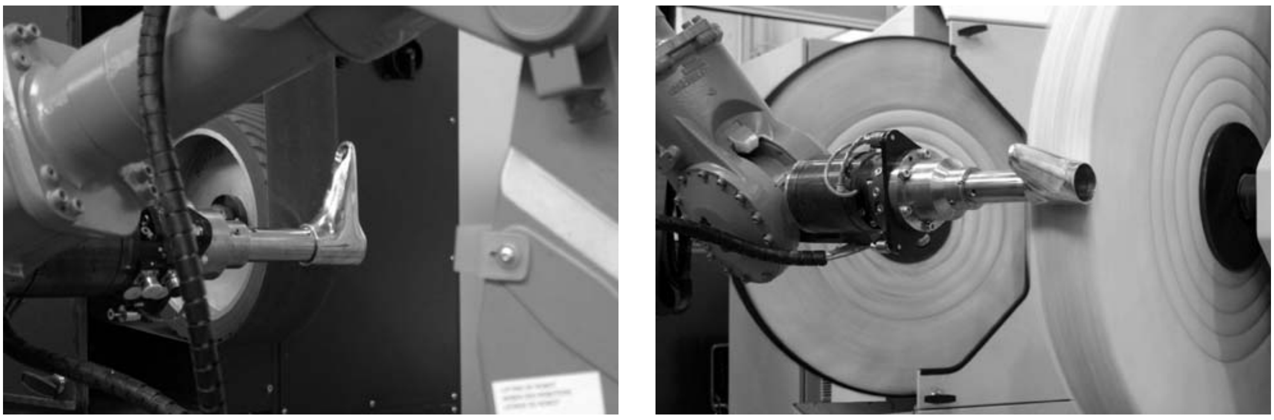

Fig. 3: Robot aided grinding and polishing in the sanitary fitting industry

rences require full automation.. The techniques to be developed for manual use differ considerably from those for fully automatic use. In manual procedures the focus lies on efficient interaction with the operator, whereas full automation requires the development and integration of a complex measuring method, data processing and process control.

3 Development of an offline-programming system for small batch sizes and a wide variety of modifications

One aspect of the project deals with process-specific further development of the offline-programming system – as approved in practise – in order to achieve greater efficiency in manual programming and optimization. Present day systems are designed for universal use, and are similar to complex 3D-CAD-systems in their layout and operation. Processes that do not need an extra path or parameter optimization, such as palletizing, assembling or varnishing, can be programmed efficiently using these programs by highly-qualified engineers and technicians in the planning department. For the grinding and polishing processes, however, no appropriate tools are available directly at the robot cell for the optimization phase. The use of a conventional offline programming system in the vicinity of the workshops usually fails, because it is too complex for underqualified operators.

There is a lack of process specific functions, and, as a result, there is a need for a suitable system to be developed. The intended system is directed at a target group that, due to small batch sizes and numerous modifications, must often make new programs or adjust their products to changed conditions. Moreover, the methods and procedures to be developed can enable future uses beyond grinding and polishing, e.g. robot-aided milling and water torching.

Another aspect of the project deals with disturbing influences that "frequently" occur and must therefore be detected and compensated for automatically. While in the first aspect of the project the operator of the robot machine is of the centre of the decision-making and should be given PC-based decision guidance for a structured next step, and suitable tools for efficient program optimization, the skills for error detection and classification and also the deduction of parameter optimization strategies (see [1,2,3]) through measuring methods and process control must be performed fully automatically. (Fig. 4)

4 Optimized automation through innovative robot systems

The developments presented below aim at raising the tolerances of handling systems to changing conditions, and also their flexibility toward frequently changing workpieces in order to increase the reliability of the machines in the end and to expand the use of solutions involving industrial robots. The focus lies here on industrial robot-aided processes like grinding and polishing of complex free forming geometries with high demands on the optical quality of the resulting surface. These processes show a high degree of program generation with several hundred robot targets, and optimizing times in the range of weeks, as well as high sensitivity to differences in the starting qualities of the workpiece.

In order to shorten the programming and optimizing times, the operator must have access to modern offline-programming procedures, taking into account the qualifications and experience usually available in industrial production. The acceptance of such systems will be raised by a stronger orientation to the process and greater integration of knowledge. Thus, the operator will be able in the future to take over programming and optimizing tasks which until now have been carried out only by highly-specialized staff in the planning department, or which have been given up in favour of manual manufacturing.

Higher tolerance toward changing the starting qualities of the workpiece will be achieved by combining image processing measuring systems, grinding and polishing process models, adaptive control techniques and intelligent software components.

A special challenge is posed in this context by the automation of "seeing and evaluating" processing errors on highly shiny surfaces, which are even difficult for the untrained human eye to detect. However this problem can be resolved with the help of special illumination. Furthermore, errors in the workpiece material in the process chain of rough grinding, finish grinding and polishing can often be detected only after a part, or all, of the processing has been done. This results in greater cooperation among what are now single machines, which are only interlinked due to the material flow in order to enable complete or partial reworking of inadequate workpieces.

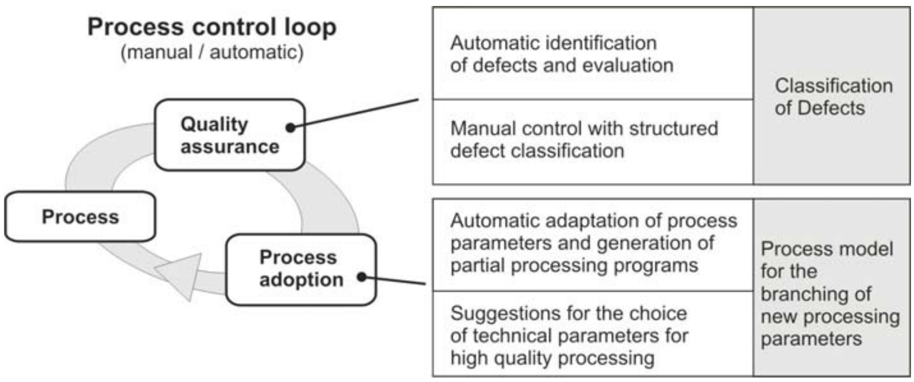

Fig. 4: Central aspects of the project

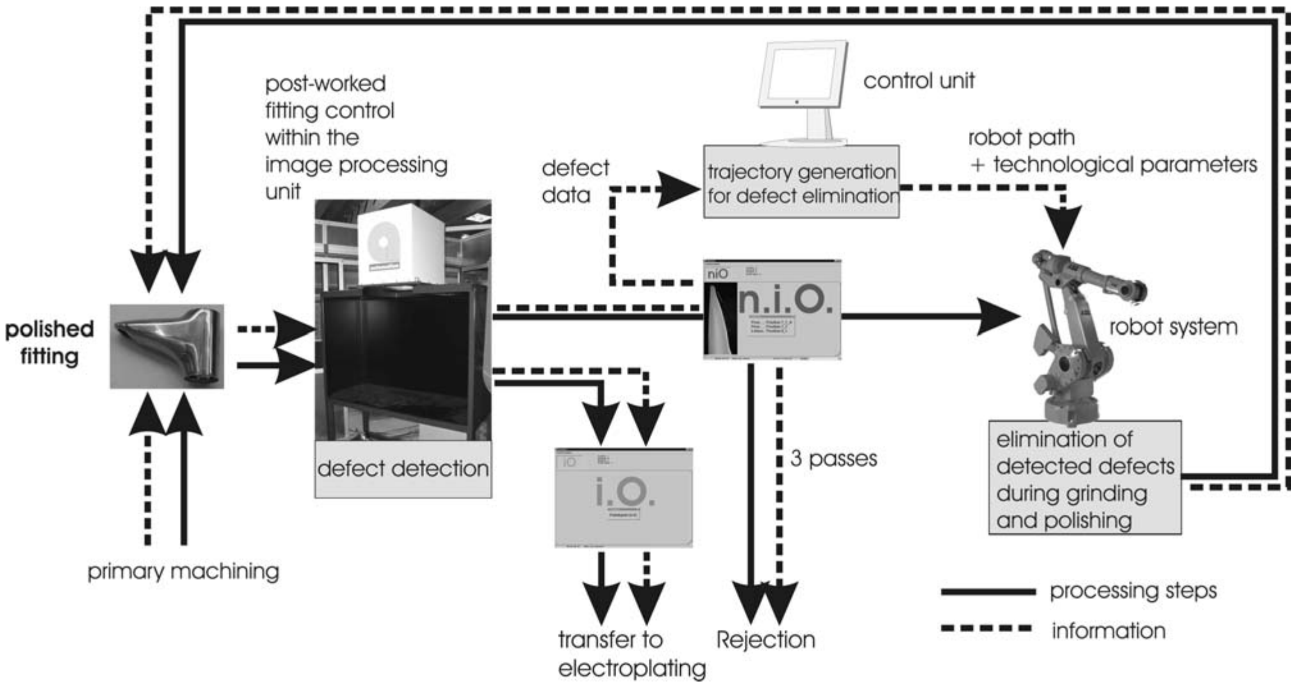

Fig. 5: Flow chart of the fully automated process chain

To account for these problems, the following developments have been made:

a) The development of a software system in the vicinity of the workshop for demanding robot processing applications such as grinding and polishing. This software system closes the gap between multi-functional, but complex offline-programming systems used in the planning department, on the one hand, and inefficient possibilities of robot control used by the operator for optimizing the program on the other hand.

b) The development of a fully automatic working process chain for industrial robot-aided grinding and polishing that, on the basis of the measurements of an image processing system, modifies a given machining course in such

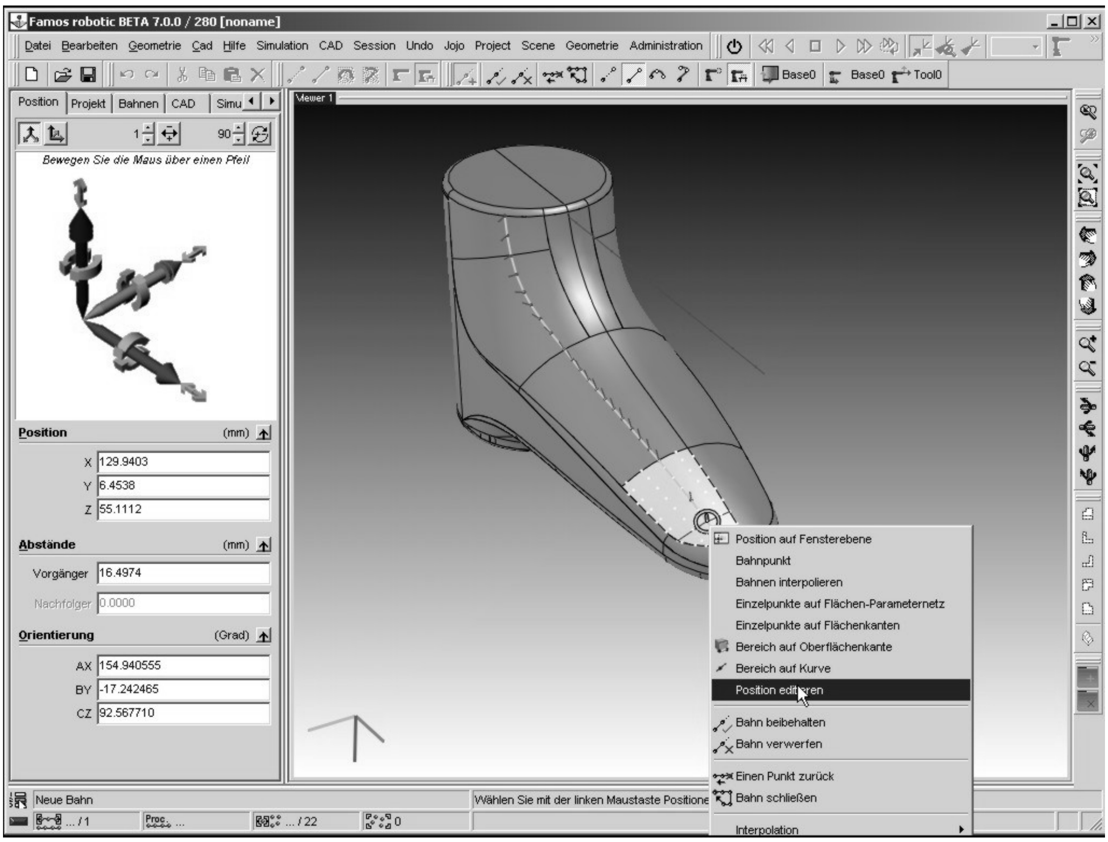

Fig. 6: User-orientated offline-programming and simulation system [5]

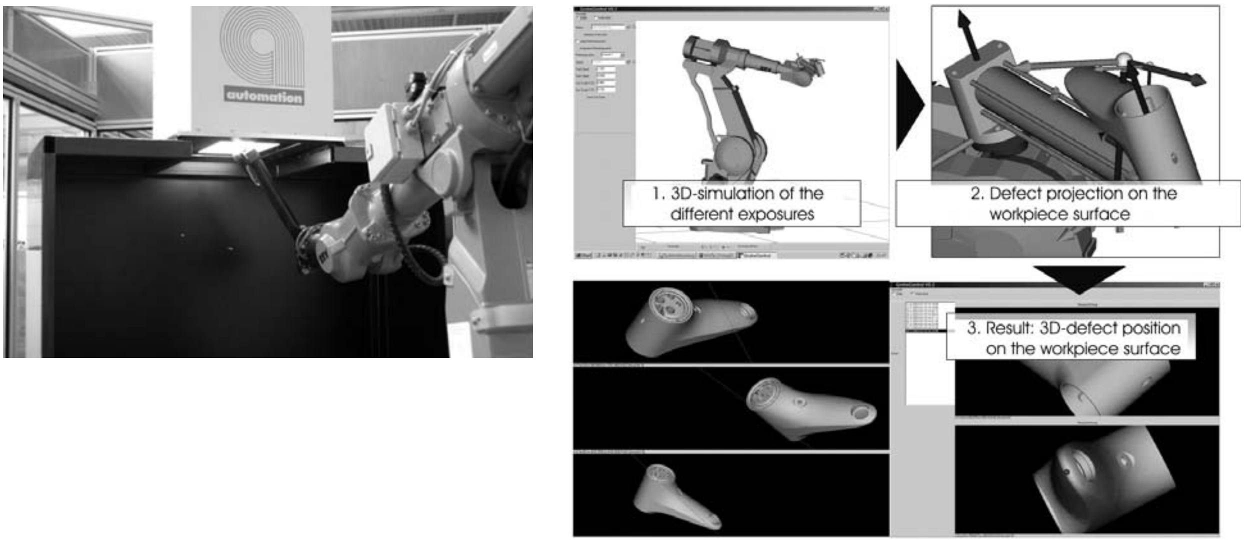

Fig. 7: Integrated image processing systems and error detection

a way that an optimum surface quality is achieved despite fluctuating starting conditions. If the required standard is not achieved, the component is rejected as scrap. (Fig. 5)

A software system has been developed for a workshop-lose programming robot systems without a workshop that has an intuitively operable graphic 3D-user surface and provides process-specific optimizing tools. An information-technical combination of interfaces of different offline-programming systems and robot control has already been realised. The software is supplemented by an adaptive consulting centre for the allocation of errors, causes of errors and compensation strategies and an internet connected process-know-how-database.

Fig. 6 shows how grinding paths/slideways are simply generated on the surface of the workpiece, which is then produced accordingly by the robot system.

With the help of an image processing system and an error data base, fully automatic error detection and classification is implemented for geometrically and optically difficult (highly--polished) free forming parts (Fig. 7).

Independent "intelligent" establishment of optimum error compensation is under preparation given the example of the grinding and polishing applications, to enable automatic compensation of detected surface errors specific generation of machining processes. Parts of the automatic program selection,or automatic generation of a program for the handling system for reworking the detected errors have already been realized. An important consider is that the target contour and surface must be kept.

In the course of the project presented here, a new generation of robot systems is originating that can process sensory feedback to surface errors, and can establish and carry out experience-based optimum error compensation strategies.

5 Acknowledgment

This research and development project is funded by the "Bundesministerium für Bildung und Forschung" (BMBF) within the framework of Research for the Production of Tomorrow and supervised by the project supporter of the BMBF for the Production and Manufacturing Technologies (PFT) research centre in Karlsruhe.

References

[1] Kneupner, K., Kuhlenkoetter, B., Zhang, X.: "A New Force Distribution Calculation Model for High Quality Production Processes." *International Journal of Advanced Manufacturing Technology*, Springer Verlag, London (article accepted – to be published soon).

[2] Čabaravdić, M., Kneupner, K., Kuhlenkoetter, B.: "Methods for Efficient Optimisation of Robot Supported Grinding and Polishing Processes." International Conference on "Trends in the Development of Machinery and Associated Technology", Barcelona (Spain), September 2003.

[3] Kreis, W., Schueppstuhl, T., Kneupner, K.: "Den Bandschleifprozess automatisieren – Prozessplanung und –optimierung bei der Bearbeitung von Freiformflächen." mo *Metalloberfläche*, S. 12–15, 4/2000.

[4] Schueppstuhl, T.: *Beitrag zum Bandschleifen komplexer Freiformgeometrien mit dem Industrieroboter*. Shaker Verlag, Aachen 2003.

[5] Kuhlenkoetter, B., Schueppstuhl, T.: "Vollautomatisierung durch innovative Robotersysteme. In: VDI-Berichte 1892.2, Mechatronik 2005, Innovative Produktentwicklung, VDI Verlag, Düsseldorf 2005.

Dr.-Ing. Bernd Kuhlenkoetter
phone: 0049 231 755 5611
fax: 0049 231 755 5616
e-mail: bernd.kuhlenkoetter@udo.edu
www.irf.de

University of Dortmund
Robotics Research Institute
Otto-Hahn-Str. 8
44221 Dortmund, Germany