SpringerBriefs in Electrical and Computer Engineering

For further volumes:
http://www.springer.com/series/10059

Richard Doornbos · Sjir van Loo
Editors

From Scientific Instrument to Industrial Machine

Coping with Architectural Stress in Embedded Systems

Springer

Editors
Richard Doornbos
Research Fellow
Embedded Systems Institute
Den Dolech 2
5600 MB
Eindhoven
The Netherlands

Sjir van Loo
Senior Research Fellow
Embedded Systems Institute
Den Dolech 2
5600 MB
Eindhoven
The Netherlands

ISSN 2191-8112 ISSN 2191-8120 (electronic)
ISBN 978-94-007-4146-1 ISBN 978-94-007-4147-8 (eBook)
DOI 10.1007/978-94-007-4147-8
Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2012935675

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword

"There is plenty of room at the bottom" is the title of a famous lecture in which Richard Feynman, Professor of Physics at several US universities, challenged electron microscopy to improve its resolving power. "It would be really easy to understand properties of materials, we only have to look at it and see where the atoms are. Is there no way to make electron microscopes powerful enough to do this?" This is exactly what FEI has been doing over the last decades: improving the resolving power from about 2 nm in 1960 to the current 0.05 nm; and improving detection capabilities to the point where we can determine the position of individual atoms in a thin sliver of material.

About 5 years ago, however, we realised there was another challenge to face. Our fantastic instruments were highly inflexible and really only suited to work in a research laboratory. How could we make them so they would also be suitable for more demanding environments in several industries. And capable of being operated by persons whose primary interest is not so much in microscopy per se, but in the results they could get. A typical market where this was already happening was the electronics industry. To develop semiconductor processes and designs, and to ramp-up novel processes in the factory and analyse failures, they needed our very best high-end transmission electron microscopes (TEMs). They were interested in automatic applications, in reliable performance and reproducible results. And this trend did not just have an industrial driver. Our life-science customers, even in universities, started making similar demands for their microscopes: higher throughput, quality and reliability of data, etc. At the same time, we realised this challenge could not be solved by building dedicated tools which would only fit one particular application: cost and development efforts would be prohibitive.

In our first contacts with the Embedded Systems Institute, we put the challenge to be investigated in what became the Condor project as follows: "How can we transform our electron microscopes from a research instrument, used by specialists, to an industrial-grade, person-independent measurement tool, without losing flexibility?" Together with ESI we defined a series of subprojects to investigate this challenge from different angles, all on the general foundation of model-based design. Subjects ranged from automatic alignments (image-based),

via motion-control, scanning strategies and magnetic field control, towards novel system architecture concepts and implementations. We found partners in the universities of Antwerp, Leuven, Delft and Eindhoven, and in the company Technolution. Some groups were already familiar with electron microscopy; others needed to invest in understanding this field. Finding the right students was no easy task either, but about one year after the project was approved, the new PhDs and postdocs, together with a team from FEI and ESI, started to work on their subjects.

Looking back on the project, we see several types of results from which the various partners profit in different ways. There has been an important scientific output in terms of peer-reviewed papers, conference contributions and PhD theses. At the same time, it has been an interesting experience for some of the groups and individuals to perform scientific investigations in a more industrial environment ("Industry as a lab"), and sometimes really at (or just beyond) the boundary of their original competences. For ESI, there has been a major knowledge build-up in the field of architecture for electron microscopy, or scientific instruments in general. For FEI, the first result has been to get an outside view from the ESI and university partners into the technology and architectures we develop in-house. Some initial investigations from partners busted a few myths which originated from too narrow a view, and not enough time spent on properly investigating some aspects "which always worked this way". In other cases potential solutions were investigated that FEI would originally have regarded as far-fetched, like using field-sensing probes for fast control of lens fields. Some investigations yielded results that could easily be implemented, like the application of a Nelder-Mead optimisation algorithm for beam control and alignment. And of course there are the results yet to be implemented in new product developments. This book gives an excellent overview of the more tangible results which this project achieved.

Did FEI reach its objective: did we transform our instruments into flexible but more industrial-grade tools? It has not always been easy to see this through the very dynamic business environment at FEI, but the long-term strategy in this direction is even stronger than when we started. To really transform our architectures and systems is a long and difficult process. However, it is really happening, and the Condor project helped to overcome some of the first hurdles!

Eindhoven
15 December 2011

Dr. Frank de Jong
Director Research and Technology FEI

Preface

In 2007, the Condor project was set up as a first step to answering the question "how can we adapt the current system architecture of an electron microscope to obtain a predictable and automated system that can be used in industry?" While the question was posed with a specific type of system in mind, namely one of FEI Company's electron microscopes, both the question and the project's results are equally valid for other systems.

This book focuses on the main challenges of the Condor project, outlining these and summarising the research carried out across the various routes taken towards solutions. The project showed that the issue of "architectural stress" is of great importance to many industrial businesses. Turning a purpose-built precision-critical system, such as the classical FEI electron microscopes, into a system that is more flexible, predictable and more easily adapted to changing circumstances is rapidly becoming a desirable pathway to evolving new systems.

This book is the seventh in our industry-as-laboratory projects series.[1] These large 5-year projects are put together and led by the Embedded Systems Institute (ESI), in close collaboration with its industrial and academic partners.

In addition to ESI, Condor involved a consortium of industrial and academic partners. The industrial partners were FEI Company, the carrying industrial partner, and Technolution. The academic partners were the Eindhoven University of Technology, Delft University of Technology, Katholieke Universiteit Leuven and University of Antwerp.

[1] Books about earlier industry-as-laboratory projects—Falcon, Boderc, Tangram, Ideals, Trader and Darwin—can be found on ESI's website: http://www.esi.nl/knowledge-transfer/publications/books.

I would like to thank all partners and individuals, researchers and managers, companies and academia alike, involved in the Condor project. Through individual efforts and splendid teamwork, they contributed to the project's success. It is now time to pass on the experience gained and results achieved to a wider industrial and academic audience.

Eindhoven
February 2012

Prof. dr. ir. Boudewijn Haverkort
Scientific Director and Chair
Embedded Systems Institute

Acknowledgments

From scientific instrument to industrial machine is a result of the Condor project conducted under the responsibility of the Embedded Systems Institute with FEI Company as the carrying industrial partner. This project is partially supported by the Netherlands Ministry of Economic Affairs under the Embedded Systems Institute (BSIK03021) program.

We gratefully acknowledge the cooperation of the FEI employees throughout the 5-year project. Electron microscopy is an intriguing field. It combines cutting-edge technology with a high system complexity and has led to many Nobel prize-level results. Together with our academic partner's research and the vast experience and knowledge in electron microscopy of FEI's employees, especially Seyno Sluyterman, Mart Bierhoff and Auke van Balen, we performed our research on building complex systems. This formed the basis for *From scientific instrument to industrial machine*, a book aimed at system architects, engineers and other practitioners working on the challenges of creating complex high-tech systems.

We would like to thank the employees of our partners (Embedded Systems Institute, FEI Company, Technolution, University of Antwerp, University of Leuven, Delft University of Technology, Eindhoven University of Technology) for contributing to this book.

We would also like to thank the reviewers from FEI Company, Daimler, Delphino Consultancy and the Embedded Systems Institute.

Finally we express our special thanks to the Condor project leader Jan Schuddemat of the Embedded Systems Institute.

Contents