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A New Programming Approach for Robot-based Flexible Inspection Systems

Dipl.-Ing. (Univ.)

William Brice Tekouo Moutchiho

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Editor's Preface

Production engineering is of central importance to the continuous development of our industrial society. The performance capacity of manufacturing companies is highly dependent on the utilized resources, the applied production techniques, and the implemented organization strategies. Guaranteeing a company's success entails an ideal combination of technology, organization and workforce management.

Achieving an optimal configuration of cost, time and quality is a highly complex and intricate task which requires production strategies to be continuously monitored, reviewed and enhanced. This involves both a reduction in, and a sound understanding of, the complexity of products, manufacturing systems and operations.

The *iwb* strives to continually improve production systems, planning processes and manufacturing technologies. In each of these aspects, particular focus is given to employee-oriented requirements. Despite an increase in the degree of automation, human employees play an important role in the product development process, and need be optimally integrated into the manufacturing process.

The research presented in this document is part of a series which spans through the various research areas of the *iwb*. These areas range from the development and planning of production systems as a whole, to more specific technologies such as individual manufacturing and assembly processes. Research in supply chain management and changeable production systems is aimed at optimizing production processes. Virtual production methods such as simulation tools are implemented at all levels of the production process, for testing and evaluation purposes. In terms of manufacturing technologies, the *iwb* conducts innovative research and develops new concepts in the areas of microassembly and handling, bonding processes, mechatronics, rapid manufacturing and laser technologies.

The *iwb* research series presents new results and findings which are highly relevant to the industrial world, and therefore serves as a transfer of knowledge between the university and industry.

Gunther Reinhart Michael Zäh

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This dissertation is the result of my work at the Institute for Machine Tools and Industrial Management *(iwb)* at the Technische Universität München.

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Cordial thanks go to my institute colleagues who have helped me in many matters during my time at the *iwb* especially Dipl.-Ing. Zitzmann, Dr. Pörnbacher, Dr. Vogl, Dr. Munzert, Dr. Radi, Dipl.-Ing. Braunreuther, my colleagues from the robotic and automation department as well as all the service centers' staff. I would also like to thank my former student Dipl.-Ing. Tschochner for his pertinent contribution to the success of this dissertation.

I wish to gratefully acknowledge the support of Perceptron Inc. in terms of high-tech equipment and industrial application examples.

There are many people to whom I am indebted for making my life a productive and enjoyable experience. First and foremost, my parents Emilienne Nguiedoum and Pierre Moutchiho, who have always shown me guidance, patience and love, and who untiringly reminded me of the importance of education. Although neither of you possessed a tertiary degree, you both worked so hard to give your children the best possible education. Profuse thanks go to my siblings Alain, Irene, Rodrigue, Leopold, Armand and Karlette for always being supportive of my endeavors. I am also deeply obliged to my uncle Mr. Foumbi Joseph for his immeasurable support for our family and for being a role model for me. Without this great family, I never would have been able to make it this far – thank you!

Words fail to describe my appreciation to Julia for her support, confidence in me, and unconditional love over the past years. Without you, my path would have certainly been more difficult – thank you!

Finally, I will be always indebted to Germaine for her confidence in me and for enabling me to move to Germany. This gratitude also extends to Delphine, Etienne, and Junang for their relentless support at my arrival in Germany – thank you!

Munich, April 2012 *William Brice Tekouo Moutchiho*

This work is dedicated to my Mother and my late father and brother Alain who didn't live long enough to see me reach this accomplishment.

Abstract

When a workpiece becomes defective at an early stage in the production process, unnecessary costs are incurred by completing the manufacture of a product that cannot be sold. Therefore, it is of fundamental interest to manufacturers that faulty workpieces are identified as soon as they are misprocessed. To this end, flexible metrology equipment, such as flexible inspection systems (FISs), are deployed across manufacturing lines to locally assess the quality conformity of workpieces before they are released to the next production steps. In their most versatile configuration, FISs consist of a robot manipulator that carries a high-accuracy optical sensor on its tip. To carry out an inspection task, FISs operate by first capturing a 3D range image of the physical workpiece under investigation. This range image, also referred to as point cloud, is then compared with the workpiece's CAD model to detect potential geometrical deficiencies.

During the past few years, a large number of FISs have been deployed on manufacturing floors. However, the range of applications is still restricted to those in which FISs are used to repeatedly gauge a small number of predefined standard components. These days, FISs still have to find their way into small batch or high-variety manufacturing environments. The greatest hurdle that prevents them from doing so is the huge effort required to invest in programming activities to adapt them to different inspection tasks. This programming effort is necessitated by the myriad of restrictions that have to be simultaneously fulfilled during digitization operations by both the sensor and the manipulator. Existing programming methods and system still fall short of properly addressing the aforementioned challenges.

Consequently, the research described is this doctoral dissertation is geared towards developing a programming methodology that reduces the amount of effort currently necessary for programming FISs. The methodology is based on a task-oriented approach and consists of five steps: a) the extraction of feature contour lines from the CAD model of the workpiece, b) the description of the inspection task based on the extracted features lines, c) the automatic generation of sensor trajectories that allow the digitization of these features, d) the automatic synthetization of feasible movements of the manipulator carrying the sensor and, finally, e) the online adaptation of the sensor trajectories at execution time to cope with modeling inaccuracy issues related to model-based programming.

The key advantage of this new methodology is that operators are shielded from technical details and therefore do not need to familiarize themselves with either robotics or metrology. This approach is believed to take the flexibility of FISs up another notch by deskilling their programming processes. As a result, the utilization ratio of FISs is expected to considerably increase, opening up access to new market opportunities, especially in small batch manufacturing companies.

Zusammenfassung

Zur Überprüfung der Form- und Maßhaltigkeit von Blechbauteilen werden in zunehmendem Maße robotergestützte flexible Messsysteme eingesetzt. Eine wesentliche Herausforderung bei der Neu- und Umkonfiguration solcher Systeme besteht aktuell in dem unverhältnismäßig hohen Programmieraufwand. Dieser liegt darin begründet, dass die Trajektorie des optischen Messsensors und die Bewegung des Industrieroboters eine Vielzahl an komplexen Einschränkungen simultan erfüllen müssen.

Im Rahmen der vorliegenden Dissertation wurde daher eine neue Methodik zur effizienten und aufwandsarmen Programmierung von robotergestützten Messsystemen entworfen und prototypisch implementiert. Diese Methodik zeichnet sich aus durch eine CAD-basierte Beschreibung der Messaufgabe, eine automatisierte Generierung von optimalen Sensortrajektorien und Roboterbewegungen sowie eine Kompensation von Trajektorieabweichungen während der Realisierung der Messaufgabe. Desweiteren unterscheidet sich diese von existierenden Lösungen durch die Tatsache, dass weder tief greifende messtechnische Kenntnisse noch Roboter- oder IT-Kenntnisse seitens des Programmierers benötigt werden.

"Talent helps but it won't take you as far as ambition."

Paul Arden

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