UNIVERSITÄT
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Annual Report

2008 – 2010

ziti

Institute for Computer Engineering

Dear Reader,

With the accomplished transition from the University of Mannheim to the University of Heidelberg in 2008, the newly formed Institute for Computer Engineering (ZITI) will continue its tradition of issuing an annual report. The reporting was interrupted for some time due to all the efforts that were required in the restructuring process. The new institute "ZITI" was established as a central institution of the University of Heidelberg. Its six member chairs are assigned equally to the Department of Physics and Astronomy and the Department of Mathematics and Computer Science and have successfully integrated themselves into the research landscape of Heidelberg. Meanwhile, a seventh assistant professorship has been established. At the same time, the institute was involved in implementing the Bologna process, which implied termination of the existing Diploma-program, an integration into an existing Bachelor program and the formation of a new Master program. This newly established Master of Computer Engineering is starting this winter term 2011/12. Along with the restructuring, the institute has established 9 research groups, which complement the research at the chairs and strengthen the broadness and the depth of research and serve in interacting with activities outside the institute. The research areas of the institute can be summarized as:

- Advanced Computer Architectures
- Application Specific Computing and Microchips
- High Performance Computing
- Process Control and Dependable Systems
- Next Generation Networks
- Particle an Photon Detection

With this report, ZITI is covering the period from 2008 to 2010. The research topics indicate a clear tendency towards high performance in every aspect of computing. The architectural fraction deals with the utilization of an increasing degree of parallelism and all the challenges involved there. In the network fraction, optical networks with terabit communication bandwidth and microsecond latency are addressed. The unique mixture of computer engineers and physicists is certainly helpful in order to put together this ambitious research program. We hope that this report will find your interest and provide some insight into the structure and the aims of this institute.

Karl-Heinz Brenner
Executive Director

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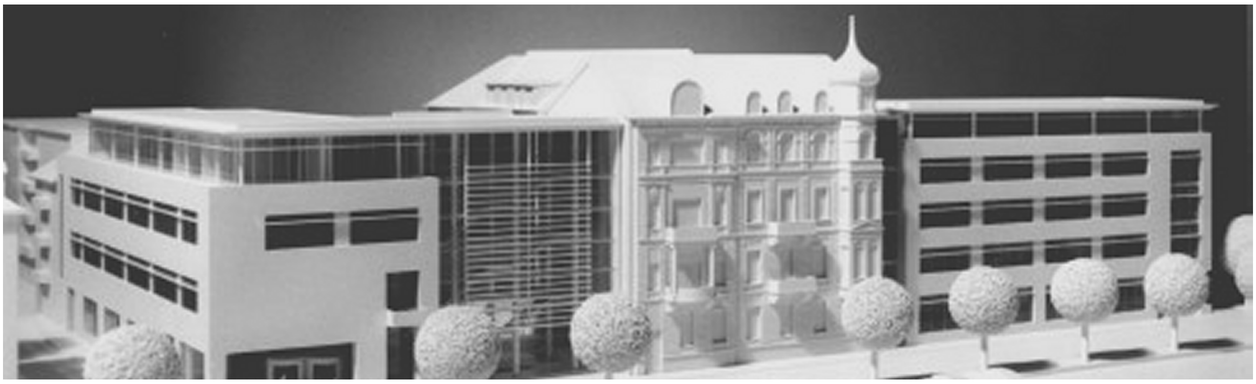

Institute

Short Description

Data 2008 – 2010

Research Groups

Teaching

Short Description

The Institute for Computer Engineering (ZITI) dedicates its research and teaching activities to the understanding, the implementation and the optimization of highly performant systems in information technology. With the integration into the university of Heidelberg, having its research focus on fundamental science, also more elementary aspects of Mathematics and Physics are incorporated into the development of innovative and intelligent computer systems. Another important research aspect is to apply new developments and methods emerging from computer engineering to sensing and instrumentation in physics, astronomy, biology, medicine and other natural and life sciences.

Three main features characterize the profile of computer engineering in Heidelberg: multi-disciplinarity, application-orientation, and orientation towards future developments. Due to their broad competences, our chairs are able to bring together their diverse knowledge and their different methodological approaches in order to jointly develop integrated hardware and software solutions. This synergistic combination distinguishes ZITI from classical departments of computer science at many other universities. Thus, research and teaching contents can be aligned constantly with current, as well as with future requirements. From the beginning, ZITI has always put an emphasis on market-oriented education for our graduate students, thus enabling them to meet their future responsibilities in industry and in research.

The result is an innovative orientation towards current and future developments, an internationally leading position in several research areas, lively spin-off activities and an academic education, tailored to meet market demands.

Data 2008-2010

Professors	6
Secretaries	7
Technicians	2
PhD Candidates and Research Assistants	129
Projects	54
Funding (spent)	2008: 2.276.390 € 2009: 2.362.380 € 2010: 2.490.297 €
Partners	32
Publications	184

Patents	5
Colloquia and Conferences	8

Research Groups

With the new founding of the institute, ZITI has established a number of research groups, which enable an exchange between different disciplines and provide young scientist with an opportunity to enhance their scientific skills and pursue their own research goals. Therefore, in June 2010, the following research groups were founded by advanced research assistants:

- Advanced Computer Architecture
- Application Specific Computer
- Accelerated Scientific Computing
- High Speed Short Range Interconnects
- New Detectors for Scientific and Medical Applications
- Next Generation Network Interfaces
- Process Control
- Dependable Robotics
- Virtual Patient Analysis

Research groups act independently under the umbrella of ZITI. They can work interdisciplinarily and foster cooperation between chairs. The research groups are led by group speakers. They have a sharing in ZITI resources.

Teaching

Apart from various lectures held in the Department of Physics and Astronomy as well as the Department of Mathematics and Computer Science, ZITI mainly provides lectures in two programs: Applied Computer Science (B.Sc.) and Computer Engineering (Diploma). Moreover, our new M.Sc. in Computer Engineering was prepared.

B.Sc. Applied Computer Science

The B.Sc. Applied Computer Science is hosted by the Department of Mathematics and Computer Science and is mainly organized by the Institute for Computer Science. It combines knowledge from Mathematics, Computer Science, Computer Engineering, Physics, and Electrical Engineering. Students must complete 180 CP, usually within 6 semesters. In the program, students can choose a major in Computer Engineering, which includes

- Practical Course Measurement Techniques
- Physical Basics of Computer Engineering
- Signals and Systems
- Digital Circuitry
- Elective module

It is also possible to visit single courses without majoring in Computer Engineering.

Diploma Computer Engineering

Due to its history at the University of Mannheim, ZITI is also still involved in teaching activities for the diploma program Computer Engineering in Mannheim. Students already enrolled in the program before the transfer of the Institute to the University of Heidelberg can complete their studies on regular terms until 2012. Between 2008 and 2010, 67 students graduated from the program. In the winter term 2011/12, 28 students were still enrolled in the program.

M.Sc. Computer Engineering

Since its transfer to the University of Heidelberg, ZITI has planned to establish a Master program in Computer Engineering (M.Sc. TI) as a key component to teach young academics who can contribute to our research as Ph.D. candidates later on. These plans have been delayed by political and organizational difficulties. Only at the end of 2010, the final layout of the program could be fixed, so that the Master can start in the winter term 2011/12. It is hosted by the Department of Physics and Astronomy, being strongly interconnected with the Natural Sciences in the environment of Heidelberg University. The nominal duration of the Master in Computer Engineering is 4 semesters.

The M.Sc.TI at Heidelberg University addresses graduates from B.Sc. programs in Computer Science or Natural Sciences with a sufficient minor in Computer Science (>24 CP). According to their personal interest, students can focus on one of the areas

- Hardware Design,
- Application Specific Computing,
- Photonic and Optical Signal Processing, or
- Intelligent Autonomous Systems.

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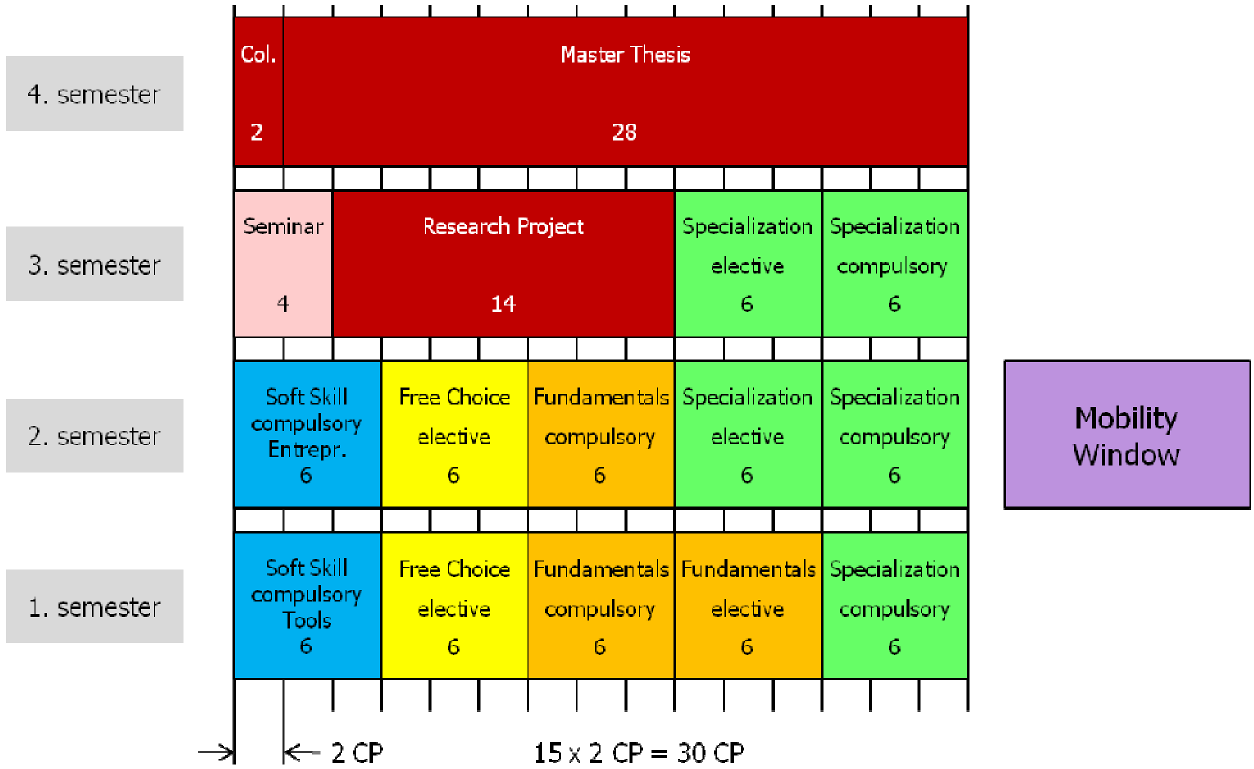


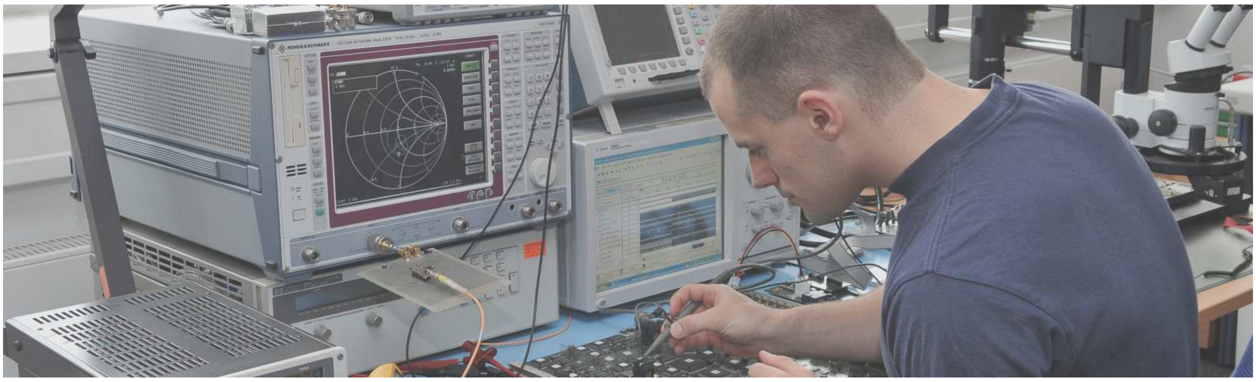
The courses can be classified into four different types, marked in different colors:

- Fundamentals (orange, 3 modules),
- Soft skills (blue, 'ÜK', 2 modules),
- Free courses (yellow, 2 modules) and
- Specialization (green, 'Major', 5 modules)

In each type, a certain number of modules (or CP) has to be passed. Some modules are compulsory and must be passed, while others are elective modules which can be chosen from various options. Finally, some modules can be chosen freely. Modules in the specialization usually belong to one of four fields of computer engineering (majors). The third semester, also includes

- a seminar (horal presentation of a specialized subject, 4 CP), and
- a student research project ('Projektpraktikum' or 'Studienarbeit') in a research group, which can also be used as a preparation for the master thesis (14 CP).

The master thesis with a final colloquium covers the complete fourth semester.



Research

Chairs and Research Groups

Chair for Automation

Chair for Computer Architecture

Chair for Circuit Design

Chair for Computer Science V

Chair for Optoelectronics

Chair for Computer Vision, Graphics and Pattern Recognition

Research Group Advanced Computer Architecture

Research Group Application Specific Computer

Research Group Accelerated Scientific Computing

Research Group High Speed Short Range Interconnects

Research Group New Detectors for Scientific and Medical Applications

Research Group Next Generation Network Interfaces

Research Group Process Control (ProCon)

Research Group Dependable Robotics (DeBot)

Research Group Virtual Patient Analysis (ViPA)

Chair for Automation

Prof. Dr. Essameddin Badreddin

CYCLOBOT
Efficient COMponent based develOpment of Dependable computIng Systems (ECOMODIS)
Control of the surgical robot “Intelligent Tool Drive”
Optimal Engineering Design for Dependable Water Power Generation in Remote Areas Using Renewable Energies and Intelligent Automation (OPEN.GAIN)
Human Sitting Posture Exposed to Horizontal Perturbation and Implications to Robotic Wheelchairs

CYCLOBOT

A. Wagner, PP. Pott, E. Badreddin

The aim of the CYCLOBOT project is to construct a bone fixed machine for working out cavities in bones Fig.1. For this purpose a robot with small dimensions yet with a sufficiently large workspace is desirable.

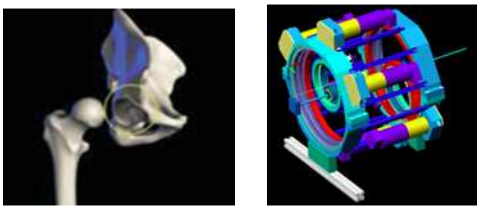


Fig. 1: a) Milling of cavities into bone b) Proposed robot design

One of the most important criterions for a robotic instrument is the ratio of workspace and installation space, which depends strongly on the chosen kinematic typ. Serial kinematics (e.g. articulated arm robots) provide a good ratio of workspace and installation space, but are inherently hazardous as endeffector, segments or joints of the robot can reach very high velocities and injure staff or patient. In contrast, parallel kinematics (e.g. the Hexapod) provide high stiffness, precision, and low velocities but a very limited workspace compared to the size of the robot. Within the CYCLOBOT project, a novel type of hybrid kinematics [1], the so-called Epizactor has been proposed, which promises an advantageous large workspace while providing small dimensions of the robot itself and good mechanical properties (number of kinematic elements, weight, and dynamic behaviour). This novel kinematic structure possesses six degrees of freedom (6 DOF). It uses two disk systems with 3 DOF each. Each disk system constitutes a redundant serial 3-link planar manipulator.

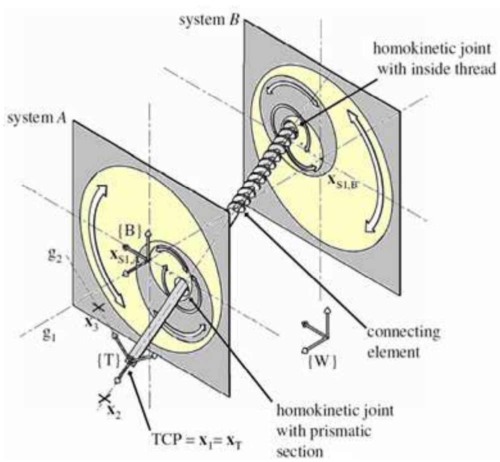


Fig. 2: System A and B and the connecting element that is mounted in two homokinetic joints.

A connecting element is attached to the two disk systems by homokinetic joints. One of these joints has a prismatic inner geometry so that rotation can be transferred while the other joint is provided with a lead screw to move the connecting element in its axis.

Cascaded approach for velocity and pose control

In CYCLOBOT a cascaded model-based control approach for velocity and pose control for a 6-DOF functional EPIZACTOR-prototype has been developed (Fig.3) [2]. Experimental results for different test trajectories have shown that the robot can reach sufficient static and dynamic position accuracy according to the requirement of complex task in orthopedic surgery. This makes the device attractive for the milling cavities with round shape into bone. Arbitrary trajectories are also possible considering kinematics constraints.

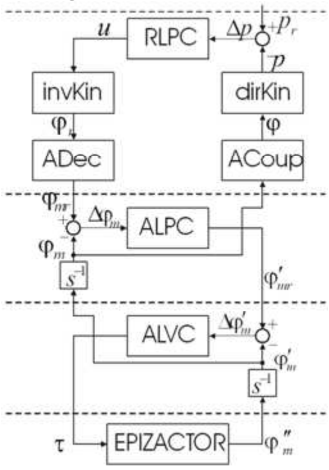


Fig. 3: The cascaded EPIZACTOR-control structure consisting of the Axis-level motor velocity control (ALVC), the Axis-level motor position control (ALPC) and the Robot-level pose control (RLPC)

Supported by: DFG-PROINNO II
Total Support Amount: 500.000 Euro.

References:

[1] Pott PP, Schwarz MLR, Heute S, Weiser P, Wagner A, Badreddin E, “Novel hybrid kinematics with small dimensions and large workspaces make medical robots convenient for orthopaedic surgery”. Proc. of the CARS, Berlin, Germany, 2009.

[2] Pott PP, Wagner A, Badreddin E, Weiser HP, Schwarz MLR, “Inverse Dynamic Model and a Control Application of a Novel 6-DOF Hybrid Kinematics Manipulator”, J Intell Robot Syst, ISSN 0921-0296, 2010.

Efficient COMponent-based develOpment of Dependable computIng Systems (ECOMODIS)

A. Wagner, L. Zouaghi, Y. Luo, M. Jipp, E. Badreddin,

In the framework of the ECOMODIS project, a seamless component-based design methodology and tools for dependable systems have been developed and implemented on a demonstration platform "The Intelligent Wheelchair" (fig.1).

Fig.1: Demonstration platform for ECOMODIS-methodologies

Generic System Architecture

Within the scope of ECOMODIS, a generic hierarchical system architecture for complex dependable systems has been proposed. Using case studies it was shown how a hierarchical architecture and description methods for hardware, software and human-computer interaction can be integrated in the component-based design.

Integrated dependability model

In ECOMODIS an integrated dependability model which includes system, hardware, software, and human properties on a behavioural view has been developed. The proposed dependability measure results in a single number, which can be used to compare the dependability of different systems against each other. The overall dependability number (fig.2) results from various terms, which define the margin by which the system behaviour deviates from the desired mission's trajectory and the given safety boundary [1]. The dependability model and the method of measuring the dependability has been integrated into the system design methodology resulting in the proposed generic system architecture and the seamless component model.

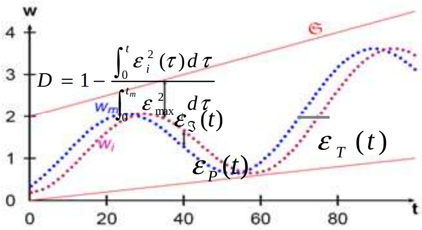


Fig.2: Dependability Measure

Hierarchical system monitoring and reconfiguration

Monitoring is an important method of assessing and assuring the dependability of the system and sub-systems. The objective of such component is to observe the behaviour of a system component while it is running. In ECOMODIS, a monitoring component has been realized, which estimates the behaviour of a subsystem using its inputs and outputs signals and a state observer based on the behavioural specification.

The estimated behaviour and the externally visible behaviour of the component are compared to each other in order to detect deviations. The approach has been applied for different abstraction levels according to the RNBC structure (fig.3) to built a hierarchical monitoring [2]. The developed approach is based on the hybrid modelling of systems using particle Petri nets. A tool has been developed based on a Petri net simulator to monitor the behaviour of components online.

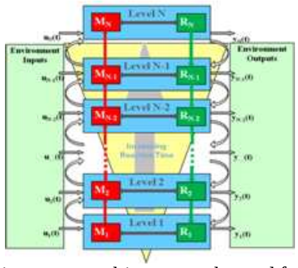


Fig. 3: Generic system architecture enhanced for hierarchical system monitoring and reconfiguration.

Dependable Human-Technology-Interaction

The human operator is a critical factor in relation to the failure of the entire system. In order to ensure dependable operation, the technical system and the user must be adapted to each other as symmetrically as possible considering the individual users. In order to achieve such a matching between the characteristics of the user and the nature of the technical system, a method based on Bayesian Networks by which a technical system can assess the user's dependability-relevant characteristics was developed [3].

Supported by: Ministry for Science, Research and Art, Baden-Württemberg
Coordinator: Automation Lab. Heidelberg Univ.
Total Support Amount: 1.2 Mio. Euro

References:

[1] Wagner, A., C. Atkinson and E. Badreddin, "Towards a Practical, Unified Dependability Measure for Dynamic Systems. Proceedings of International Workshop on the Design of Dependable Critical Systems, Sept. 15, Hamburg, 2009.

[2] Zouaghi L, Wagner A, Badreddin E. Hybrid, Recursive, Nested Monitoring of Control Systems Using Petri Nets and Particle Filters, Workshop on proactive failure avoidance, recovery and maintenance (PFARM), Chicago, USA, 2010

[3] Jipp M., Wagner A. and Badreddin E. "Individual ability-based system design of dependable human-technology interaction". In Proceedings of the 17th IFAC World Congress (IFAC'08). Elsevier Ltd., 14779–14784

Control of the surgical robot „Intelligent Tool Drive“

A. Wagner, A. El Shenawy, P. Pott, E. Badreddin

Today’s medical robotics focuses on new small devices, which facilitate the surgical interventions in the operation theatre through its easy-to-use functionality.

The goal of the project „Intelligent Tool Drive” is to develop a handheld surgical robot, which combines the advantages of computer aided navigation and automatic orthopaedic bone treatment [1]. The surgical process is controlled by the operator for a high working precision using optical positioning and dynamic robot control methods, while the operator has the possibility to change or to interrupt the surgical task safely in case of unpredicted events.

The project was performed in cooperation with the Chair of Application Specific Computing (subproject Pro INNO Moscot) as well as with partners from the Clinical Medicine Mannheim and from Industry.

Development of a real-time control unit

Within the project the Automation Laboratory developed a real-time control system and integrated sensors, actuators and processing units. The overall system (fig. 1) is decomposed into the robot mechanical device, tracking system MOSCOT, and real-time host-target control components. Using a model-based control approach [2], the tool platform is stabilized against a moving patient, while the robot tool was compensated for disturbances induced by the operator at the robot base. The control algorithm has a cascades structure, which combines a local actuator level velocity and position control with a global position control and disturbance cancelation algorithm. While the feedback control loop stabilizes the tool against the robot base in 6 DOF (Degrees-Of-Freedom) using a kinematic description of the robot, the global control is enhanced by a dynamic robot model to describe the tool motion and to suppress disturbances [3].

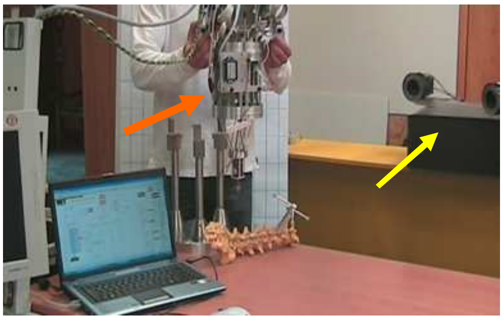


Fig. 1: Integrated ITD_V0.2-System consisting of the handheld robot mechanical device (red arrow), tracking system MOSCOT (yellow arrow) and control PC (Notebook displays control console). The real-time control rack is not shown in the figure.

Stabilization of Position Control System

The capabilities for position stabilization are demonstrated in fig. 2. Here, the robot was carried by a test person. While the robot is moved up (fig. 2 a) and down (fig. 2 b) the controller stabilizes the tool in the free space. Thus the position of the tool keeps constant with a small error relatively to the rectangle patterned background.

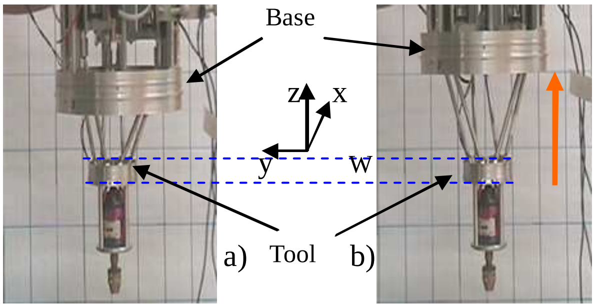


Fig. 2: Stabilization of the tool in direction of the z-axis.
a) Tool is in the centre of the robot workspace.
b) The robot is moved up, while the tool keeps its position relatively to the rectangle patterned background. The tool moves to the lower edge of the robot workspace (relatively to the robot base).

Additionally, the system was tested for dynamic properties using a mechanical disturbance generator and under handheld conditions. The measurement results reveal the system overall functionality, while there is still a high potential for accuracy and dynamics improvements.

Supported by: AIF/Bundesministerium für Wirtschaft und Technologie Total Support Amount: 400.000 Euro

References:

[1] M. L. Schwarz, A. Wagner , A. El-Shenawy, R. Gundling, A. Koepfle, H. Handel, E. Badreddin, R. Männer, H.-P. Scharf, M. Götz, M. Schill, P. P. Pott , “A Handheld Robot for Orthopedic Surgery – ITD”, *Med. Phys. World Congress* (2009).
[2] Achim Wagner, Matthias Nübel, Essameddin Badreddin, Peter Pott, Markus L. R. Schwarz, ”Disturbance feed forward control of a handheld parallel robot”, *ICINCO-RA* (1), 2007: 44-51.
[3] Pott PP., Wagner A., Badreddin E., Weiser HP., Schwarz M, “Inverse Dynamic Model and a Control Application of a Novel 6-DOF Hybrid Kinematics Manipulator. In: Journal of Intelligent & Robotic Systems ISSN 0921-0296 [Artikel] , (2010)

Optimal Engineering Design for Dependable Water Power Generation in Remote Areas Using Renewable Energies and Intelligent Automation (OPEN-GAIN)

A. Kandil, A. Gambier, E. Badreddin

The use of reverse osmosis (RO) plants for water desalination is becoming more popular especially in remote arid areas, where grid electricity might be unavailable. In this case hybrid energy sources, such as wind and solar energy, are used to generate the necessary electricity for running the RO-plant and for domestic use.

The design and running of such a system specially requires a careful overall-system engineering [1]. Thus, the main goal of the project OPEN-GAIN is to develop a new model-based optimal system design approach to economically improve the overall performance and dependability of co-generating water-electricity plants powered by renewable energy sources for remote arid areas using a high level of automation and to meet specific cost requirements.

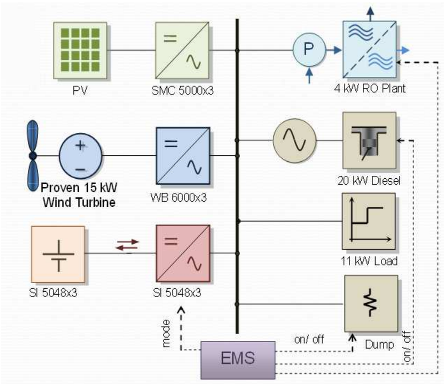


Fig. 1: Hybrid energy system architecture.

To achieve this goal a design support tool was developed to help engineers by optimal sizing of various plant components during the design phase, such as wind turbine, photovoltaic modules, diesel generator, batteries and inverters (fig. 1). A multi-criteria optimization algorithm is implemented to adequately size the system components under the given site and market conditions, which enables the reduction of developing costs.

Dynamical mathematical models of the different plant components are necessary to simulate and test different plant configurations, as well as control strategies. The models are developed and provided as a library of components OSMOSIS that runs under the simulation software package EcosimPro.

Due to the strongly varying renewable energy supply, an energy management system (EMS) is integrated to decide in an optimal way, how the different energy sources have to be combined according to forecasting information of weather and demand of both energy and water, and the current conditions of subcomponents and loads. The EMS can also maximize the power utilization from renewable energy sources.

To design a dependable system, a model-based fault tolerant control strategy was utilized. The integration of such strategy on the supervisor level allows the plant to keep produce water when subject to faults [2]. The supervisor includes a diagnosis unit, which is responsible for the detection and identification of faults, and a recovery unit that adjusts the control to the faulty system.

Fig. 2: Wind turbine (left) and photovoltaic modules (right) at site

The developed methods within the framework of the European project OPEN-GAIN were implemented and demonstrated on a plant, which was built in the Mediterranean city of Burj-Cedria in Tunisia (fig. 2). The prototype plant will be used for posterior research and teaching purposes and will serve as an example for know-how transfer to the industry as well.

Supported by: EU (INCO-CT-2006-032535)
Total Support Amount: 1.3 Mio. Euro
www.open-gain.org
Coordinator: Automation Lab., Heidelberg University

References:

[1] Kandil, A; Gambier, A.; Badreddin, E.: "Optimal Design for Water and Power Co-Generation in Remote Areas Using Renewable Energy Sources and Intelligent Automation," Proceeding of the 22nd European Modeling & Simulation Symposium, Fes, Morocco, Oct. 2010.

[2] Gambier, A.; Miksch, T.; Badreddin, E.: "Fault-tolerant supervisory control of a reverse osmosis desalination plant powered by renewable energies," Proceeding of the 22nd European Modeling and Simulation Symposium (Simulation in Industry), Fes, Morocco, Oct. 2010.

Human Sitting Posture Exposed to Horizontal Perturbation and Implications to Robotic Wheelchairs

K. A. Tahboub, E. Badreddin

In this project the human sitting posture when exposed to horizontal seat perturbations is analysed and modelled. The aims of this study are to investigate the implications of such vibrations to robotic wheelchairs and to make suggestions to enhance user's comfort and safety.

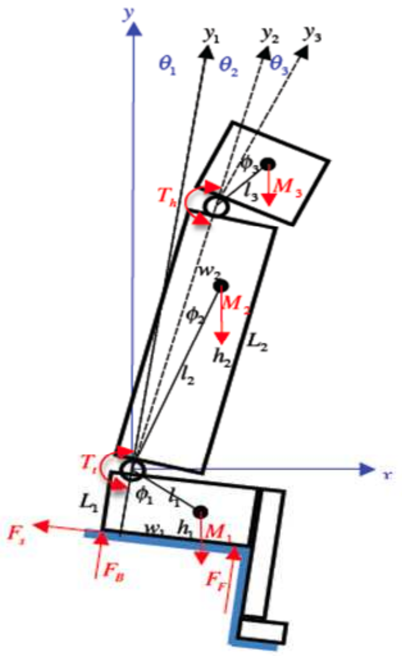


Fig. 1: Schematic diagram of a seated human

As shown in Fig. 1, the trunk, which is represented as an inverted pendulum, is inherently unstable causing a major problem for people with spinal cord injuries. Thus, trunk muscles must play a major role in maintaining upright sitting posture when disturbed by seat motion. The complexity of the observed muscle activation pattern and its independence of muscle stretch lead to the suggestion that the responses are, in contrast to reflexes, centrally generated [1]. Further the importance of co-activation of antagonist muscles to produce stability by increasing the stiffness of the trunk is recognized. On the sensory side, it is concluded that the vestibular system plays a minor role compared to proprioception (rotation of pelvis and hip movement) and cutaneous receptors that measure the distribution of the pressure under various parts of the buttock and thigh. Although sitting seems to be easier than standing (due to lower CG, larger base support, and less number of joints), patients with stroke for example still exhibit some disability in trunk function and in maintaining sitting posture. This disability is explained by body scheme miss-representation and loss of force in the trunk musculature.

In contrast to several published inert biomechanics models for human seated posture which consider neither active nor reactive control through the muscles, the biomechanics model proposed in this project (Fig. 1) incorporates a simplified active control law composed of an inner stabilizing loop and an external tracking loop. Simulation results of this biomechanics model come inline with published experimental results. Transmissibility function of seat vibration to the head, as shown in Fig. 2, demonstrates a considerable magnification of transmitted vibration at frequencies around the peak frequency of 3 Hz. Such a magnification is a source of discomfort to the seated subject.

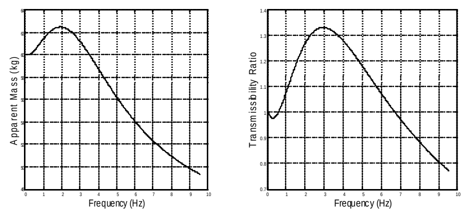


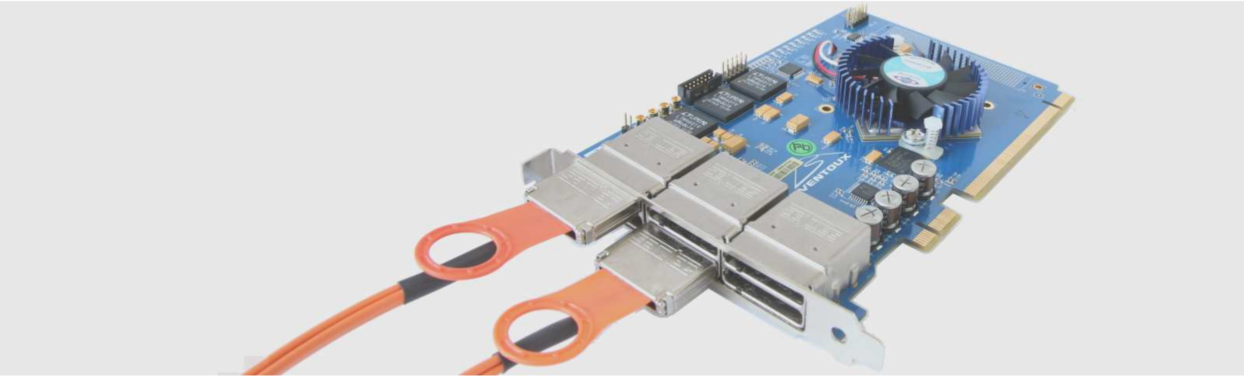
Fig. 2: Apparent mass magnitude response and seat-head transmissibility ratio of a body seated without a back support under vibration along the fore-aft direction

For improving wheelchair user's acceptance, comfort, and feeling of safety, it is proposed in this work to limit the wheelchair acceleration in the frequency range where transmissibility is high. This implies applying a band-stop filter around the 3-Hz frequency.

References:

[1]Forssberg, F., Hirschfeld, H, "Postural adjustments in sitting humans following external perturbations: muscle activity and kinematics," Experimental Brain Research, Vol. 97, pp. 515-527, 1994.

[2]Tahboub, K. A., Badreddin E., "Human Sitting Posture Exposed to Horizontal Perturbation and Implications to Robotic Wheelchairs," International Conference on Intelligent Robotics and Applications, Aachen – Germany, 2011.



Chair for Computer Architecture

Prof. Dr. Ulrich Brüning

Chair of Computer Architecture
Precise Time Synchronization and Customized Interconnection Network for the CBM Project at Fair
Cooperation Project between IAS at RWTH Aachen and LSRA at ZITI to enable High Quality Mixed Signal Designs
High Frequency Trading Acceleration using FPGAs
Scalable Interface for High Performance Computing
HyperTransport Center of Excellence
Cadence Academic Network

Chair of Computer Architecture

Prof. Ulrich Bruening and team
[1] *University of Heidelberg, Germany*

The ZITI chair for Computer Architecture at the University of Heidelberg has the expertise to design complex hardware/software systems. As system architects we cover not only the operation principles but include the technology and the software to build real working prototypes. The Computer Architecture Group (CAG) holds a profound expert knowledge in the area of design space analysis, hardware design of processors and devices, interconnection networks, and software driver development, especially for the construction of large computing clusters based on PC technology.

All levels of system design are covered, starting at the application programming interface, e.g. the message passing interface library (MPI), through the efficient design of device drivers finishing at custom build hardware devices based on standard cell ASIC and FPGAs.

Goals of the applied research activities are to cover a broad range of methodologies for the design of complete high performance systems with the possibility to optimize every level and educate students on the various real world topics.

The group mainly focuses on the design of parallel architectures, which achieve their high performance by improving communication between computational devices/units. Scaling such systems is a great challenge to the architecture of the interconnection networks (IN) and the network interface controllers (NIC). Special attention is paid on the interface between software and hardware to setup communication instructions.

Beside a number of interesting industrial projects, the chair focuses its internal research on the question of latency reduction in various application areas. Interconnects and interconnect switches on the network side and host interfaces and device control at the host side suffer significantly on designs which are not optimized for latency reduction or latency hiding. The EXTOLL project is an examples where a holistic optimization approach leads to a very low latency and high performance network interface controller (NIC), which was operational in 2009 and demonstrated at the ISC10 in Hamburg and at the largest supercomputer conference and exhibition SC10 in New Orleans (US). Fig. 1 shows the CAG research booth at the SC10.

Fig. 1: EXTOLL Project presentation at the SC2010 in USA

The EXTOLL NIC in FPGA technology is comparable to fast industrial ASIC designs from the perspective of latency.To improve the IN also on bandwidth we developed in cooperation with Samtec and the HyperTransport Consortium a high density board edge connector (HDI6) for up to 10Gbit/s per lane providing 12 bidirectional lanes with a total bandwidth of 240Gbit/s.
In 2010 we received a grant from the Federal Ministry of Econimics and Technology (BMWi) in the EXIST program to support the development of a prototype system and the funding effort for a startup company [1]. This interconnect technology has been selected as interconnect for a large research prototype at the Juelich Supercomputing Center (JSC) to be build in 2012.

For a US startup company we have developed a low latency high throughput solid state storage device based on FLASH chips. The design utilizes a low cost FPGA from Lattice with an innovative internal architecture, which is scalable due to its inherent interconnection network based on Serializer/Deserializer technology (SERDES). The device prototype was completed but the project has been terminated unexpectedly by the industrial partner at the beginning of 2009 due to the finance crisis. Google Inc. donated a grant for further research in this area.

In 2007, the HyperTransport Center of Excellence was founded together with AMD and since then it is operated by the Computer Architecture Group. HyperTransport (HT) is the processor interface of AMD CPUs and can be used to interconnect CPUs in a coherent and non-coherent way. Using this interface reduces latency for CPU to device communication significantly compared to standard IO-Busses. Therefore, the CAG developed their own HT cores and could utilize this technology in some projects with AMD and other industrial partners to build HT-based devices. Together with Numascale, we integrated a coherent HT core into their communication device and it turned out to be a success for scalable shared memory interconnects. For Xilinx and Altera we have developed various reference platforms with high performance FPGAs and HT interface. In February 2009, we hold the Second Symposium for HyperTransport™ Technology in combination with the International Workshop on HyperTransport Research and Applications (WHTRA) with international participation.

In order to design and develop such complex hardware components the CAG runs some internal developments in the area of EDA tools for closing specific design gaps. This is mainly done for productivity reasons and for raising the level of abstraction in the design phase. The FSMDesigner4 [2] for example, is used intensively in the design of finite state machnies (FSM). It allows graphical definitions of FSMs and after automatic checking, optimized hardware description language (HDL) and verification code is generated.

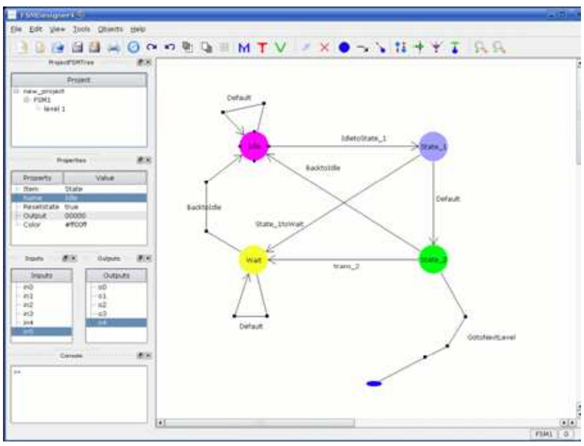


Fig. 2: FSMDesigner4 main working window

The development of the tool is done as an open source project on Source Forge. Fig. 2 shows the main working window of the FSMDesigner. Furthermore, tools and scripts have been developed simplifying automatic generation of parametrized HW-structures, like a Register File generator, on-chip Crossbars, FIFOs, etc. In addition to the RF-HDL code, SW drivers are generated automatically to test the RF in PCIe and HT devices. For most of the projects, a common methodology for mapping hardware to FPGAs and ASICs with the same source code is used.

The CAG of the University of Heidelberg is member of the Cadence Academic Network and plays a major role in this network, as we are the "Lead University for Functional Verification". The Cadence Academic Network is a university/industry collaboration to support and improve Universities activities in the design of analog and digital semiconductors.

We have established close collaborations with other research groups, especially with Prof. Jose Duato from the Universidad Politécnica de Valencia and with Prof. Rehm from the Technical University of Chemnitz. In the area of chip design the CAG is working with Prof. Stefan Heinen from the RWTH Aachen.

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[1] Zuwendungsbescheid vom 18.08.2010 der PTJ: EXIST-Forschungstransfer: EXTOLL – Innovative skalierbare Hochleistungs-Rechnersysteme, Förderkennzeichen: 03EFT5BW24.

[2] Frank Lemke, Mondrian Nüssle, Ulrich Brüning, Experience with the FSMDesigner4 high level design entry tool for design and verification in research and teaching,
CDNLive! EMEA 2009, Academic Track, May 18-20, 2009, Munich, Germany.

Precise Time Synchronization and Customized Interconnection Network for the CBM Project at Fair

F. Lemke, S. Schenk, U. Brüning

The Compressed Baryonic Matter (CBM) experiment at the Facility for Antiproton and Ion Research (FAIR) at GSI Darmstadt needs a Data Acquisition (DAQ) system. The Computer Architecture Group's (CAG) activities within the CBM Collaboration focus on designs and implementations concerning the DAQ system. FAIR works together with the GSI for constructing and running the planned FAIR facility. It will extend the existing GSI Linear Accelerator and the GSI Synchrotron. CBM, as one of the planned experiments, consists of seven different detectors. Self-triggered front-end electronic modules are used to collect data from them. The final event selection will be done after event building on a processor farm. The data flow will be up to 1TB/s and special mechanisms are required for synchronization of the detectors. Radiation tolerance must be provided by the frontend hardware (HW). The following paragraphs give an overview of our work.

The CAG research within the CBM project focuses on two parts in the CBM network. Designing a CBM protocol for the network and developing HW solutions at different hierarchy levels [1]. This CBM protocol must efficiently support four features: clock distribution, support for time synchronization, control messages, and data streams. This is implemented with clock and data recovery (CDR) over optical links and the use of three traffic classes. The traffic classes are Deterministic Latency Messages (DLM), Data Transport Messages (DTM) and Detector Control Messages (DCM) for communication over unified optical bidirectional links.

A variant of the planned CBM Network DAQ System is presented in fig. 1. It consists of frontend electronic boards (FEB) for detector readout, *hub* ASICs for data aggregation and speed conversion, *opto* converters to extend the communication range using fiber optics, data processing boards (DPB) for further data aggregation and pre-processing, the detector and experiment control system (DCS/ECS) for control and synchronization, and a data sink within the compute cluster.

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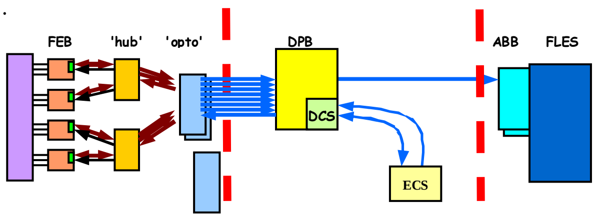

Fig. 1: CBM Network Diagram.

For detector readout during beam times, a chain consisting of previously developed prototypes was created [2]. This build-up used during tests in December 2010 is presented in fig. 2. It shows two DPB prototypes connected to an Active Buffer Board (ABB) that served as emulation for the ECS providing the clock and system synchronization with DLMs via the CBM protocol version one. Both DPB prototypes have four connections to the front end for attachment of Readout Controllers (ROC) using the unified CBM protocol for synchronization and data acquisition. The received data is combined into a single data stream within the DCBs and sent to an ABB plugged into a workstation running the data collection software. During the complete test this readout demonstrator was used. Data acquisition ran without any problems and ECS emulation providing control and clock distribution was reliable. Network synchronization worked delivering bit-clock synchronization with at least 400 ps accuracy.

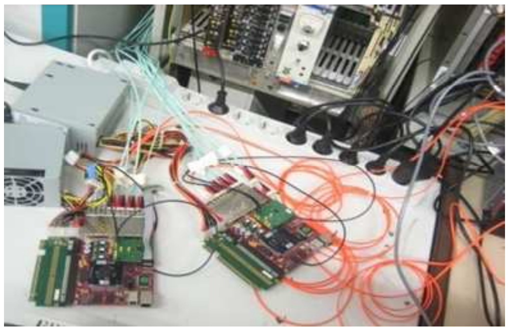

Fig. 2: Beam Time Setup during Dec. 2010.

The concept of using the unified link providing DLMs for synchronization has shown its valuable improvement for future detector system solutions and the CAG will continue developing components concerning the CBM protocol and network.

Supported by: BMBF (06HD9117I), Cooperation with GSI

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[1] Lemke, F; Slogsnat, D.; Burkhardt, N.; Brüning, U.; A Unified DAQ Interconnection Network with Precise Time Synchronization", *IEEE Transactions on Nuclear Science* (TNS), Journal Paper, VOL. 57, No. 2, April 2010.

[2] Lemke, F.;Schenk,S.;Bruening,U.; „Experiences and results using the CBMnet protocol including precise time synchronization and clock distribution", *Deutsche Physikalische Gesellschaft EV* (DPG11), Fruehjahrstagung, Muenster, Germany, March 21-25, 2011

Cooperation Project between IAS at RWTH Aachen and LSRA at ZITI to enable High Quality Mixed Signal Designs

F. Lemke, S. Schenk, R. Leys, U. Brüning

In a collaboration project between the two Cadence Academic Network members, the IAS of RWTH Aachen and the LSRA at ZITI of the University of Heidelberg, a prototype design of a Radio Frequency Digital Analog Converter (RF-DAC) based Multistandard Transmitter System for mobile communications was fabricated in a 65nm standard CMOS technology [1]. During the creation of this Mixed Signal Design IAS was leading the project and developed all analog blocks and integrated them together with digital parts within their environment, while LSRA was bringing their experience in digital module design into the project. The prototype [2] features a PLL-less serial control interface using Current Mode Logic (CML) signaling, transmitting inphase and quadrature path along with word and bit clock. For testing the RF integrated circuit, this interface was connected to a Virtex 6 FPGA. The digital part of the interface and the analog full custom design has been developed using the Cadence tools Encounter and Virtuoso. Both parts can then be unified within the tool chain and for verification purposes mixed signal simulations have been conducted.

The system features a fully digital input and analog/RF output. The RF-DAC consists of several parallel unit cells. Each unit cell contains a current source that is controlled by a digital baseband signal and of a switching quad, which translates the baseband signal to RF. Since the test data is generated using Xilinx transceivers with high data rate (2.5Gbps), a DDR connection was chosen for the control interface. The interface is shown in fig. 3. The FPGA serializers can be used with a data rate of 2.88Gb/s in order to generate a double oversampled data stream of 1.44Gb/s. Thus, the clock MGT can then provide a DDR clock with center aligned edges for the data sampling point, simplifying the receiving logic on the ASIC.

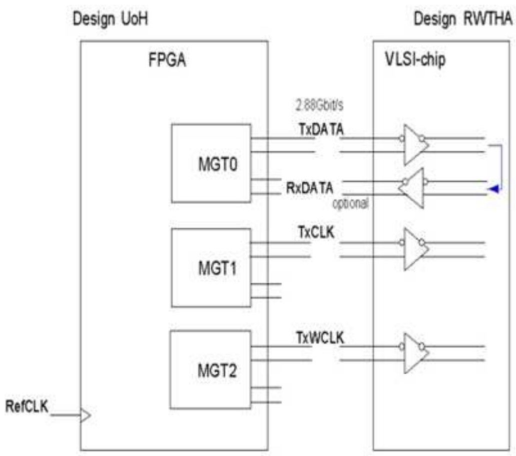

Fig. 1: Block Diagram of the DDR SERDES Interface.

A second joint project between RWTH and ZITI continued the productive collaboration and created a second prototype. It provides an improved version of the interface built as a generic digital building block. An 8B/10B encoder determines the word boundaries properly. On-chip delay paths adjust the phase shift between clock and data signals. A return channel analyzes the received RF signals. In addition, a register file, generated by a register file generator tool, was inserted into the design. This tool was developed by the LSRA group and improves the register file handling during the design process. In addition, configuration registers used within the analog design part can easily be added to a register file and rapid changes within the analog design improve the analog design process. Fig.2 shows a block diagram of the second ASIC including the generic digital building block.

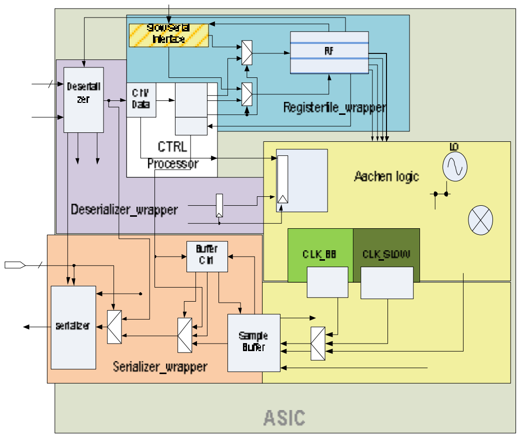

Fig. 2: Block Diagram of second ASIC prototype.

Supported by Cadence Academic Network; In Cooperation with Lehrstuhl für Integrierte Analogschaltungen, Institut für Halbleitertechnik, RWTH Aachen

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[1] Mohr, B.; Zimmermann, N.; Thiel, B.; Zhang, Y.; Negra, R.; Heinen, S.; „RF-DAC Based Multimode, Multistrand Transmitter for Wireless Communication", Activity Report 2010, Europractice IC Service, 2011.

[2] Mohr, B.; Zimmermann, N.; Wang, Y.; Thiel, B.; Negra, R.; Heinen, S.; Lemke, F.; Schenk, S.; Leys, R.; Brüning, U.; Implementation of an RF-DAC based Multistandard Transmitter System, CDNLIVE! 2011, Academic Track, Munich, Germany, May 3-5th, 2011.

High Frequency Trading Acceleration using FPGAs

Heiner Litz, Christian Leber, Benjamin Geib

High Frequency Trading (HFT) has received a lot of attention over the past years and has become an increasingly important element of financial markets. The term HFT describes a set of techniques within electronic trading of stocks and derivatives, where a large number of orders are injected into the market at sub-millisecond round-trip execution times. High frequency traders utilize a number of different strategies, including liquidity-providing strategies, statistical arbitrage strategies and liquidity detection strategies. All strategies have in common that they require absolute lowest round-trip latencies as only the fastest HFT firm will be able to benefit from an existing opportunity.

Electronic trading of stocks is conducted by sending orders in electronic form to a stock exchange. In common systems the so-called market feeds which provide real time information about stock prices are received via usual network interface. Feed handlers transmit the data using UDP and TCP/IP encapsulated in Ethernet packets. The feed itself is transmitted using the FAST protocol. In the course of this research project the Computer Architecture Group of the University of Heidelberg has developed a Field Programmable Gate Array (FPGA) based Accelerator for receiving, decoding and interpreting such market feeds [1].

A hardware design was developed in Register Transfer Level (RTL) code that is loaded on the FPGA, which has a direct 10 Gb Ethernet connection. The design is able to decode Ethernet, UDP, and the FAST data stream. FAST is a complex protocol that uses compression to reduce the data bandwidth and which is generally decoded on the host CPU. To accelerate FAST decoding a microcode engine with a corresponding assembler tool has been developed. The instructions to decode a particular FAST data stream can be defined in a domain specific assembler language. This language is then translated into binary form through the assembler tool. Subsequently, the binary code is loaded into the microcode engine to enable decoding of incoming packets. The decoded data can then be interpreted to perform trading decisions, for example whether to buy or sell a stock. Orders, which can also be offloaded to the trading accelerator, are then transmitted via TCP/IP to the stock exchange. As a platform for the trading engine, our in-house developed HTX board is used, which is shown in Figure 1.

Figure 1: FPGA Accelerator Platform

The result of this research project is a significant acceleration of the complete trading process. This allows the sponsoring company to perform more trades successfully, which benefits the complete financial environment as the company can thereby provide liquidity to the market.

Supported by: AMD (Research Grant 250.000 EUR)

References:

[1] Christian Leber, Benjamin Geib, Heiner Litz: "*High Frequency Trading Acceleration using FPGAs*", FPL 2011, September 5-7, 2011, Chania, Greece.

Scalable Interface for High Performance Computing

Heiner Litz, Benjamin Kalisch, Niels Burkhardt, Alexander Giese

Current High Performance Computing (HPC) systems are built from hundreds of thousands of compute nodes and feature several million compute engines. These so-called compute clusters are composed of off-the-shelf components including a large number of x86 processors from Intel or AMD. The major challenge of building HPC clusters is to interconnect the large number of components in an efficient way. Therefore, SUN Microsystem in collaboration with the Computer Architecture Group of the University of Heidelberg has developed the Scalable Interface (SIF) Architecture. The SIF represents a novel and extremely fast network interface that enables to connect a large number of compute nodes into a cluster.

Major features of the SIF are the lowest latency for message transactions, very high bandwidth and scalability to multiple thousands of nodes. These goals are achieved through a tightly coupled architecture between the processors and the network, leveraging AMDs cache coherent HyperTransport (HT) host interface. It allows attaching the SIF directly to the processor instead of using PCIe as the host interface.

In the course of the project, the SIF architecture was defined and a HyperTransport interface has been developed [1]. The work includes the specification, implementation as well as the verification of the developed components.

Verification of the design was conducted using two different approaches. First, a System Verilog based Verification suite which is shown in Figure 1 has been developed, to simulate the HyperTransport core comprehensively.

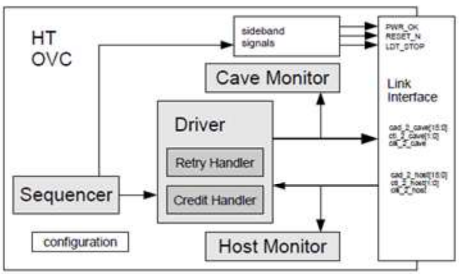

Figure 1: HT Verification Environment

Second, a Field Programmable Gate Array (FPGA) based prototype, seen Figure 2 has been developed [2] to test the design a real system. Therefore, the complete hardware design has been loaded onto the FPGA which has been plugged into an AMD based server. A linux kernel driver has been developed to operate the card and to run system level tests.

Figure 2: FPGA based Prototype

Supported by: SUN Microsystems (Grant 360.000 EUR)

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[1] Benjamin Kalisch, Alexander Giese, Heiner Litz, Ulrich Brüning: *'HyperTransport 3 Core: A Next Generation Host Interface with Extremely High Bandwidth'*, First International Workshop on HyperTransport Research and Applications (WHTRA), February 12th, Mannheim, Germany.

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HyperTransport Center of Excellence

Ulrich Brüning, Heiner Litz, Christian Leber, Benjamin Geib, Alexander Giese, Benjamin Kalisch, Holger Fröning, Mondrian Nüssle, Frank Lemke, Niels Burkhardt, Sven Kapferer, Sven Schenk

The Computer Architecture Group of the University of Heidelberg has established the HyperTransport Center of Excellence (HTCE) which is funded by AMD. The HTCE aims to promote the HyperTransport (HT) technology and to provide an HT ecosystem for industry and academia. The ecosystem components that have been developed in the course of this work include HyperTransport IP cores, Verification environments, HyperTransport Extension prototyping devices, frameworks, documentation and 3rd party customer support. In the following some of the projects which are part of the HTCE initiative will be presented.

HyperTransport 1.x Core [1]: The HT 1.x core, shown in Figure **1** represents a fully compliant HyperTransport 2.0 IP core. It is provided in synthesizable hardware description language and can be mapped to different Field Programmable Gate Array (FPGA) and Application Specific Integrated Circuits (ASIC). The HT core represents a host interface component that provides significantly reduced latency and increased bandwidth compared to PCIe.

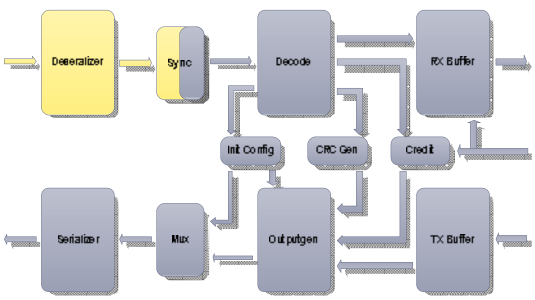

Figure 1: HyperTransport 1 Core

HyperTransport 3.x Core: The HT 3.x core represents a fully compliant HyperTransport 3.0 IP core. It is provided in synthesizable hardware description language and can be mapped to different FPGA and ASIC platforms. The HT 3.x core has been utilized in numerous projects including Sun Microsystems's SIF project and AMD's Debug Tool and Engineering project.

HyperTransport Extension (HTX) boards [2]: As a FPGA based test and prototyping platform, HTX boards have been developed which represent an excellent target for the HyperTransport cores. To operate HTX boards in systems, Linux drivers as well as software libraries have been developed.

Figure 2: HTX Prototyping Board

As a result, the developed HyperTransport components have stimulated a number of related research projects in collaboration with universities and several commercial industry projects.

Supported by: AMD (Grant 200.000 USD)

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[1] David Slogsnat, Alexander Giese and Ulrich Bruening: "*A versatile, low latency HyperTransport core*", Fifteenth ACM/SIGDA International Symposium on Field-Programmable Gate Arrays, Monterey, California, February 2007.

[2] Holger Fröning, Mondrian Nüssle, David Slogsnat, Heiner Litz, Ulrich Brüning: "*The HTX-Board: A Rapid Prototyping Station*", 3rd annual FPGAworld Conference, Nov. 16, 2006, Stockholm, Sweden.

Cadence Academic Network

S. Kapferer, U. Brüning

The Cadence Academic Network [1] was founded in 2007 by Cadence Design Systems, a global vendor of EDA software. The goal of the initiative is to establish a network among European universities together with Cadence in order to share knowledge and expertise in the field of analog and digital design. As one of three founding member universities the University of Heidelberg, in particular the Chair of Computer Architecture, took on its role as lead university in the field of advanced SoC (System-on-Chip) verification.

Since then the network has grown considerably and currently consists of 11 lead institutions covering eight methodologies ranging from Advanced Verification, Analog-Mixed Signal, and Digital Design to PCB Co-Design, thus incorporating the whole range of design and implementation of microelectronic circuits. Furthermore the network includes more than 20 contributor universities and research institutes from all over Europe.

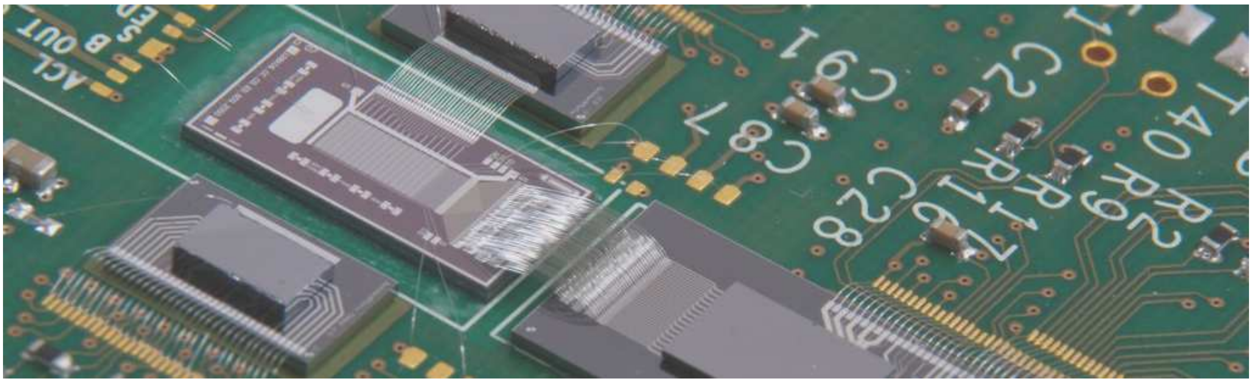
The ability to access leading-edge methodologies from industry allows the integration of teaching material into lectures that benefit students with a state-of-the art education as well as industry because their future employees are already equipped with practical skills acquired in their studies.

Since 2008 the Cadence Academic Network is also visible at the annual CDNLive! EMEA conference. A special academic track at the conference allows universities to present their academic work or curricula to academic peers and attendees from industry. The track is fully integrated into the conference and the accepted submissions are visible to all visitors in the conference guide. Interest in the academic track has also grown considerably in the last years, reaching its peak at this year's conference with 147 individuals attending a session in the track (a 50% increase since 2010), out of these 76 were coming from industry.
Over the last years researchers from the Computer Architecture Group held several invited talks detailing research projects at the group and education at the University of Heidelberg. Other talks at the conference promoted open source EDA tools (FSM Designer) and verification environments (e.g. for the HyperTransport ecosystem) that were developed internally and are free to use for other universities.

With the beginning of 2011, the Cadence Academic Network started to provide its technical information via the LinkedIn network. It offers advanced possibilities to receive tailored information and also a platform for discussions with fellow researchers as well as Cadence employees. The "Cadence Academic Network" group [2] acts as the main portal, whereas several subgroups such as "Advanced Verification Methodology" provide a platform for special interests in a particular technical field. The groups are moderated by the lead institutions of the academic network, ensuring a constant flow of information and discussions.
The main LinkedIn group is already followed by more than 360 members, not only from European academia but from institutions and companies all over the world.

The Cadence Academic Network also was the source for a successful collaboration of the Computer Architecture Group with another network member, RWTH Aachen University, for a joint project to combine our expertise in digital design and verification with Aachen's knowledge in analog design at small technology nodes.

References:
[1] http://www.cadence.com/support/Pages/academic_network.aspx
[2] http://www.linkedin.com/groups?gid=2839375



Chair for Circuit Design

Prof. Dr. Peter Fischer

The SPADIC Amplifier / Digitizer ASIC for the TRD of CBM
Pixel Readout ASIC for the DSSC detector at XFEL
The XNAP Fast 2D X-Ray Photon Detector
Simultaneous PET / MRI Imaging
The Pixel Vertex Detector of the Belle II Experiment
Compact Microscopy Unit for Cell Biology
School and Outreach Projects
Development of Single Chip Bump / Flip Chip Technologies

The SPADIC Amplifier / Digitizer ASIC for the TRD of CBM

T. Armbruster, M. Krieger, I. Peric, P. Fischer

The FAIR facility (Facility for Antiproton and Ion Research) which is being constructed at the GSI in Darmstadt will deliver very intense proton and ion beams to study, among many other physics goals, nuclear matter at very high temperature and density. The CBM experiment (Compressed Baryonic Matter) will be searching for evidence of the Quark-Gluon-Plasma and will study the phase transitions and the density of state.

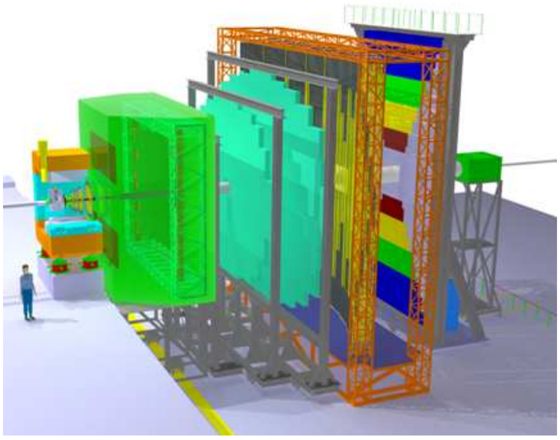


Fig. 1: Planned CBM Experiment at FAIR / GSI. The TRD detectors are the green circular structures in the centre.

The CBM collaboration, composed of about 50 institutes, is developing the fixed target detector sketched in fig. 1 to reach the various physics goals. Several different sub-detectors will be used to measure particle tracks and to identify their type, energy and momentum with high precision. One component is a large Transition Radiation Detectors (TRD) which can localize particle tracks and distinguish between different particle types (electrons, pions). The TRD is composed of a 'radiator' structure where a traversing high energetic particle generates a burst of X-ray photons and a gas filled gap where the X-ray photons are absorbed again. The absorption process generates free electrons which drift to the backside where they are amplified in high electric fields. The generated charge cloud finally induces electrical signals on pad electrodes with a size of some cm^2.

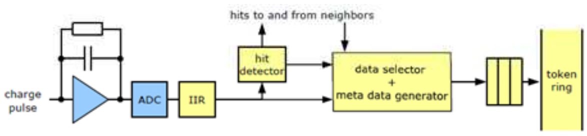


Fig. 2: Main SPADIC Functionality.

The signals of 100.000-500.000 pad electrodes must then be amplified, digitized and processed with a specialized integrated circuit, the SPADIC (Self Triggered Pulse Amplification and Digitization ASIC, fig. 2) which is fully being developed by our group.

Each SPADIC channel will contain a low power, low noise charge amplifier with a pulse shaper (800e @ 90 ns, 30 pF, 3.8 mW), a compact low power 8 Bit ADC (ENOB = 7.5 Bit @ 24 MSpS, 4.5 mW) and an Infinite Impulse Response (IIR) filter to digitally process the signal further. A hit detection logic cuts out relevant pulse segments from the continuous data stream and stores them in a FIFO for serial readout through the CBM network.

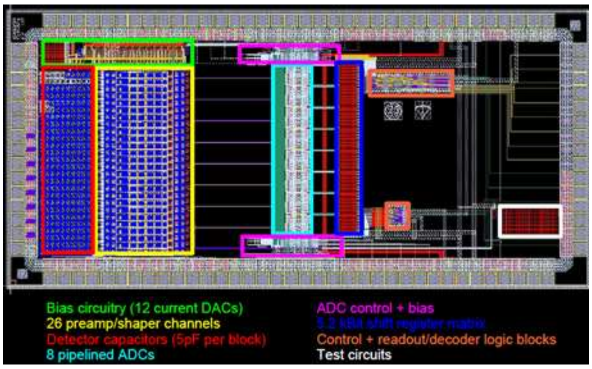


Fig. 3: Layout of the SPADIC 0.3 ASIC.

A chip with the fully working frontend & ADC part has been designed and produced. The ASIC and a suited fast USB readout board with associated data acquisition control and online monitoring software has been made available to the TRD groups for detector characterization. This infrastructure has been successfully used in a first TRD test beam campaign at CERN. More than 12 setups will be provided for the test beam in 2011.

The next generation of the chip will contain 32 channels with the IIR filter, hit finding and an improved fast digital readout scheme.

Supported by: BMBF (06HD9120l), Cooperation: CBM Collaboration

References:

[1] http://spadic.uni-hd.de

[2] A Self Triggered Amplifier/Digitizer Chip for CBM**,** T. Armbruster, P. Fischer, I. Perić, Proc. of the TWEPP2009 conference

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Pixel Readout ASIC for the DSSC detector at XFEL

F. Erdinger, J. Soldat, P. Fischer

Synchrotron X-ray sources are popular and valuable facilities for material studies and fundamental research. A next big step in intensity and brilliance will be made by the XFEL free electron laser which is being constructed at DESY in Hamburg. In order to exploit the unprecedented possibilities of the machine, the XFEL GmbH is funding the development of advanced 2D detector arrays which can image photons of only a few keV energies with ~100 µm spatial resolution at an image frame rate of up to 4.5 MHz.

One such innovative system will be the 1024 × 1024 pixel DSSC (DEPFET Sensor with Signal Compression) detector which consists of silicon sensors with intrinsic nonlinear amplification bump bonded to large (~1.3 × 1.5 cm^2) specialized pixel ASICs with 4096 channels each. Every channel of this chip contains an analogue interface to the sensor, a low noise filtering amplifier, an 8 Bit (single slope) ADC and a local static memory to store the amplitude values during the photon burst of ~1 ms duration. The data is then read out in the XFEL cool-down period of 99 ms, before the next burst arrives.

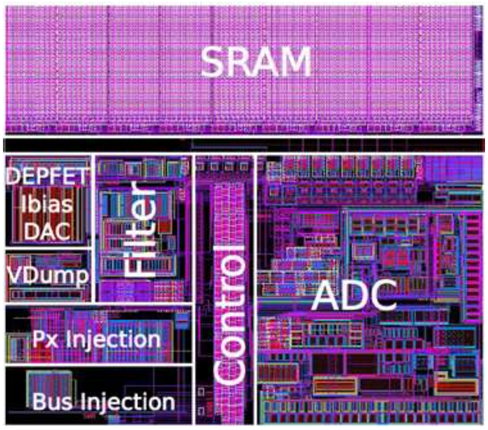

Fig. 1: Layout of one pixel of the DSSC ASIC.

Our group is coordinating the ASIC development, is responsible for the digital local storage & control and, most importantly, for the interconnection and integration of all building blocks (several others being contributed by project partners) to a compact pixel layout of 204 × 229 µm^2 size, as shown in fig 1. We are further assembling larger pixel arrays and design local and global circuitry for configuration, control and fast data readout.

Several different compact digital storage solutions (DRAMs and SRAM with minimal control overhead) have

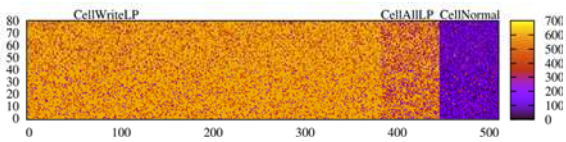

Fig. 2: Measured retention times (µs) of three different variations of dynamic RAM designs as a function of the bit position.

been designed and prototyped in the first project phase on several test chips in the 130 nm technology used. As an example, fig. 2 shows the retention times obtained by various DRAMs as a function of the bit location.

Custom made setups have been developed to characterize the test chips and arrays in details, to study the effects of temperature and radiation, and to connect DEPFET sensors. The latest setup allows for fast cycling of the supply voltages of the ASIC which will be powered only during the short active burst phases to save power. This is required as the whole detector system will be located in vacuum such that cooling away the dissipated power is difficult.

The matrix ASIC in fig. 3 has successfully been used to characterize the filter and the ADC and to measure X-ray spectra with DEPFETs.

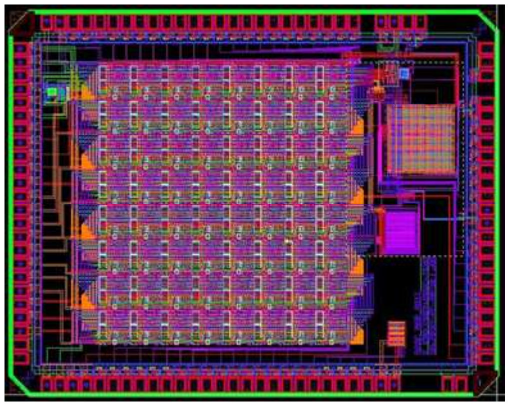

Fig. 3: First DSSC Matrix ASIC with 8 × 8 pixels

Supported by: XFEL GmbH, Cooperation: MPI HLL Munich, DESY, Universities Milano, Bergamo & Siegen.

References (for instance):

[1] Compact Digital Memory Blocks for the DSSC Pixel Readout ASIC, F. Erdinger, P. Fischer, Poster at the 2010 IEEE Nuclear Science Symposium

[2] Pixel Readout ASIC with per Pixel Digitization and Digital Storage for the DSSC Detector at XFEL, P. Fischer et al., Talk at the 2010 IEEE Nuclear Science Symposium

The XNAP Fast 2D X-Ray Photon Detector

Christophe Thil, Peter Fischer

Synchrotron light sources like the European Synchrotron Radiation Facility ESRF in Grenoble use their intense, focussed X-ray photon beams to generate diffraction patterns on crystallized samples or to study the atomic composition by fluorescence techniques. Fluorescence photons can be distinguished from prompt (scattered) photons by the arrival time differences at the detector, which can vary from few nanoseconds to microsecond. At present, such X-ray sensitive photon detectors with nanosecond resolution consist of very few (max. 10) individual pixels only, so that scans over a larger acceptance are very time consuming.

The XNAP project (Xray Nanosecond Array of Pixels) has been initiated by the detector R&D group at the ESRF with the goal to develop an array of 32 × 32 X-ray sensitive pixels with a time resolution in the ns range. The detector is based on thick, fully depleted APDs (provided by an industry partner) and a readout ASIC developed in our group.

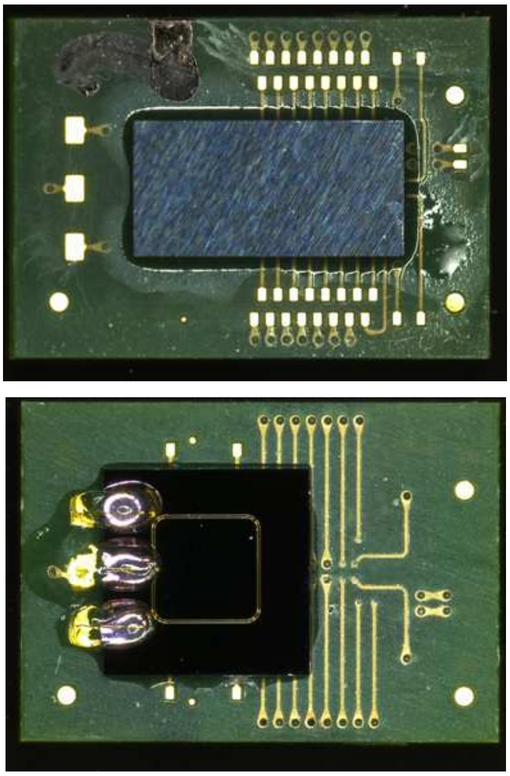

Fig. 1: Dual sided assembly with an APA2 chip on the one side (top) and an APD device on the bottom side (bottom). The assembly has a size of only 4.2 × 6 mm^2

The challenging micro-mechanical assembly consists of a support board with a bump bonded sensor on one side and the bump bonded readout ASIC on the other side. Fig. 1 shows both sides of a functional assembly with 4 ×4 pixels being read out by the second generation ASIC APA2. The final design will contain a much larger APD array and four ASICs with 16 × 16 channels each, as shown in Fig. 2.

Each pixel of the chip contains a fast transimpedance input stage to amplify the weak APD signals, a discriminator with programmable threshold to digitize the information and a fast OR tree to flag the hit to an external Time-to-Digital converter on a shared output. The address of the hit pixel is read out after an event and the chip is then cleared again. One hit requires a processing time of a few 10 ns only. An alternative operation mode allows for counting the hits in every pixel during a programmable time interval and a dead-time free readout of the values. Counter length and thus the readout time can be varied over a wide range.

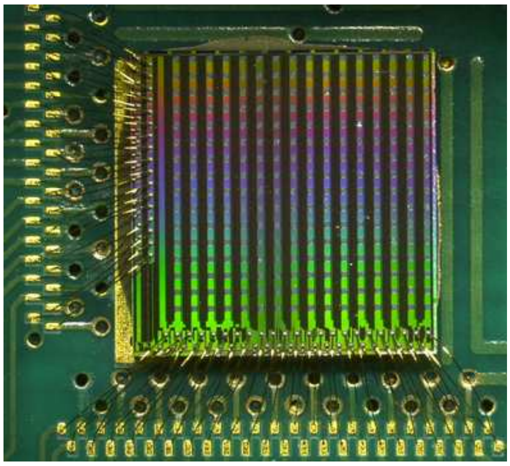

Fig. 2: Micro Photograph of a bonded APA3 readout ASIC with 16 × 16 pixels on a die area of 5 × 5 mm^2

The chip uses a fairly uncommon differential logic style in all permanently active parts to prevent possible interferences between the digital and the sensitive analogue sections.

Early prototype chips have been successfully tested with discrete APDs using ^{55}Fe X-ray sources. The second generation chip with 4 × 4 pixels is presently being used for first matrix tests, and the available final APA3 is being characterized.

Supported by: ESRF and DESY, Cooperation: ESRF (P. Fajardo), DESY (H. Graafsma), Excellitas

References:

[1] XNAP: a 2D X-ray detector for time resolved synchrotron applications based on a monolithic APD Array, P. Fajardo, R. Rüffer, H. Graafsma, H. Dautet, P. Fischer, A.Q.R. Baron, Poster at the Vienna Conference for Instrumentation VCI2010

Simultaneous PET / MRI Imaging

Michael Ritzert, Viacheslav Mlotok, Peter Fischer

Medical imaging techniques like CT (Computed Tomography), MRI (Magnetic Resonance Imaging) or PET (Positron Emission Tomography) provide very different types of information, like the tissue density, highly resolved morphological information, or functional information, i.e. the distribution of radioactive tracers in cancer studies. A hot topic in medical imaging research is to combine several such modalities, if possible in a single instrument (as compared to available consecutive image acquisition).

The EU funded Hyperimage project is developing a simultaneous PET / MRI system, in which the location of radioactive tracers is determined by the PET system and the association to organs is made by the MRI image. The continuous stream of MRI information will further allow compensating for unavoidable patient motion (breathing, heat beat) during the lengthy PET exposure times of several 10 minutes, with significant improvement in image quality.

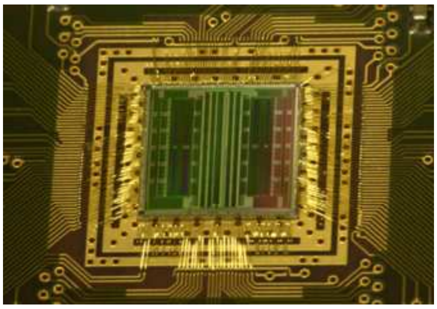

Fig. 1: PETA ASIC bonded to readout board.

This innovative project has several scientific and technical challenges. On the analysis side, the calculation of attenuation corrections from MRI information (to correct the PET image for absorbing bones, for instance) and the detection of the motion and subsequent correction of the PET data are two examples. On the hardware side, the PET scanner must be very compact to fit into the magnet bore, it must withstand the highly hostile environment in the MRI on one hand (static magnetic field, fast magnetic gradients, high power radio frequency waves) and its presence and operation may not degrade the MRI acquisition (distortion of the magnetic field, RF interference), on the other hand.

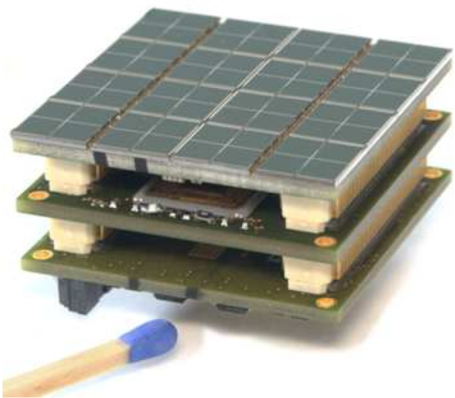

Fig. 2: Hyperimage Detector stack with Silicon Photomultipliers, ASICs and Control board.

The Hyperimage PET insert is based on magnetic field insensitive Silicon Photomultipliers to detect scintillation light from small LYSO crystals, read out by dedicated PETA ASICs (Fig. 1) which are developed entirely in our group. Each ASIC channel contains a fast hit detection, an energy measurement and a time measurement with an intrinsic resolution of <20 ps. Very compact modules with an active area of $\sim 3 \times 3$ cm^2 have 64 individual sensor elements. These MR compatible units, shown in Fig. 2, consist of three different high density PCBs which have been designed in our group as well.

Arrays of small ($2.6 \times 2.6 \times 10$mm^3) crystals are mounted onto the light sensitive top surface of the modules. When they are illuminated with 511 keV gamma rays from positron annihilation, the light generated in one crystal is detected by several photo sensors. After signal processing, the signature of each crystal is unique, as shown in Fig. 3. This is the first demonstration of a fully integrated MR compatible readout of PET crystal arrays.

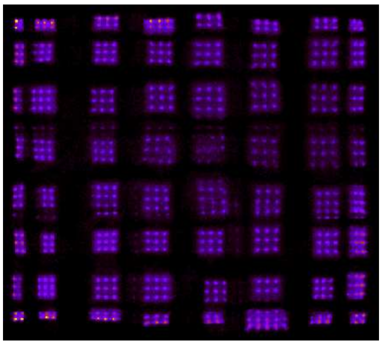

Fig. 3: Reconstructed positions of 2.6 ×2.6mm2 crystals. The systematic distortions are corrected for in later processing steps.

Many modules have been assembled to a full PET ring which is being very successfully operated in an MRI scanner. The system is presently being evaluated in preclinical studies by the Hyperimage partners.

Supported by EU FP7 under Grant Agreement No. 201651.

References (for instance):

[1] Hyperimage Web site

[2) T. Solf et al.: Solid-state detector stack for ToF-PET/MR, NSS/MIC Conference Record, 2009 IEEE, pp. 2798–2799, oct 24-nov 1, 2009.

The Pixel Vertex Detector of the Belle-II Experiment

Jochen Knopf, Christian Kreidl, Ivan Peric, Lukas Raffelt, Peter Fischer

The Belle Experiment at the KeK Accelerator Centre in Japan has made significant contributions to B-Meson physics, in particular to parity violation. The topic being still very relevant for understanding the fundamental forces of nature, Japan has decided to upgrade the KeK machine to a much higher luminosity (~×10), in order to produce significantly more collisions for more detailed studies with better statistics. In order to cope with the resulting enormous event and data rates, and to provide state of the art measurements of the collision products, the existing Belle detector will be upgraded within the next ~3 years. This Belle-II detector (Fig. 1) will also contain a novel pixel detector (PXD) in the very central part of the experiment to improve the measurement precision of the particle decay position.

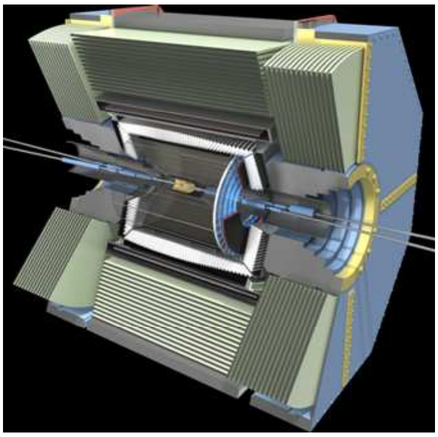

Fig. 1: Artists view of the planned Belle-II detector with a total height of ~5m. The PXD is the very innermost (red) part.

The challenging requirements for the PXD in terms of radiation length (minimal amount of material in the particle flight path), speed, noise and radiation tolerance cannot be satisfied with any available detector technology. The PXD collaboration is therefore developing a novel type of detectors based on amplifying silicon sensors (DEPFETs).

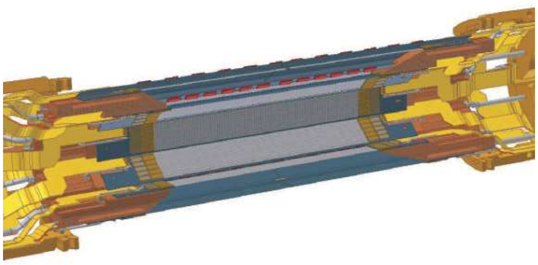

Fig. 2: PXD Design. The (gray) active module layers will be placed around the beam pipe (not shown) at radii of 13/22mm.

Silicon sensor modules of a size of ~1.2×10 cm^2 will be arranged in two layers closely around the (vacuum) beam pipe (Fig. 2). Each sensor has a thinned active area of only 75 µm thickness and is subdivided into low noise amplifying unit pixel elements of ~50×50 µm^2 size. The pixels are connected in a xy-pattern and are read out row-wise at high speed.

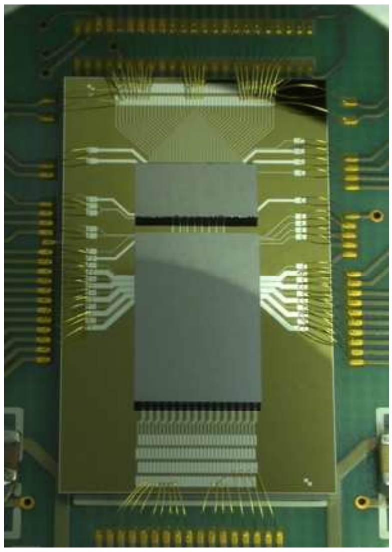

Fig. 3: DEPFET readout chip (bottom) flipped to a silicon test adapter. An additional buffer chip is used for signal buffering.

In order to control the rows (from the side) and to read out the pixels (at the ends), special chips are required. These chips are designed and characterized by our group. They will be flip chip mounted directly onto the silicon substrate to obtain a very compact module design. As an example, Fig. 3 shows the test of the fast current digitizer ASIC 'DCDB'. The chip and an auxiliary buffer chip have been flipped to a silicon substrate in our interconnection lab.

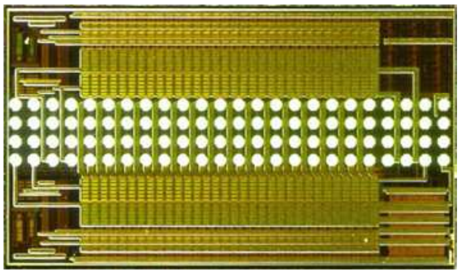

Fig. 4: SwitcherB chip with special pad layout.

Fig. 4 shows the SwitcherB chip which steers the rows. It has a very particular shape and pad arrangement to allow for a space saving integration onto the edge of the module.

The PXD collaboration has carried out several successful test beam campaigns with participation from our group. Other contributions to the PXD project are the design of the interconnection network on the sensor and the development and prototyping of the required bumping interconnect technology.

Supported by bmbf under contact number 05H09VH8

References (for instance):

[1] H. Krüger et al.: Front-end Electronics for DEPFET Pixel Detectors at SuperBelle (BELLE II), NIM A 617, Issues 1-3, 337–341 (2010)

Compact Microscopy Unit for Cell Biology

Lars Lehmann, Jonas Mossler, Axel Ganter, Michael Heinold, Peter Fischer

One research field in system biology is the development of models for specific cell activities. A promising approach to verify such models experimentally is to deliberately change the cellular conditions / environment, to measure the effect on cell behaviour and to compare the observation to model predictions. One possibility to change the cell state is to hinder the expression of specific genes by a 'knockdown' procedure. Due to the high number of genes this leads to a very large number of experiments which must be measured and analyzed with sufficient speed. As specific cell activities are often studied by fluorescence imaging, the Viroquant project has set up the goal to develop a fast parallel fluorescence microscopy system.

After an initial study and speed enhancement of a commercial Olympus IX81 microscope, we have started to develop a self contained compact microscopy unit (CMU) with a 10x magnification and spectral separation of four parallel channels using mostly commercial components.

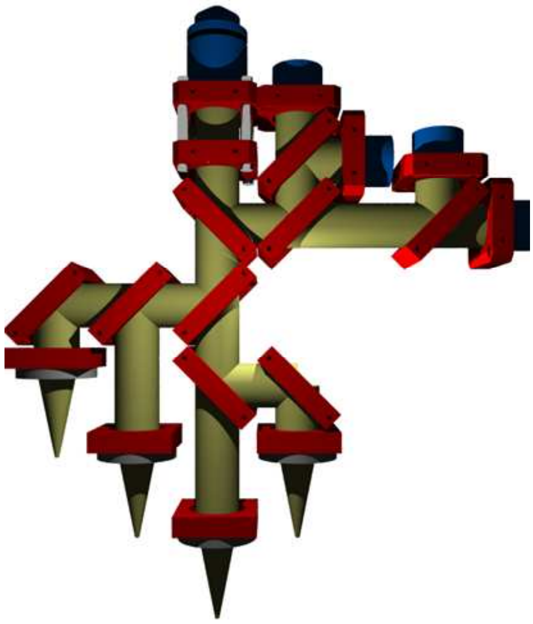

Fig. 1: Possible arrangement of object lens, beam splitters, illumination, tubus lenses and (bottom, not shown) cameras of a CMU.

Fig. 1 shows the implemented concept: Light from four light sources with different narrow band wavelengths (upper right) are merged by dichroic mirrors and injected into the object lens. This intense light excites fluorophores in the sample (above the arrangement, not shown). The emitted light is passing a central dichroic mirror, is then split up into wavelength bands and focussed to CCD cameras using four tubus lenses.

The mixing of excitation wavelengths and subsequent separation of emission wavelengths makes it possible to measure several (matched) fluorophores simultaneously so that no time consuming filter changes are required. This will lead to a significant speedup. Fig. 2 shows the measured optical properties of a prototype system for four simultaneous colours.

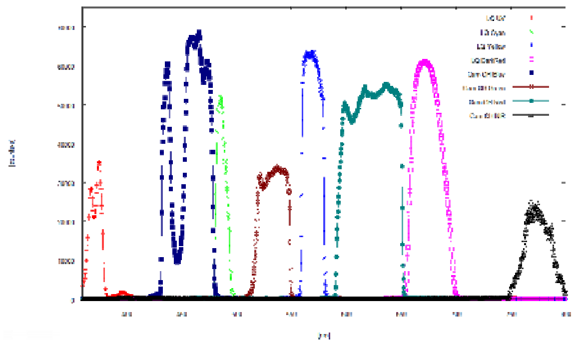

Fig. 2: Spectral transmission properties of the filter system: The excitation wavelengths (red, green, blue, pink) are clearly separated from the emission windows.

A further speedup can be obtained by operating several units in parallel. In order to be able to observe different locations of a larger sample, the lenses must be arranged close to each other. This is achieved by a compact arrangement of all elements, as shown in the demonstrator system Fig. 3, which allows for lens abutting on 3 sides with a 4-5 cm pitch.

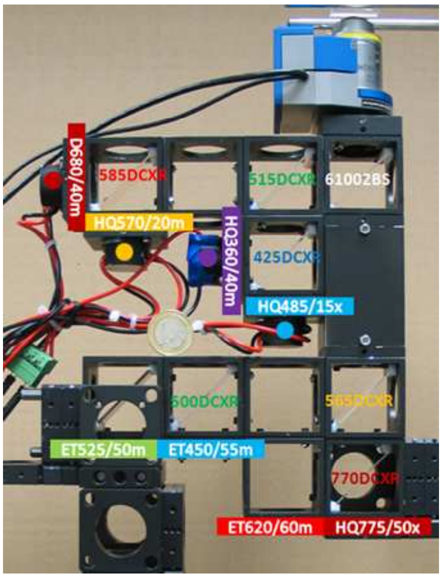

Fig. 3: Demonstrator system of the CMU. (Arrangement of the various components is slightly different than in Fig. 1.)

In parallel to the optical and mechanical work, a flexible software package to acquire data of several cameras in parallel, to analyze data in a computing cloud, and to provide real time feedback to the CMU is being developed.

Supported by BMBF in the framework of the Viroquant project

Collaboration with groups from Viroquant and the chair for optoelectronics @ ZITI

School & Outreach Projects

Dominik Gross, Christian Kreidl, Peter Fischer

In order to increase the interest of pupils for technical subjects, in particular for computer engineering, the chair of circuit design has carried out several hardware projects in cooperation with interested schools.

Groups of up to 10 pupils have worked during half year periods or in intense project weeks on the realization of an embedded hard/software project. Teams of 2-3 participants were responsible for individual sub-tasks, like PCB design, assembly, hardware tests, software development or mathematical methods.

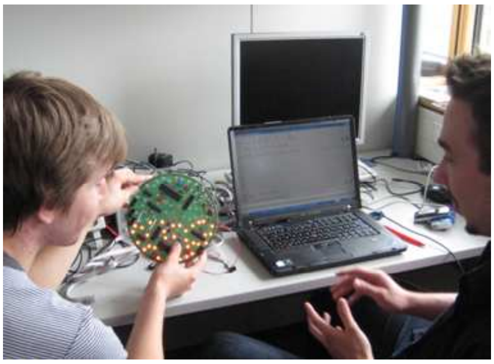

Fig. 1: Discussing about the *Intelligent Disk* design.

Two projects are described here: The *Intelligent Disk* is a circular circuit board (PCB) which contains many light emitting diodes (LED) at random positions (see Fig. 1). It can be mounted on a horizontal axis to be rotated to arbitrary angles. The disk contains a battery pack, a gravitational sensor, several simple micro processors and LED drivers. The goal of the project was to design, build and operate the disk such that only the lower half LEDs are on. A simple test board with the major components was made available to the groups to get experience and to start software development. One team was responsible for the physical disk design (Fig. 2), one for extraction of the gravitational sensor information with one microcontroller and the data transfer to the second controller. A third team took care about the mathematics to retrieve the angle from the acceleration components (given the limited mathematical possibilities of the 8 bit processors), and a fourth team provided the software for the (multiplexed) LED control. As visible in Fig. 1, the target goal was achieved.

Fig. 3: Assembling the *Intelligent Disk*.

A second project was the control of a Bluetooth receiver from a smart phone under the Android Operation System. Before starting work with pupils, a software framework for smart phone integration had been developed in a diploma thesis [1]. During a project week, this framework was used to communicate to a slave Bluetooth receiver. The receiver was integrated onto a simple vehicle made out of fischertechnik parts (Fig. 3).

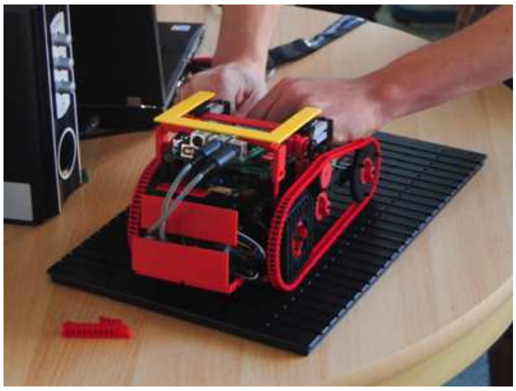

Fig. 3: This Vehicle made from fischertechnik parts will be controlled remotely from a smart phone.

The simple user interface on the smart phone (Fig. 4) could finally be used to steer the 'Androidmobil' as desired.

Fig. 4: User interface to operate the 'Androidmobil'.

Other related activities of the chair are regular workshops at the annual Girl's day ('Operation Laptop'), contributions to the BWINF competition, project proposals to the Hector series and contributions to the IT summerschool (Assembly of a Microcontroller Board).

Cooperation: Carl Benz School, Mannheim and Pamina School, Herxheim

References:

[1] Diploma Thesis Dominik Gross: 'Hardwareansteuerung unter dem Betriebssystem Android via Bluetooth'

Development of Single Chip Bump / Flip Chip Technologies

Christian Kreidl, Peter Fischer

Many detector development projects (see this report) require a large number of electrical connections between the sensor and the readout electronics. The most prominent examples are pixel detectors with a 1:1 coupling between small sensor pixels ($100\times100\ \mu m^2$ and below) and the readout ASIC (XNAP, DSSC projects). In other applications, the overall mechanical size of the assembly leaves little or no space for traditional wire bonds (Belle PXD, CBM MVD). Finally, novel detector concepts (capacitive coupled devices, MAPS) can benefit from dense interconnection methods.

A suited solution is the flip chip interconnection technique, which is widely used in industry. Unfortunately, access to the technology can be difficult and available geometries may be insufficient: The frequently used solder is mostly deposited on wafer scale processes, which are not suited for the single chips available in R&D projects. The situation is slowly increasing (bumping is offered for an increasing number of multi project runs), but still insufficient and expensive. The bump pitches offered are often not small enough, so that very expensive and time consuming agreements with specialized companies are required. This is often beyond the possibilities of a small R&D group.

We have therefore acquired infrastructure and developed the technological steps for an in-house single chip bumping & flipping technology based on gold studs and solder balls.

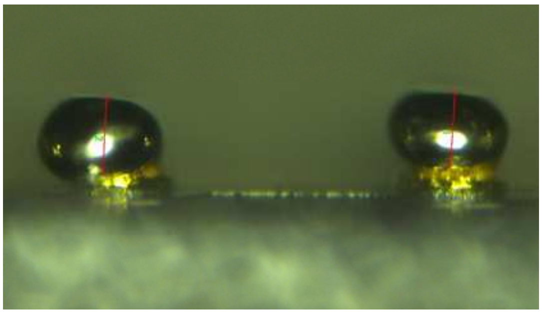

Fig. 1: Solder balls on top of gold studs used as under bump metallization.

The first step is to deposit a conducting metal onto ASICs or sensors. Because most chips have aluminized pads, direct solder deposition is not possible, i.e. an under bump metal (UBM) is required. In this common case we use gold balls deposited with a standard gold ball wire bonder with suited parameters and software. After flattening of the gold (‘coining’), small solder balls can be deposited with a dedicated machine. As an alternative, the gold balls can be used as such.

The second step is the flipping of the balled structure to a substrate, which needs suited UBM as well. This is accomplished with specialized equipment, which allows for a precise alignment of both parts. The contact is established by thermo-compression (heat & force) or be reflow (solder melting). Fig. 2 shows as an example a cut of a thermo compressed gold stud assembly with a ball pitch of ~150 µm.

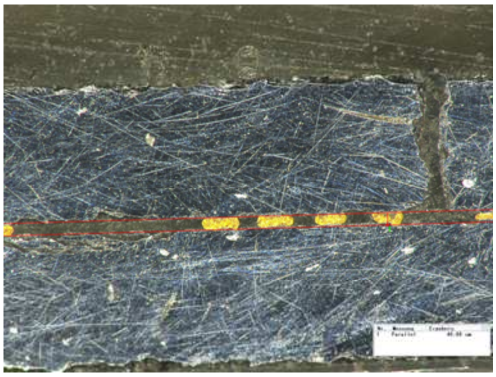

Fig. 2: Cut of a thermo compression assembly (gold studs only).

In many applications it is further required to place several chips in close vicinity. We have therefore studied the alignment limits and found that we can flip chips with a gap of below 100 µm, as shown in Fig. 3. Large assemblies with more than 20 flipped (dummy) chips have been prototyped in this way, in particular for the PXD project.

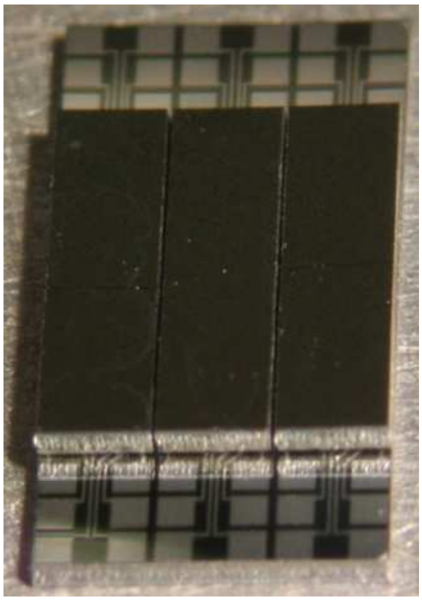

Fig. 3: Test assembly of three (dummy) chips flipped with minimum spacing (<100 µm) to a test substrate. The visible pads can be used to check the electrical integrity of all connections.

This work is supported by the Helmholtz Detector Alliance (partial financing of the Solder Placer machine).

Chair for Computer Science V

Prof. Dr. Reinhard Männer

Parallelization of the x264 encoder using OpenCL
A Echocardiographical Image Archiving and Reporting System
Dependable Hardware Composition
XFEL DSSC DAQ – A Readout System for the DSSC Detector of the European XFEL
Fast Data-path over PCI-Express
DAQ and Readout and Subsystems for ATLAS
FPGA and embedded computing
Lossless JPEG Image decompression in GPUs
Compute Haralick Texture Futures on GPUs
Implementation of Smith-Waterman algorithm in OpenCL for GPUs

Parallelization of the x264 encoder using OpenCL

Erich Marth, Guillermo Marcuss

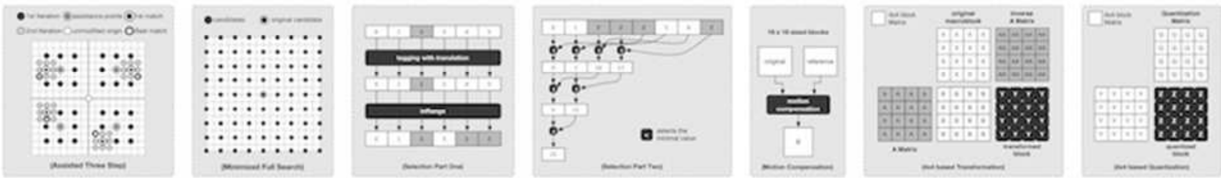

Fig. 1 OpenCL powered modules of the x264 encoder pipeline

With the introduction of H.264, the complexity on video encoders has increased dramatically. As hardware based encoding solutions profit from the strict sequential design and already feature real time capabilities for high definition material, software solutions lack most of the encoding performance. More precisely, the performance of software encoders is limited due to the computation power of encoding system as well as the high level of codec internal dependencies. As a consequence, software encoders supporting high definition needs are very rare.
The increasing computation power of massive parallel architectures such as modern graphics devices can be used to speed-up the encoding of H.264 video material. Compared to plain hardware solutions, graphics device powered encoders have the advantage of much lower initial costs and at the same time offer the flexibility of boosting the performance with future device upgrades. In addition, computers of today already include high performance graphics devices, which improve encoding times with nearly zero extra costs.
While other stand alone GPU accelerated encoding solutions exist for H.264, this work shows the first working parallelization of the open source H.264 encoder x264 using OpenCL.

Parallelization using OpenCL

In the beginning, the parallelization was targeting a straightforward OpenCL based motion estimation without the actual integration into the encoding process.
One straightforward approach was based upon the sub-optimal Three Step Search (TSS) algorithm. The implemented Assisted Three Step Search introduced additional assistant points for more concurrency. In addition, a second algo- rithm was implemented, derived from the computationally intensive Exhaustive Search (ES) – Full Search – algorithm. The Exhaustive Search Derivation (ESD) differs in using a reduced set of candi- dates – only a fourth of the original set – examining even positioned translations only.
After finishing the motion estimation, the OpenCL powered computation was integrated into the encoding flow of the x264 encoder by a plain serial design. In favor of higher encoding speeds, better device utilization as well as better adaption to the encoder architecture, the serial design was later replaced by a more autonomous OpenCL working thread approach. The new working thread pipeline was optimized by using principles from the RISC architecture. More precisely, the estimation and selection modules were stripped down to a single process, moving the extracted functionality to discrete modules. In a final step, the sub-sequential Motion Estimation, Transformation and Quantization processes were ported to OpenCL and merged into the pipeline as well.
While the Transformation was applied on blocks with 4x4 size conforming to the H.264 specification, the final Quantization process was implemented equally to the variant used inside the original x264 encoder. Compared to the H.264 specification, the x264 encoder merges the element-wise multiplication of the DCT with the Quantization step using an LUT based approach.

Considering the fact that only a fraction of the motion estimation capabilities have been ported to OpenCL, the OpenCL powered encoding is up to 55% faster than the original Full Search based encoding of the unmodified x264. While other GPU solutions claim up to 20x speedup, independent tests against unmodified x264 shows similar gains as our implementation for FullHD. Furthermore, the current work is the first open-source, working integration into the x264 encoder that enables it to profit from the computing power of high performance graphics devices.

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A Echocardiographical Image Archiving and Reporting System

D. Hlindzich, P. Krasnopevtsev, A. Rukletsov, A. Bakulina, R. Männer

Today diagnostic imaging systems are used as a daily routine in medical institutions. Echocardiography is beyond ECG the most used clinical method to assess progression of heart disease and results of treatment. Advantages of ultrasound are risk-less investigations, relative inexpensive equipment, compared with other image-guided diagnostic systems, and low cost of exploitation (energy efficient, compact size, minimal service). However the applicabiliy of cardiovascular investigations for outpatients is still low. The reason is a low level of automation and user bias, i.e. a failure of a diagnostician to measure or identify abnormalities.

This project includes two goals: development of a cardiological ultrasound archiving and reporting system that will be able to improve performance and data management as well as to integrate the system into an existing Picture Archiving and Computing System (PACS) and in order to obtain an effective storage platform and clinical interfaces.

The developed system includes special processing modules: parameter measurements with automatical computation of relevant values (Fig. 1), image and movie player, classification module, diagnosis, calibration, Stress Echo, ECG and reporting. The system allows processing and archiving of various types of ultrasound data: images, cine-loops and measured values. The data from ultrasound devices are received over a network, standardised and stored. Physicians can load necessary information from a database on diagnosing stations, process, analyse them very effectively using sophisticated tools, that support optimal diagnosing. Reports are generated automatically and sent to a Hospital Information System (HIS) using the Ashvins PACS from Medical Communications GmbH.

Additionally, in cooperation with UltraOsteon GmbH, novel experimental (non-standard) techniques are supported, like the Tissue-Doppler-Imaging (TDI), semiautomatic quantification of the Left Ventricle (LV) and 3D reconstruction. Velocity of the heart tissue and various derivative parameters can be calculated using TDI, and a quantitative estimation of the heart functionality can be obtained. This allows to estimate the failure of the heart pumping function and to rate the level of heart ageing.

A prototype of a 3D/4D ultrasound system based on electromechanical position-sensing approach was developed to acquire, reconstruct and analyse the data from heart. The system has a high degree of accuracy (< 1mm mean distance error) and can be used for further medical tasks.

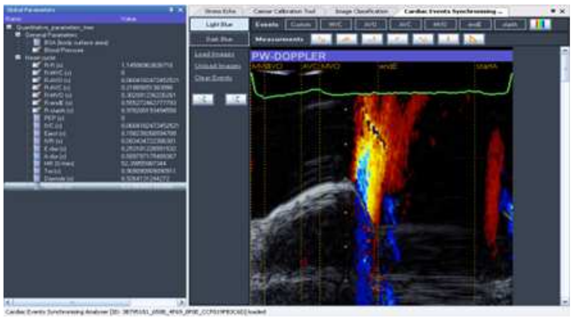
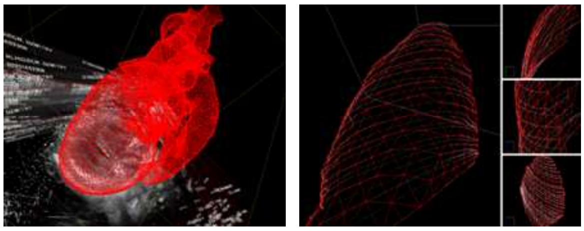


Fig. 1: Automatic parameter calculation.



a) b)

Fig. 2: a) US 3D template based heart model, b)US 3D model of a pig LV created using active propagated surfaces.

Considering a number of visualization techniques (e.g. Fig. 2 a) used in the system, we propose an alternative method of surface reconstruction for sparse ultrasound data based on the active surface model (Fig. 2 b), that has better spatial smoothing policy than e.g. a volumetric one.

Supported by: AiF (KF2351203FO0), Cooperation: UltraOsteon GmbH, Medical Communications Soft- und Hardware GmbH, Clinic for Internal Medicine I the university Hospital Jena.

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[1] D. Hlindzich, P. Krasnopevtsev, T. Poerner, A. Kryvanos. A Flexible Image Archiving and Reporting System. In 10^{th} Intern. Conf. On Pattern Recognition and Information Processing, 19-21 May, 2009, Minsk, Belarus, pp. 298-302.

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Dependable Hardware Composition

R.S.F. Silva, J. Hesser, R. Männer

Electronic and computer systems are included in more and more aspects of everyday life, and are being integrated into more and more critical systems like planes and cars. In a situation where a component is not allowed to disrupt the system by failure, the tendency has been to develop closed, customized solutions. But as the complexity of the systems grow by increasing the number of components, and more importantly, by increasing the interrelations between these components, a more flexible solution is required.

The use of verified components can still raise interoperability failures. In this project, we analyze the top down approach as an alternative to it. In the top down approach, the system functionality is described first, followed by the system architecture, and only later by the development of components or use of pre-built ones. Moreover, we port the contract testing methodology of software to hardware to tackle compatibility issues arisen by the use of pre-built components. The contract testing strategy from software specifies component interoperability conditions, and systematically creates correspondent tests ensuring the operability of the system.

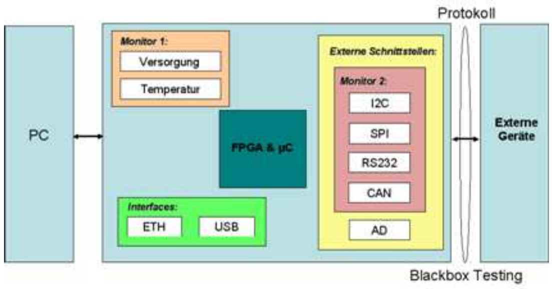

Fig. 1: Hardware platform for data acquisition and processing.

In our project, a hardware platform for data acquisition and processing was created for which different abstraction layers were modeled, i.e. specified and implemented. This allows the systems implemented for it to be designed using the top down approach. The challenge of a seamless top down approach is the missing connection between functional specification and system implementation. The underlying hardware, where HDL code is implemented and the software runs, poses functional and non-functional (speed, area and instruction set) restrictions to the design. Therefore, the hierarchical connection from the system's functional description to system implementation is not automatically supported. Its support requires the description and models of this underlying hardware.

In order to enhance the system reliability while using the bottom up approach, we investigate the transfer of the software contract testing methodology to hardware systems formalizing component specification. We categorize the four following constrained types for digital components: environment requirements (i.e. temperature and power supply), input levels of signals, timing, and logic set restrictions. We show that, similar to software systems, we are able to identify faulty component assemblies using hardware monitors. Furthermore, we categorize signal faults allowing the discovery of evidence for environment related failures, tackling the fault localization problem [1]. Our signal fault model consists of the following: voltage levels, slope times, delays, and glitches.

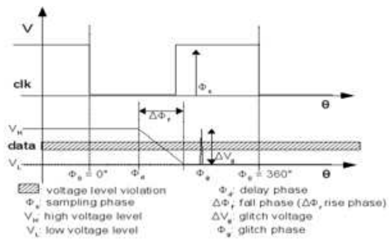

Fig. 2: Signal fault analysis.

The contract testing methodology has been ported to our hardware platform. The built-in test circuit consists of 2 ADCs, 2 quadruple operational amplifiers, and 1 instrumentation amplifier. In addition, the logic part is a synthesizable Verilog code requiring development time of about 2 person months and resulting in 1,548 LUTs, and 376 flip-flops for the used Spartan3A DSP 1800A. Moreover, a transaction level model of our signal fault model and its correspondent fault activation and propagation have been implemented. It allows for fault simulation and system failure analysis enabling the creation of recovery mechanisms [2].

References:

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XFEL DSSC DAQ – A Readout System for the DSSC Detector of the European XFEL

T. Gerlach, A. Kugel

The European XFEL (X-ray Free Electron Laser) [1] is a research facility, which is currently under construction in the area of Hamburg, Germany. The X-ray laser will produce 27.000 ultra-short flashes per second, with a brilliance which is a billion times higher compared to that of the best conventional X-ray sources available today. These flashes will allow to decipher the atomic details of viruses and cells, to make three-dimensional images of the nano cosmos, and to film chemical reactions.

The DSSC (DEPFET [2,3] Sensor with Signal Compression) detector is one of three 2-D sensors developed for XFEL to detect synchrotron X-rays with an energy $E > 0.5$ keV.

The DEPFET based sensors will produce data during the XFEL bursts (with a duration of approx. 660 ns) at a rate up to 4.5 MHz. The data is stored locally in the SRAM of the readout ASICs.

The research project project is ongoing since 2009 and focuses on developing the DAQ system for the DSSC, which will read out the ASIC SRAM during the approx. 100 ms long burst gaps between the bursts. Fig. 1 shows the timing of the XFEL bunch structure.

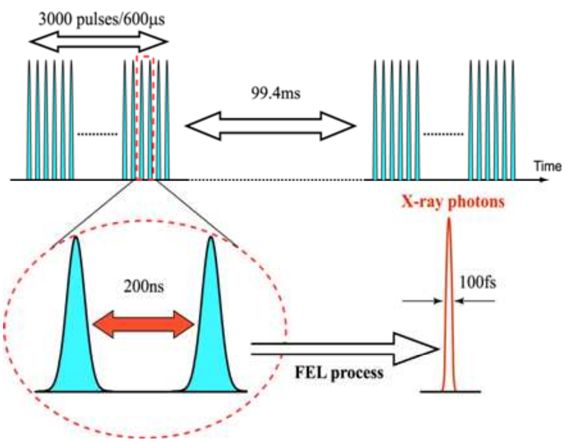

Fig. 1: The timing of the XFEL bunch structure. By XFEL GmbH.

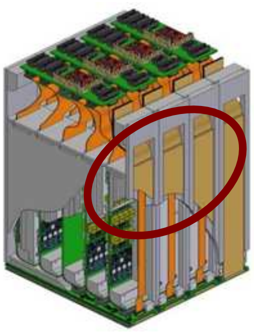

Fig. 2: A quadrant of the DSSC detector. By K. Hansen et al., DESY Hamburg.

The entire megapixel detector is made from 4 quadrants (Fig. 2) of 4 modules, each serving 64k pixels. The DAQ readout chain is sub-divided into two levels, both based on FPGA technology.

The general DAQ layout and its key components were identified. The readout chain is sub-divided into two levels. The lower level consists of the 16 I/O boards (one per sensor module, red ellipse), whose central element is an FPGA device. It's main purpose is to read out the data from all 16 ASICs of a sensor module, and to transmit it to the second level, the DAQ patch panel transceivers. Further, the I/O board administrates several controlling tasks.

The second level of the readout chain will also use an FPGA-based approach. It will merge the data streams of the four sensor quadrants into four 10 Gb/s Ethernet (GE) streams, which are then transmitted as UDP packets via optical fibers to the DAQ offline storage.

A PCB prototype was developed to verify the the operation of the 10GE interface – based upon a 10GE MAC implementation in an FPGA plus a discrete 10GE PHY device – and also to characterize the performance of the PLL device (red circle), which provides the ADC sampling clock. The prototype is shown in Fig. 3. The measured duty cycle jitter performance of 0.31 ps rms (1-σ) is in the order of 0.04 % of the width of an ADC bin (719.3 ps), representing a negligible contribution to the total ADC clock jitter. GE functionality initially verified by sending UDP packets between the FPGA an a PC equipped with a 10GE network interface.

Fig. 3: The 10GbE / PLL prototype.

Supported by: XFEL GmbH.

References:

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[2] J. Kemmer, G. Lutz Nucl. Instr. and Meth. A 253 (1987), p. 365
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Fast Data-path over PCI-Express

W. Gao, A. Kugel, A. Wurz, R. Männer

The Active Buffer system is the data relay unit between the front-end data producer and the back-end storage in the DAQ of CBM experiment. It involves multiple types of messages besides the major hit data packets, such as control and synchronous packets. High-performance is the major requirement.

Considering the Active Buffer position in the DAQ chain, we imaged it as a fast customized data path implemented in FPGA. The high-speed transceivers in FPGA and fiber links are studied. The commercial PCI Express IP core from Xilinx is a good option to build this path, which communicates with the host in full duplex mode. A DMA engine on the transaction layer of PCI Express Gen1 was designed with a 4-lane configuration. [1]

The initial DMA engine was implemented in Virtex4 FX60 FPGA and due to resource restriction, we used the PCI Express core of 32-bit interface. DMA transactions are completed in chained descriptors, which supports the USER mode memory very well. In the performance tests under Linux, DMA write achieved about 790 MB/s and DMA read about 480 MB/s, with the 32-bit version.

The PCI Express debug needs host reboot every time the FPGA firmware is updated. DPR (dynamic partial reconfiguration) is a favourable solution for debug because it allows certain parts in the FPGA to be untouched during reconfiguration so that the reboot is not required. Another benefit of DPR technology is dynamic module overlapping for resource saving.

DPR has been tested on Virtex4 FPGA and the results show that the functional behaviour is reliable during the dynamic reconfiguration. In the DPR practice with PlanAhead 9, the boundary isolation is made with synchronous bus-macros, which introduce additional cycles of delays. This pipeline change is balanced with logic rewrite in the VHDL code, because most of the synchronous pipelines are not explicit to compensate. Without synchronous bus-macros, the timing analysis will fail between the dynamic and static modules in the high-frequency design. [2]

To strengthen the optical communication capability, we transport the DMA design to an AVNET Virtex5 board. In the AVNET Virtex5 DMA engine project, the buffer size available with Xilinx built-in FIFO cannot meet the CBM DAQ requirement. A buffer size over 1 MB inside the current FPGA is very difficult. DDR FIFO has thereafter been implemented in our group, which uses commercial DDR II SDRAM modules as the FIFO kernel and equips protocol logic turning the SDRAM into standard FIFO component, as fig. 1 shows. Based on such protocol module, the transformed FIFO can be written and read simultaneously with port clock rate over 125 MHz. In terms of the size, it is 128 MB for this version and can be enlarged according to the industrial progress of DDR SDRAM.

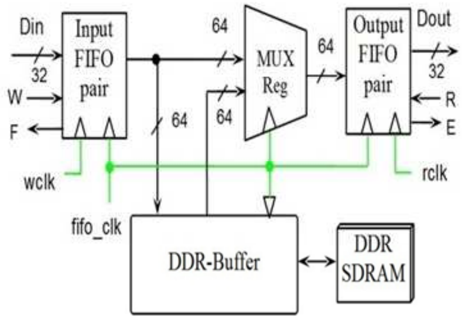

Fig.1: DDR FIFO architecture

From the Virtex4 DMA engine design to the Virtex5 version, a logic upgrade from 32-bit transaction layer interface to the 64-bit was done. The data packet processing pipelines were greatly changed and to guarantee the logic integrity, a verification environment was established. The working Virtex5 DMA engine presents 790 MB/s performance for DMA write and 380 MB/s for DMA read. The lower DMA read performance is due to the widened bus, which increases the overhead ratio on the bus.

Data generator and interrupt generator are implemented in the FPGA, providing a reliable debugging approach for hit data packet emulation and the interrupt strength test. The Virtex5 Active Buffer board is installed at GSI and successfully tested in beam tests.

References:

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DAQ and Readout Subsystems for ATLAS

A. Kugel, R. Männer, N. Schroer

ATLAS is one of four high-energy physics experiments that are operated at the LHC at CERN. The research group is involved in this experiment since 1989 and has developed and built a central component (ROBIN) of the data acquisition system (DAQ) [1]. In 2008 operation of the LHC machine started and the main activity at that time was to prepare the whole experiment for successful and stable data talking. At our side, this involved frequent modifications of the software and firmware of the 600 ROBIN cards to adapt to unexpected operational conditions and to increased performance requirements. Fig. 1 Shows the performance increase for the networked operation from 10 to 25kHz request rate at the nominal operation point.

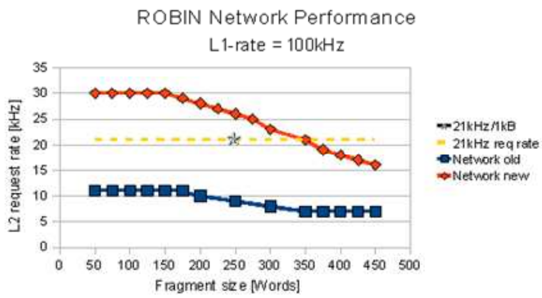

Fig. 1: Performance upgrade

A PCIe-variant of the ROBIN (Fig.2) has been developed, tested and validated in order to be prepared in case suitable PCs with many PCI-slots become unavailable during the lifetime of the experiment.

Fig. 2: PCIe ROBIN

The work in the DAQ area is continuing.

A new branch of the project started in 2009 with our participation in the development of the new IBL pixel detector [2]. The readout-ASICs of the new detector provide a 4-times higher transmission speed and thus require new off-detector readout electronics. For backward compatibility a system of VME card-pairs (ROD + BOC) is used. The BOC [3] interfaces towards the detector and the back-end DAQ (actually to the ROBINs), while the ROD handles control and higher level functions. The basic architecture is shown in Fig.3. An initial decomposition of firmware modules was done and implemented on a set of FPGA prototyping cards, shown in Fig.4. This arrangement was useful to establish a common understanding between the different partners (Bologna, Heidelberg, Wuppertal) of the inherent boundaries of the architecture.

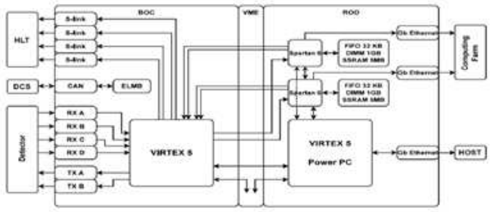

Fig. 3: ROD-BOC architecture

Dedicated DSP devices like on the previous ROD are no longer present. Instead, calibration histograms accumulated in the ROD FPGA while processing capability is available on remote PCs, possibly with GPU acceleration. This approach is viable only due to the local network interconnect on the ROD, which bypasses the VME bottleneck.

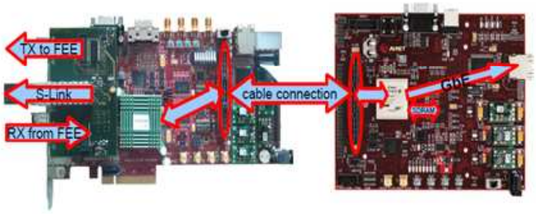

Fig. 4: ROD-BOC prototyping hardware

A performance study comparing the original DSP performance (40µs per pixel) to modern multi-core and GPU implementations showed that a quad-core PC can achieve a speedup of 10 compared to a quad-DSP ROD.

Supported by: BMBF (05H09VHA), Cooperations: CERN, Wuppertal University, NIKHEF (NL), RHUL (UK), INFN Bologna (I)

References:

[1] A Kugel: The ATLAS ROBIN – A High-Performance Data-Acquisition Module, Aug. 2009, http://madoc.bib.uni-mannheim.de/madoc/volltexte/2009/2433/

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FPGA and embedded computing

W. Gao, T. Gerlach, A. Kugel, G. Marcus, N. Schroer, A. Wurz

The activities of the group focus on the development and evaluation of FPGA-based and general embedded hardware components and of the related development tools. The results are typically used by other research groups of the institute and for education.

Fig. 1: MPRACE-2 Coprocessor

Fig. 1 Shows MPRACE-2, a PCIe-base FPGA coprocessor card developed by the research group. In addition to the typical DDR-2 DRAM memory slot it provides 2 banks of fast DDR-2 SRAM, which allow true cycle-to-cycle random access without the increased latency of DRAM. MPRACE-2 can be extended with a mezzanine card to prototype various applications. So far, it is used by the group "Accelerated Scientific Computing" to implement an SPH computational algorithm, by the XFEL DSSC project to prototype a 10G-Ethernet module, by the CBM project to prototype basic DMA and DPR functionality and as embedded system platform with either the integrated PowerPC processor or the Microblaze soft processor.
In addition to this custom board several commercial boards are under evaluation, for example the XILINX boards ABB-2 (Virtex-5), SP-605 (Spartan-6) and ML-605 (Virtex-6). The DMA functionality and the Microblaze embedded platform have been ported to these boards as well, demonstrating the portability of the designs.

Fig. 2: Virtex-5 ABB-2

The ABB-2 card is used as active buffer card in the CBM project.
In the software area, the low-level driver "pciDriver" and the board access library "mpracelib" are constantly kept up-to-date in order to support new boards and new Linux kernel releases. Besides the basic functionality an important topic is to support portability of applications not only from kernel version to kernel version but also from hardware platform to hardware platform, in order to maximise code re-usability.
The latter aspect is the main focus of the "LogReu" tool, which aims to automate the process of modifying existing VHDL code for a partitioned design flow requiring synchronous elements only on the partition boundaries. A partitioned flow is needed for dynamic partial reconfiguration applications and is also a de-facto prerequisite for high-density implementations with latest FPGA families.
In the embedded area there are a number of primarily educational projects using hardware platforms either based on ARM microcontrollers (Fig. 3) or on the generic Microblaze FPGA platform supporting the recent Linux kernels.

Fig.3: ARM Platform

Cooperations: FG Accelerated Scientific Computing, Projects ATLAS, XFEL, CBM

Lossless JPEG Image decompression in GPUs

Timo Bernard, Guillermo Marcus

In order to accommodate bandwidth restrictions from a high-throughput microscope, it was needed to compress the image stream in transit from the FPGA-based capture cards to the GPU-based online image processing. To achieve lossless compression, several algorithms were investigated, and finally decided to use lossless JPEG for the ability to implement a parallel decompressor efficiently in the target GPUs.

To decompress a lossless JPEG stream in parallel, we first need to divide the stream in meaningful segments that can be processed concurrently. For this, we use a row index table that points to the start of every image row into the stream. Each of these segments can therefore be processed independently to recover the residual value of the pixels. While this index table is not part of the standard, it is a byproduct of the FPGA encoder and does not affect the content of the bitstream (which remains standard compliant).

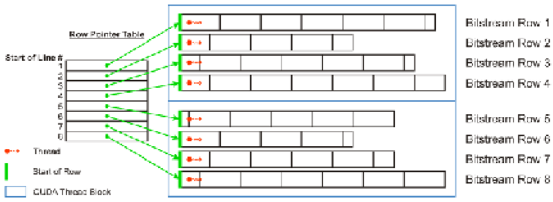

Fig. 1: First Kernel, decoding of residual value

With this information, the first kernel (a first pass over the bitstream) reconstructs the residual values for every pixel in parallel, one row per GPU block, as shown in Fig. 1. The residual value is used by the next kernel to reconstruct the image.

The second kernel is executed multiple times, as multiple wavefronts in two different scales are needed. This wavefront is a consequence of the pixel relationship needed to reconstruct a pixel value based in neighbouring pixels, which needed to be already decoded. Fig. 2 shows a summary of these wavefronts.

On the grid level, the result image is divided into blocks, and these blocks are processed in a wavefront (shown in blue). In this way, all necessary blocks are already processed. The block structure corresponds to a CUDA block in the computing grid of the GPU.

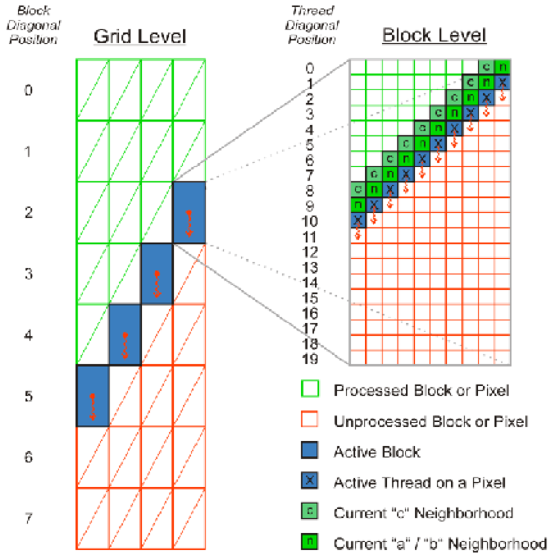

Fig. 2: Second Kernel, reconstruction of the image

On the block level, every thread inside a block advances processing the corresponding stage of a wave, as shown in the right section of Fig. 2. The blue wave is the result pixel being calculated, while the green pixels are the neighbour pixels required for the correct reconstruction. In this way, multiple pixels can be decoded simultaneously and the decoding time is reduced.

With these optimizations, the decoder is capable of decoding lossless JPEG bitstreams 15-30 times faster than a CPU host.

References:

[1] T. Bernard, G. Marcus, M. Gipp, and R. Männer, “Using GPUs for Lossless-JPEG real-time image decompression of high-throughput microscope data,” NVIDIA Research Summit 2009. pp. 1–1, 2009.
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Compute Haralick Texture Features on GPUs

M. Gipp, G. Marcus, N. Harder, A. Suratanee, K. Rohr, K. König, R. Männer

In biological applications, features are extracted from microscopy images of cells and are used for automated classification Fig. 1 shows an example of a microscopy image which includes several hundred cells. Typically a very large number of images have to be analyzed so that computing of the features takes several weeks or months.

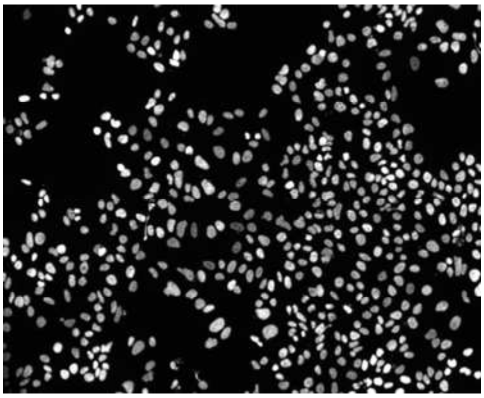

Fig. 1: The Microscopy image with several hundred cells.

We have analyzed the calculation in two steps, the co-occurrence matrices (co-matrices) and the Haralick texture features (features). The co-matrices are computed from an image and the features are calculated based on the co-matrices. After this we parallelized the computation on the many core architecture of GPUs in CUDA [1].

Analyzing the features results in a graph (Fig. 2) showing the dependency of the feature computations on intermediate results and on other features. With the dependency graph the optimal order of the feature computation could be determined which saved costly double computations.

Analyzing the co-matrices showed that they are sparsely filled and for a highly parallel approach they consume too much memory. We reduced the size of a full co-matrix by removing all rows and columns filled with zeros (Fig. 3). This reduction strategy offered to keep up to two hundred co-matrices in the memory of an ordinary graphics card with direct memory access.

For each single cell image 20 co-matrices with different orientations are generated. Altogether the features of 8 cells can be computed in parallel, requiring the calculation of 160 co-matrices. To reduce the complexity of the feature computation 24 kernel functions are used on the GPU and each one maps all co-matrices to the parallel computing architecture of the GPUs.

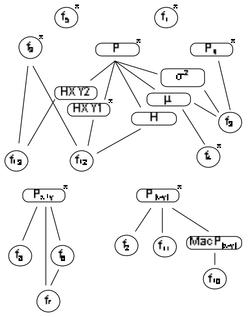

Fig. 2: The dependency graph gives an order to compute the features and intermediate results

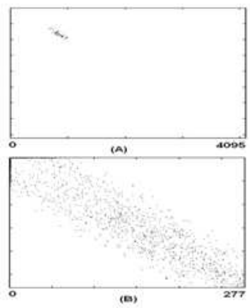

Fig. 3: The sparsely Matrix (A) could reduced to a much smaller packed matrix (B).

	Execution time [s]	Speed up factor to CPU	Speed up factor to GPU I
Original Software Version CPU	2378	-	-
GPU Version I (8800 GTX)	11.1	214x	-
GPU Version II (GTX 280)	6.6	360x	1.6x
GPU Version III (GTX 480)	**2,55**	**930x**	**4.3x**

Fig. 4: Speed up table of Haralick Texture Feature algorithm executed on different computing architectures

The costly computation of the co-occurrence matrix and the Haralick texture features can be speed up by a factor of 930 in comparison to the original software version (Fig.4). This allows biologists to perform much more tests to acquire novel knowledge in cell biology in weeks or days instead of several months. For further details see [2].

Supported by: Viroquant Project
Cooperation: DKFZ Karl Rohr, Reiner König

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Implementation of Smith-Waterman algorithm in OpenCL for GPUs

D. Razmyslovich, G. Marcus, M. Gipp, M. Zapatka and A. Szillus

There are currently a lot of biological questions being investigated using the second-generation sequencing technology. This technology is characterized by short lengths of the read sequences (35-100 nucleotides).

One possible application of the second-generation sequencing technology is cancer genomics. All cancers are results of changes occurred in the DNA sequence of the genomes of cancer cells. The Smith-Waterman algorithm is one of the best solutions for the identification of these changes, because this algorithm is quite sensitive to identify most complex changes unrecognizable with alternative faster algorithms.

Our approach aims to provide a solution for the alignment of the short reads from second-generation sequencing technology along the long genome sequence, which would be acceptable according to the time characteristics. The main problem of the Smith-Waterman algorithm usage for the described task is the O(n*m) time complexity, where n is the length of a short read (a query sequence) and m is the length of a long genome sequence (a reference sequence). Moreover, the algorithm requires a lot of memory (of the order of 16 GB), additionally decreasing the performance and putting high requirements for the target system.

Our result is the accelerated implementation of the Smith-Waterman algorithm which uses the latest technologies for heterogeneous parallel systems. This implementation is written using an OpenCL standard, which provides the interface independence from the type of the target system. The code is optimized for running on high-end CUDA-enabled NVIDIA GPUs.

The implementation is done as a series of steps. Each step contributes to an improvement of the performance.

Step A. *Parallelization granularity*. Choosing a nucleotide from a query sequence as a parallelization grain makes it possible to calculate the paths for the already calculated part of the matrix and truncate the matrix concurrently with computation of the new piece of the matrix.

Step B. *Long reference sequences processing.* The main heuristic used to reduce the memory usage for the calculation and enabling the long reference sequences processing is shown in figure 1.

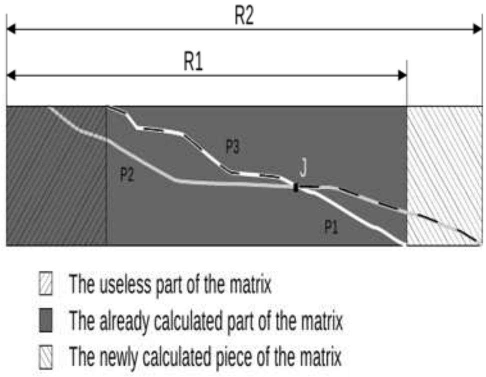

Fig. 1: The heuristic model.

Step C. *Multi-query processing.* Concatenating several short sequences into a big one makes multi-query processing possible, which provides a better occupancy of a GPU.

Step D. *The calculation shape.* The usage of the diamond shape instead of the usually chosen rectangular shape provides an additional speed-up on every iteration.

Step E. *The concurrent transfer and execution.* The ring buffer usage makes the time gap needed for transferring data from GPU memory to host memory overlapped with the main kernel execution improving the GPU utilization and reducing the calculation time by approximately 25%.

The effect of each step on the implementation performance is summarized in figure 2.

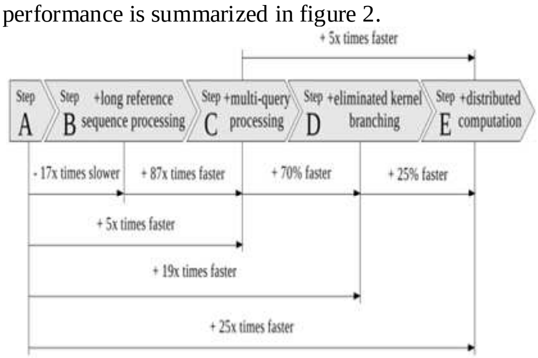

Fig. 2: The effect of the implementation steps on performance.

The key advantages of this OpenCL implementation in comparison with the other toprated implementations are:

- the implementation is able to process efficiently the long reference sequences (up to 28 million in the tests);
- the alignment paths can be calculated effectively, which is the key feature of this implementation;
- the computation performance is competitive to Farrar’s implementation and 3x as fast as CUDASW++v2.0 implementation for the 600-query database file;
- the acceleration in comparison with our CPU implementation is 9x for the path calculating version and 130x for the no path calculating version;
- the implementation is written in the OpenCL standard, which provides the possibility to use it on different parallel systems on condition of a proper tuning of the implementation.

Supported by: DAAD; Cooperation: DKFZ Marc Zapatka, Andreas Szillus

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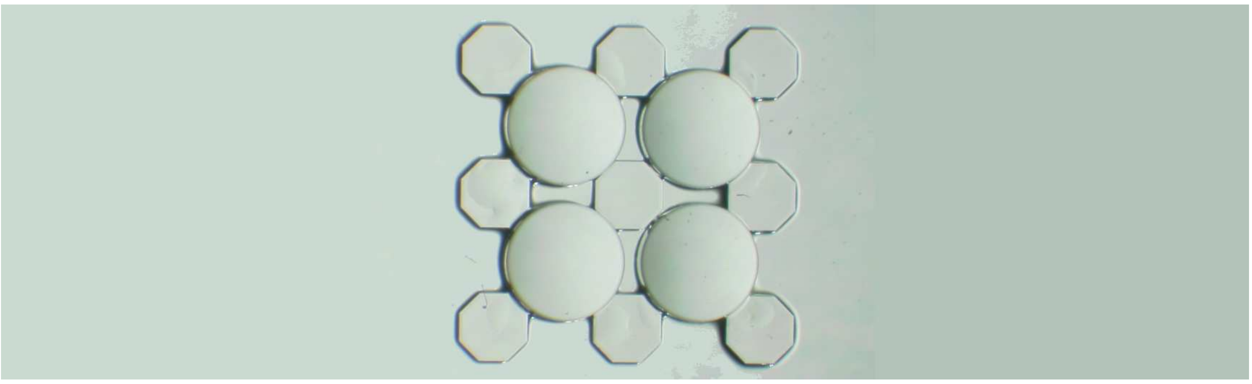

Chair of Optoelectronics

Prof. Dr. Karl-Heinz Brenner

Full control of light intensity by beam shaping
Vector wave propagation method Full (VWPM) An extension to the wave propagation method
Parallel image scanning with binary phase gratings
Minimal realization of arbitrary optical systems defined by ray transfer matrices
Integrated fabrication of optical coupling structures
New method for rigorous simulation of local absorption in periodic structures
Accelerating microscopy

Full control of light intensity by beam shaping

K.-H. Brenner

Beam shaping is commonly used to transform a given intensity distribution into a different, desired intensity distribution. Applications of one-dimensional (rotationally symmetric) beam shaping [1,2] are typically in the area of high power lasers and optical illumination systems. Unlike one-dimensional beam-shaping, which leads to a simple differential equation, which can be integrated in a straight forward manner, the two-dimensional beam shaping problem leads to a nonlinear Monge-Ampere type equation, for which numerical solutions [3] are difficult to obtain. Recently, we have generalized the equations for optical beam shaping with two surfaces, derived a nonlinear Monge-Ampere type differential equation, which became solvable with the shifted-base-function (SBF) approach [4].

In an optical implementation, beam shaping can be realized by diffractive, by reflective or refractive optics. In fig. 1, we consider a refractive system in a telescopic geometry. The input medium and the output medium are assumed to have the same refractive index, here denoted by n_1. The intermediate medium with a thickness of *D* on the optical axis has a refractive index of n_2. The input and output coordinates are distinguished by small and large letters.

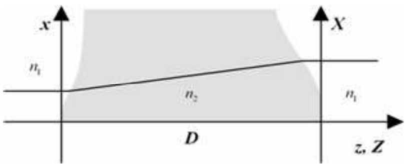

Fig. 1: Geometry for general two-dimensional beam shaping in a refractive telescopic arrangement.

Any beam shaping problem can be decomposed into a sequence of two tasks: 1) to find the mapping *M* of the input coordinates (x,y) to the output coordinates (X,Y) and 2) the calculation of the optical surfaces, required to achieve this task. With respect to the second task, we found an analytic expression for finding the surface z from the mapping *M*:

$$\begin{pmatrix} z_x \\ z_y \end{pmatrix} = \frac{1}{\sqrt{(\nu-1)^2 D^2 + (\nu^2-1)\Delta^2}} \begin{pmatrix} \Delta x(x,y) \\ \Delta y(x,y) \end{pmatrix} \qquad (1)$$

This equation relates the beam shift $\Delta x = X - x$, $\Delta y = Y - y$ to the gradient of the front surface *z*. $\nu = n_1/n_2$ is the index ratio. The back surface *Z* can be determined uniquely using the constant path length condition. From the gradient, the surface can be determined easily by SBF-integration [4].

With respect to the first task, we use a far field approximation of eq. 1, which is sufficiently accurate, if the beam shift is small compared to the separation *D*, and express it in the form:

$$\nabla_\perp z \cong \frac{1}{|\nu - 1|} \nabla S \qquad (2)$$

With this, the beam shaping requirement can be expressed as a Monge-Ampere-type second order differential equation for *S*:

$$I_1\left(x+S_x, y+S_y\right) \cdot \left[\left(1+S_{xx}\right)\left(1+S_{yy}\right) - S_{xy}^2\right] = I_0(x,y) \qquad (3)$$

It relates the second order partial derivatives of *S* to the input intensity I_0 and the desired output intensity I_1. For solving this equation, we have developed a local optimization algorithm, which finds an acceptable numerical solution in less than 50 iterations.

As an example, we considered a Gaussian input illumination (fig 2, left) which is to be transformed into an image of the letter B. For verification, the result (fig. 2 right) was obtained by an independent calculation using Monte Carlo ray tracing through the surfaces *z* and *Z*.

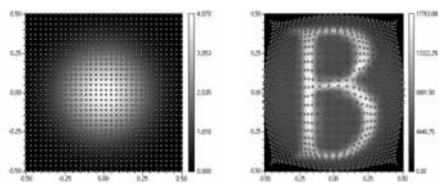

Fig. 2: left: Gaussian input distribution and reference positions of the SBF-approximation, right: Intensity obtained by Monte-Carlo ray trace with mapped positions

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[1] F. Dickey and S. Holswade, Laser Beam Shaping: Theory and Techniques (Marcel Dekker, 2000).

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Vector wave propagation method (VWPM)
An extension to the wave propagation method

M. Fertig, K.-H. Brenner

We have extended the scalar wave propagation method (WPM) to vector fields. The WPM [1] has been introduced in 1993 in order to over-come the mayor limitations of the beam propagation method (BPM). The BPM is a paraxial light propagation method for the simulation of inhomogeneous media. Due to the paraxial approximation, its main application is in the simulation of wave guides. With the WPM, the range of applications could be extended from the simulation of waveguides to simulation of conventional optical elements like lenses and gratings. In [1] it was demonstrated that the (scalar) WPM provides valid results for propagation angles up to 85 degrees. Here, we extend the WPM to 3D vectorial fields by considering the polarization dependent Fresnel coefficients of amplitudes for transmission in each propagation step. Like in the WPM, we start with a plane wave expansion of the field at z = 0, which is the starting point at layer m

$$\tilde{\mathbf{E}}_{\perp,m}(\mathbf{k}_\perp) = \iint \mathbf{E}_{\perp,m}(\mathbf{r}_\perp) \cdot \exp(-i\,\mathbf{k}_\perp \mathbf{r}_\perp)\, d^2\mathbf{r}_\perp \qquad (1)$$

Unlike the WPM, we now consider the vectorial properties of the wave. The z-component is not needed for this step, since $\tilde{\mathbf{E}}_m(\mathbf{k}_\perp)$ must satisfy the Maxwell equations. The transfer at the interface between layer m and m+1 is described by the Fresnel equations. These can be reformulated into a linear transformation

$$\tilde{\mathbf{E}}_{\perp,m+1}(\mathbf{k}_\perp) = \mathbf{M}_{m,m+1}(\mathbf{r}_\perp,\mathbf{k}_\perp) \cdot \tilde{\mathbf{E}}_{\perp,m}(\mathbf{k}_\perp) \qquad (2)$$

The next step treats the propagation of a single plane wave component in an inhomogeneous layer

$$\tilde{\mathbf{E}}'_{\perp,m+1}(\mathbf{r}_\perp,\mathbf{k}_\perp) = \tilde{\mathbf{E}}_{\perp,m+1}(\mathbf{k}_\perp) \cdot \exp\left(i\phi_{m+1}(\mathbf{r}_\perp,\mathbf{k}_\perp)\right) \qquad (3)$$

Due to the inhomogeneity of the medium, the propagation phase is dependent on both, position and direction. In the final step, the propagated wave amplitudes are summed up.

$$\mathbf{E}_{m+1}(\mathbf{r}_\perp) = \iint \tilde{\mathbf{E}}'_{m+1}(\mathbf{r}_\perp,\mathbf{k}_\perp) \cdot \exp(i\,\mathbf{k}_\perp \mathbf{r}_\perp)\, \frac{d^2\mathbf{k}_\perp}{(2\pi)^2} \qquad (4)$$

For homogeneous media, this step has the form of a Fourier back-transformation. In the inhomogeneous case, however, $\tilde{\mathbf{E}}'_{\perp,m+1}(\mathbf{r}_\perp,\mathbf{k}_\perp)$ is dependent also on position. Therefore, an inverse Fourier transformation cannot be applied. We verify the validity of this approach by transmission through a prism and by comparison with the focal distribution from vectorial Debye theory. The simulation provides the correct amplitudes and deflection angle according to electromagnetic theory.

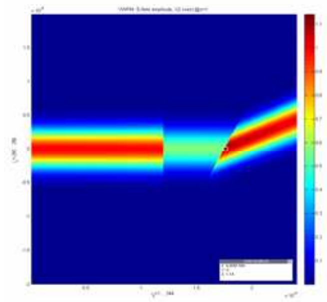
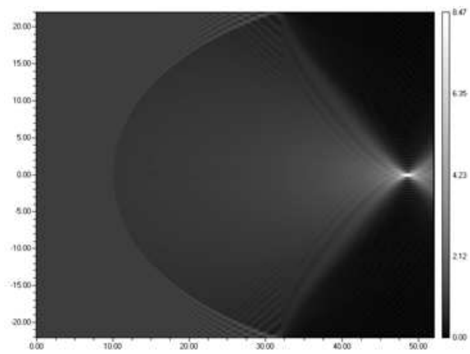


Fig. 1: Electric field intensity of a Gaussian beam propagating though a prism

Fig. 2 shows the amplitude distribution of a plane wave passing through an ideal focussing lens with a numeric aperture of 0.85. The focal distribution agrees perfectly with the results from vectorial Debye theory.



Unlike rigorous methods, which are only able to simulate small volumes, the VWPM, due to the decomposition into separate layers can also simulate much larger volumes and is therefore a suitable tool between the macroscopic and the microscopic world.

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Parallel image scanning with binary phase gratings

R. Buschlinger, K.-H. Brenner

Microscopy applications like in system biology or in industrial inspection generate an increasing demand for high-speed imaging techniques. An approach to satisfy this demand is spatial parallelization of the imaging system. In the case of wide-field imaging, the scan time depends on the ratio of lens diameter to field of view of each individual imaging system. To minimize the scan time, the number of lenses has to be maximized and therefore the size of the imaging systems has to be minimized.

Recently, we have developed a novel approach for parallel image scanning, whereby the intensity peaks are generated by a binary phase grating instead of a lens array. These binary phase gratings in a special configuration generate sharp spots for grating periods down to 3 wavelengths [1]. This was observed also experimentally.

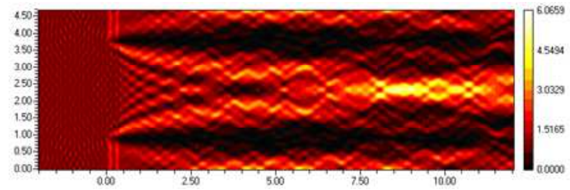

Fig. 1: Intensity in the x-z-plane behind a 2D-grating. Units are in microns

Compared to micro lenses, such gratings can be easily manufactured and enable a high degree of miniaturization The diameter of the focal spot is not restricted by a numeric aperture according to Abbe's law and can be used to scan specimens with many spots simultaneously. Due to the high degree of parallelism, the imaging speed can be increased significantly.

In order to analyze, which grating configurations are practical for generating intensity patterns with distinct spots, the intensity on the optical axis was calculated for different *z*-positions and for a range of gratings with different fill factors using both, scalar diffraction theory and rigorous diffraction theory. A high intensity in the resulting plot is an indicator for the existence of a focal spot. With this method, optimum spot generation was predicted for fill factors, which lie on a straight line. Such a plot is shown in fig. 2. The horizontal axis shows the *z*-position in units of the Talbot length z_T. Due to symmetries, the plot is only shown for a quarter of the Talbot length. The vertical axis shows the fill factor ranging from zero to one. The light distribution clearly exhibits a fractal behaviour. For the focussing condition in fig. 1, we chose a fill factor of ~ 0.7 at a focussing distance of ~ 0.12 z_T.

The absolute value of the grating period also plays an important role, since smaller periods reduce the number of propagating modes. As a result, the plot in fig. 2 appears more blurred and the tolerances for fabrication a focusing grating are thus more relaxed. For smaller grating periods, we also observed an increase in effective numerical aperture, but also an increase of the bias amplitudes.

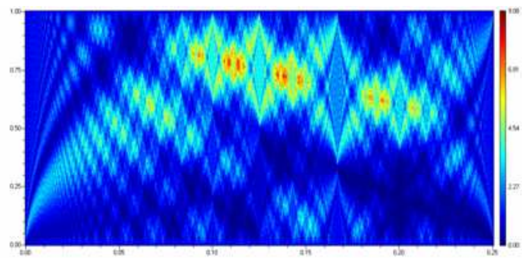

Fig. 2: left: Gaussian input distribution and reference positions of the SBF-approximation, right: Intensity obtained by Monte-Carlo ray trace with mapped positions

In an imaging application, only one spot plane should contribute to the detected information in each scanning step. If a specimen is placed inside one of the focal planes of a binary phase grating, its light transmission properties at the position of the spot can be measured in a detection plane behind the specimen. Figure 3 shows the result from a simulation using an absorber with a diameter of 1/8 of the detector pixel size. The period of the grating, $P = 10\lambda$ matches the period of the detector array. The resolution obtained is approx. 1/5 of the detector pixel size.

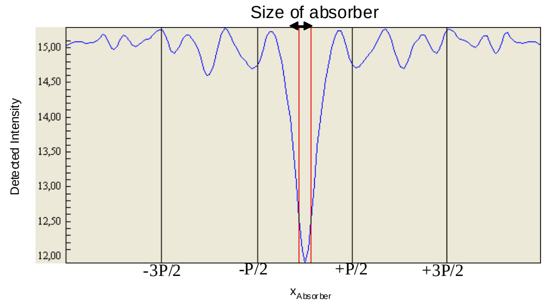

Fig. 3: Integrated detector intensity when an absorbing spot is scanned through the focal plane.

References:
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Minimal realization of arbitrary optical systems defined by ray transfer matrices

X. Liu and K.-H. Brenner

Optical systems can be described paraxially by ray transfer matrices that specify the relation between paraxial entrance rays and exit rays. In this research project, we consider the inverse problem: a desired optical system is given by the ray transfer matrix, and by means of the matrix decomposition we look for the minimal optical realization that consists of only lenses and pieces of free-space propagation.

Summarized and outlined in book [1], similar decompositions have been studied before but without a restriction to these two elements types - lens and propagation, also without an attempt for minimization. As the main results of this research, general one-dimensional (1D) optical systems can be synthesized with a maximum of four elements and two-dimensional (2D) optical systems can be synthesized with six elements at most.

One-Dimensional Optical Systems

Any 1D optical system can be described by a 2x2 symplectic matrix $\mathbf{M}=\begin{pmatrix} A & B \\ C & D \end{pmatrix}$. The two primary elements, lens and propagation over a positive distance, exhibit the ray matrices **L** and **P** respectively as following

$$\mathbf{L}(f)=\begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix},\quad \mathbf{P}(z>0)=\begin{pmatrix} 1 & z \\ 0 & 1 \end{pmatrix},$$

where f denotes focal length and z is positive propagation distance.

The coordinate inversion matrix $\mathbf{\Psi}(\pi)=-\mathbf{I}$ is introduced as an auxiliary element in the decomposition. Its presence does not increase the complexity of the optical system. It will be located, if present, only at the entrance or exit side of systems, which means a 180° rotation of the object or the optical detector. Following are the minimal decompositions for 1D systems:

- $B>0$: $\mathbf{LPL}$. If $A=1$ (or / and $D=1$), the right (or / and left) lens can be omitted.
- $B<0$: $\mathbf{\Psi}(\pi)\mathbf{LPL}$. If $A=-1$ (or / and $D=-1$), the right (or / and left) lens can be omitted.
- $B=0\;\; A=D=1$ or -1: $\mathbf{L}$ or $\mathbf{\Psi}(\pi)\mathbf{L}$
- $B=0\;\; A\neq D\;\; A>0\;\; C>0$: $\mathbf{PLP}$
- $B=0\;\; A\neq D\;\; A>0\;\; C>0$: $\mathbf{\Psi}(\pi)\mathbf{PLP}$
- $B=0\;\; A\neq D\;\; A<0\;\; C\geq 0$: $\mathbf{PLPL}$ or $\mathbf{LPLP}$
- $B=0\;\; A\neq D\;\; A>0\;\; C\leq 0$: $\mathbf{\Psi}(\pi)\mathbf{PLPL}$ or $\mathbf{\Psi}(\pi)\mathbf{LPLP}$

The maximal cases include 4 primary elements.

Two-Dimensional Optical Systems

Any 2D optical system can be described by a 4x4 symplectic matrix $\mathbf{M}=\begin{pmatrix} \mathbf{A} & \mathbf{B} \\ \mathbf{C} & \mathbf{D} \end{pmatrix}$ with $\mathbf{A}^T\mathbf{C}=\mathbf{C}^T\mathbf{A}$, $\mathbf{B}^T\mathbf{D}=\mathbf{D}^T\mathbf{B}$, and $\mathbf{A}\mathbf{D}^T-\mathbf{B}\mathbf{C}^T=\mathbf{I}$, where **A**, **B**, **C, D** are 2x2 block matrices and **I** is the identity matrix. The two primary elements, astigmatic lens and isotropic propagation over a positive distance, exhibit the ray matrices **L** and **P** respectively as following

$$\mathbf{L}(f_x,f_y)=\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ \frac{-1}{f_x} & 0 & 1 & 0 \\ 0 & \frac{-1}{f_y} & 0 & 1 \end{pmatrix},\quad \mathbf{P}(z>0)=\begin{pmatrix} 1 & 0 & z & 0 \\ 0 & 1 & 0 & z \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix},$$

where f_x and f_y denote focal lengths and z is positive propagation distance.

Coordinate rotation in the lateral plane corresponds to

$$\mathbf{R}(\varphi)=\begin{pmatrix} \cos\varphi & \sin\varphi & 0 & 0 \\ -\sin\varphi & \cos\varphi & 0 & 0 \\ 0 & 0 & \cos\varphi & \sin\varphi \\ 0 & 0 & -\sin\varphi & \cos\varphi \end{pmatrix},$$

which is an additional auxiliary element. Its multiple presence does not increase the complexity of the optical system since it can be implemented practically by rotating the subsequent optical element.

To determine the optical minimal decomposition, we distinguish between two cases:

- $|\mathbf{B}|\neq 0$: a maximum of five optical elements (lens and propagation) is sufficient for a realization of this matrix type: $\mathbf{RLRPLPRLR}$.
- $|\mathbf{B}|=0$: a maximum of six optical elements (lens and propagation) is sufficient for a realization of this matrix type: $\mathbf{RLRPLPRLRP}$.

Decomposition of 2D systems thus consists of a maximum of six primary elements.

References:

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Integrated fabrication of optical coupling structures

F. Merchán, K.-H. Brenner

High speed short-range interconnects have become a multidisciplinary research since the data links consist not only of electrical- but also of optical components. This combination offers at first, a utilization of the advantages of optics over electronics for signal transmission such as lower energy, lower noise-figure and light-weight cables and second, it also offers the advantages of electrical connectors like simplification of the handling, which is often difficult with optical connectors.

The research in this project is based on the design [1], integration and fabrication [2] of optical micro-couplers and the design of the electronic systems used for the test of the optical systems. The optical system is shown in figure 1. The coupler integrates mechanical systems like the funnel, the guide and the spacer; optical systems like the fiber, the (Gradient Index) GRIN-Lens and the mirror; and the optoelectronic components, in this case a VCSEL with the correspondent electrical connections.

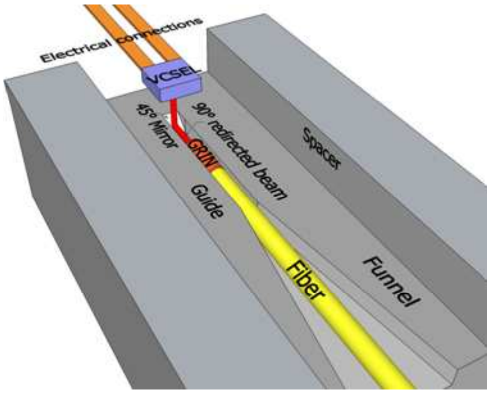

Fig. 1: 3D model of the optical system used to couple light from a VCSEL into a multi-mode fiber.

The optical micro-coupler is fabricated using plastic replication of metal masters. The metal masters are fabricated using a High-Speed-Cutting (HSC) machine for the shape and a robot lapping for the finish of the optical surfaces. The masters were manufactured with an accuracy of about 1µm and the surfaces had a roughness of about 10 nm after polishing.

In order to increase the coupling efficiency, a GRIN-lens can be introduced into the coupling system. The imaging properties of GRIN-lenses have been studied and characterized. One of the most relevant results is shown in figure 3. There, the comparison between two systems with and without GRIN-lens shows the advantages of using a GRIN-lens when the working distance between the VCSEL and the fiber is above 70 µm.

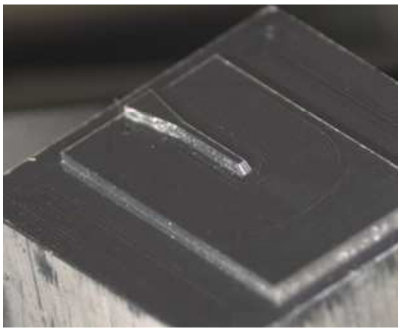

Fig. 2: Fabricated single channel metal-master

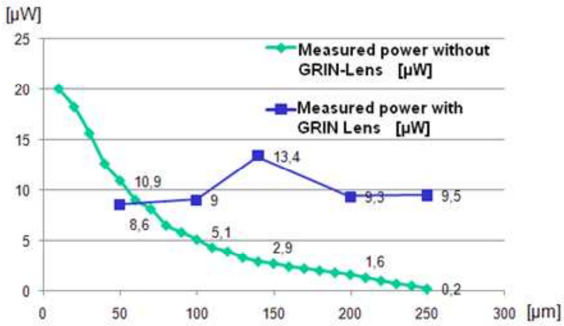

Fig. 3: Comparison of coupled power for two systems: with and without GRIN-lens

References:

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[2] F. Merchán, K.-H. Brenner, R. Börret, U. Berger, „Cost optimized fabrication of Micro-Optical Couplers", Optical Fabrication and Testing (OF&T), OSA, Technical Digest, ISBN 978-1-55752-893-3, 13.-16-06.2010, Jackson Hole, Wyoming, USA, (2010)

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New method for rigorous simulation of local absorption in periodic structures

M. Auer and K.-H. Brenner

For computer-aided optimization of lithography, photo-detectors and photovoltaic elements, precise mathematical models of the underlying physical absorption processes are indispensable. Nevertheless, in most cases, the standard tools for optimization of light efficiency in photo-sensitive materials only consider the intensity distribution in these devices. In the context of lithography, for example, the resist exposure is proportional to the amount of energy, which is absorbed in a finite volume element. In photodetector design, the location of photon-electron generation plays an important role for the responsivity of the photodiode, because only those electrons, which are generated near the depletion region, contribute to the photocurrent, while electrons generated in other regions mostly contribute to local heating.

Starting with Poynting's theorem, one can derive a formula for the quantitative calculation of the ratio of absorbed power to incident power in a volume element (V) for an illumination with a plane wave according to:

$$\frac{P_a}{P_i} = \frac{k_0^2}{k_{i,z}} \cdot \frac{1}{A} \cdot \iiint\limits_V \mathrm{Im}\big(\varepsilon(\mathbf{r})\big) \cdot \left|\mathbf{E}_1(\mathbf{r})\right|^2 dV \qquad (1)$$

The absorbed power thus depends on the imaginary part of the permittivity $\mathrm{Im}\big(\varepsilon(\mathbf{r})\big)$ at location $\mathbf{r}$. k_0 and $k_{i,z}$ refer to the vacuum wave number and the *z*-component of the wave vector of the incident wave, exposing an area *A*. $\mathbf{E}_1$ refers to the electric field response inside the material to an incident field with unit amplitude. Using the "Rigorous Coupled Wave Analysis" (RCWA), a standard method for the calculation of diffraction efficiencies, the near-field distribution $\mathbf{E}_1$ does not provide the correct absorption values in the case of TM-polarization. By modifying the field definitions, taking mode truncation into account, we have achieved perfect agreement between global absorption and integrated local absorption[1]

Based on this result, we also developed a new concept for a SOI-CMOS-compatible photodetector [2]. Using this technology for photo detection, there are many problems to deal with: Ultra thin layers limit the height (about 70nm) of the active zone. High doping levels cause narrow depletion regions. The assortment of materials is rather limited. Furthermore, for wavelengths above 850nm, Silicon is almost transparent.
Our approach utilizes the poly-silicon layer, which usually forms the transistor gates, as a resonant grating to concentrate the incident light inside the depletion region (cf. Fig.1-a,d). Unlike other approaches using Fabry-Perot-resonances or surface plasmon resonances, our approach utilizes **lateral resonances**.
In a simulation, grating period and gate width form a two-dimensional parameter space, which can be scanned **layerwise** for absorption maxima (cf. Fig.1-b,c). By realizing a grating with a suitable combination of design parameters, we have optimized our design to an absorption level of 68.4% in the active channel - in contrast to 2.18% absorption obtained without optimization. This corresponds to an increase of efficiency by a factor of 31, while staying fully CMOS-compatible without any need for additional post processing steps.

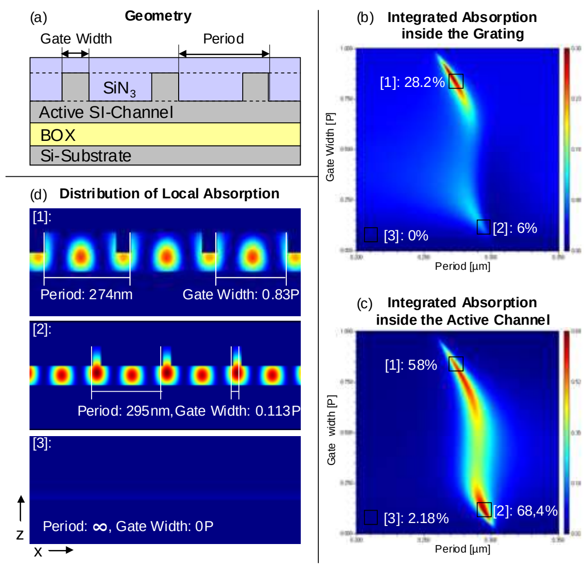

Fig. 1:
(Polarisation: TE, Wavelength: 850nm)

- Geometry of the layer stack and the simulation parameters (a).
- Integrated absorption of the grating layer (b) and the active layer (c) for a wide range of gate width and period values.
- Distribution of local absorption inside the layer stack for three parameter combinations (d).

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Accelerating microscopy

E. Slogsnat, K.-H. Brenner

In systems biology there is a demand for accelerated image acquisition, especially when performing genome-wide screens.

In the first period of this research project a method was developed to eliminate the focus search, which is the most time-critical factor. Focussing is needed, when different positions on a substrate are examined. It is necessary due to the deformations of the glass layers used in most sample substrates, which are 50- to 100-times larger than the depth of field. By eliminating the focussing step, the data throughput can be enhanced significantly.

Deflectometry is used to determine the height deviations of the glass layer [1]. In deflectometry, the slopes of the surface can be measured by observing a regular pattern, reflected from the glass surface. For the reconstruction of the height distribution, a new algorithm was developed [2], which allows an accurate, noise insensitive and fast surface reconstruction. Fig. 1 shows the reconstruction result for a simulated height distribution.

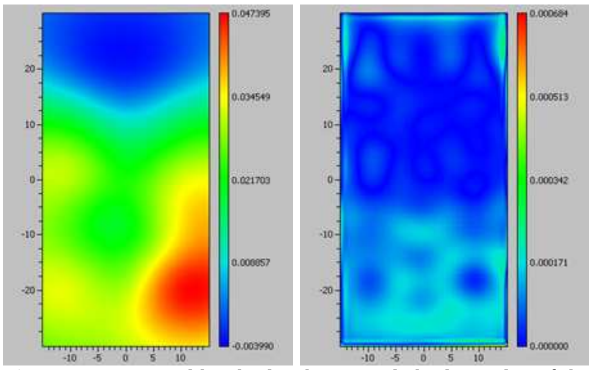


Fig. 1: Reconstructed height distribution and absolute value of the difference between reconstructed and simulated height distribution (units: mm)

In the second part of this project an optical system for a miniaturized parallel fluorescence-microscope was designed. It consists of three layers: To guide the excitation light to the object, a beamsplitter layer resides between two GRIN-lens arrays, which are fixed on glass substrates (Fig. 2).

To analyze the image quality and the assembly of the layers, a demonstrator for the imaging path was set up [3]. The optical system was optimized for the use with the fluorophore DAPI. The assembled demonstrator consists of four parallel optical channels with an NA of 0.44, a magnification of 4.29, a field of view of 400 µm and a lens diameter of 2 mm. With this system 125 line pairs/mm can be resolved precisely (Fig. 3).

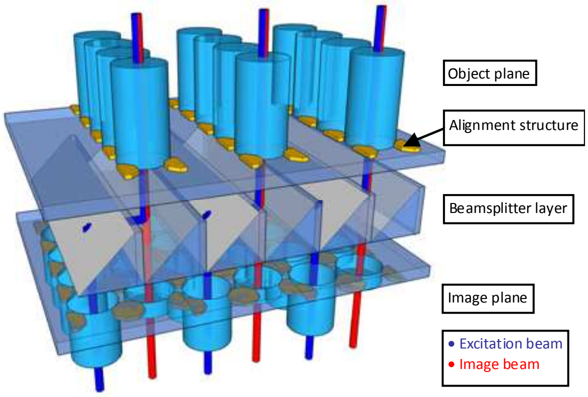


Fig. 2: Integration scheme of the miniaturized parallel fluorescence-microscope

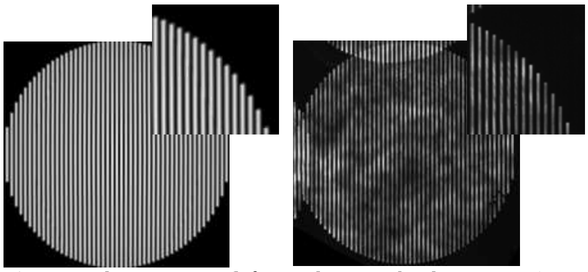


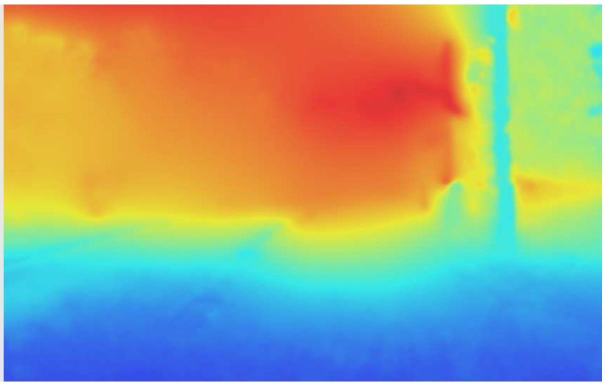
Fig. 3: 125 line pairs/mm (left: simulation, right: demonstrator)

References:

[1] E. Slogsnat, K.-H. Brenner, P. Ehrle, W. Stumpfs, "Selbstkonsistentes iteratives Verfahren zur Bestimmung glatter Oberflächen", DGaO-Proceedings (Online-Zeitschrift der Deutschen Gesellschaft für angewandte Optik e. V.), ISSN: 1614-8436, 109. Jahrestagung in Esslingen am Neckar/Deutschland (2008)

[2] E. Slogsnat, K.-H. Brenner, "Non-stereoscopic method for deflectometric measurement of reflecting surfaces", DGaO-Proceedings (Online-Zeitschrift der Deutschen Gesellschaft für angewandte Optik e. V.), ISSN: 1614-8436, 110. Jahrestagung in Brescia/Italien, (2009)

[3] E. Slogsnat, R. Buschlinger, K.-H. Brenner, "Miniaturisierte parallele Mikroskopie in der Systembiologie", DGaO-Proceedings (Online-Zeitschrift der Deutschen Gesellschaft für angewandte Optik e. V.), ISSN: 1614-8436, 111. Jahrestagung in Wetzlar (2010)

Chair for Computer Vision, Graphics and Pattern Recognition

Prof. Dr. Christoph Schnörr

Contour Methods for View Point Tracking
The Benefits of Dense Stereo for Pedestrian Detection
An Adaptive Variational Approach to Fluid Flow Estimation
Parallel Computation of Large Variational Problems
Variational Representation and Decomposition of Image Flows
Graphical Models for Object Recognition
The 2D an 3D Physically Consistent and Efficient Variational Reconstruction of Image Fluid Flow Estimates
Adaptive Cuts for Image Segmentation
Learning Based Object Detection in Medical Imaging
Convex Models and Global Optimization for Image Segmentation and Labeling
Relaxation and Inference for Discrete Graphical Models
Discrete Tomography for Particle Image Velocimetry
Model-Based Multiple 3D Object Recognition in Range Data
Recent Advances in Multi-Cue Pedestrian Classification
Pedestrian Path Prediction and Action Recognition
Generative Modelling of Appearance and Shape for Medical Image Analysis
Variational Models for Image Segmentation with Shape Priors

Contour Methods for View Point Tracking

C. Gosch, C. Schnörr

Fig. 1: Illustration of a rotating aeroplane, extracted contours, and shapes tracked using an internal representation based on a fixed number of known shapes. Right hand side: Positions tracked on the view sphere.

Within the scope of this project, we sought to investigate possibilities to use purely 2D outline shape based methods for determining a relative pose change between observer and known object within an image sequence. To this end, particular methods for 2D shape representation were examined. Additional methods were also researched and combined to enable tracking of relative object pose based on changes in 2D outline.

Introduction

One important cue that has been used frequently in the past for object detection, object classification, object tracking, pose estimation, and related tasks, is the shape of a silhouette or contour that separates an object of interest from the background within an image. Related problems are naturally image segmentation, i.e. extraction of object outlines from images, and the quest for computational frameworks to handle the outlines' shape. There has been much research in the past in these areas, continuously pointing out the relevance of shape information for tasks like recognition. More recently, manifolds of shape were introduced at several points in the literature which model shape in ways that appear natural, allowing e.g. for calculation of sensible distances between shape instances, and also for modelling invariance to certain transformations.

The problem of finding a pose change that an object undergoes given its outline has been tackled before, using 3D internal object representations. We are examining the possibilities of an internal representation utilising a number of outlines from known views, not knowing a 3D model. In fact, there even appears to be some psychophysical evidence for humans using 2D outline representations for object recognition, not creating a "virtual" 3D model internally.

Methods and Results

A recently introduced type of representation for 2D shape was utilised. Shape of a 2D curve $c : \mathbb{R} \mapsto \mathbb{R}^2$ is represented by tangents in the complex number plane as

$$c(t) = c_0 + \int_0^t e^{\Phi(\tau)} e^{j\theta(\tau)} d\tau.$$

Only the function pair (Φ, Θ) is used as representative of the shape of c. A suitable elastic metric is used to enable calculation of sensible distances and interpolations. The view sphere around an object is modelled by storing the shape and view positions of a number of known views. A method for following shape change along an image sequence by minimising a distance between a given new outline shape q and a currently known shape p, $F = (\mathrm{dist}(p,q))^2$, has been proposed. The method is integrated with variational image segmentation by re-inserting information about the current view position as weak prior in the segmentation process, in order to favour known outline shapes q.

Difficulties arise from symmetries and formation of inner contours, which are not captured by current 2D shape manifolds. Results were published in [1].

Outlook & Future Work

Possible future work would include examining ways of efficiently sample a view sphere in order to minimise the number of needed samples used to model an object. What is more challenging is the search for better shape representations, allowing for the formation of multiple connected components while retaining the benefits of a shape manifold with a sensible metric allowing also for interpolations. Computation time is also an issue.

Funding: IPA/ZITI

References:

[1] C. Gosch, K. Fundana, A. Heyden, and C. Schnörr. View Point Tracking of Rigid Object Based on Shape Sub- Manifolds. In Computer Vision – ECCV 2008, vol. 5302 of LNCS, pp. 251–263. Springer, 2008.

The Benefits of Dense Stereo for Pedestrian Detection

C. Keller, C. Schnörr

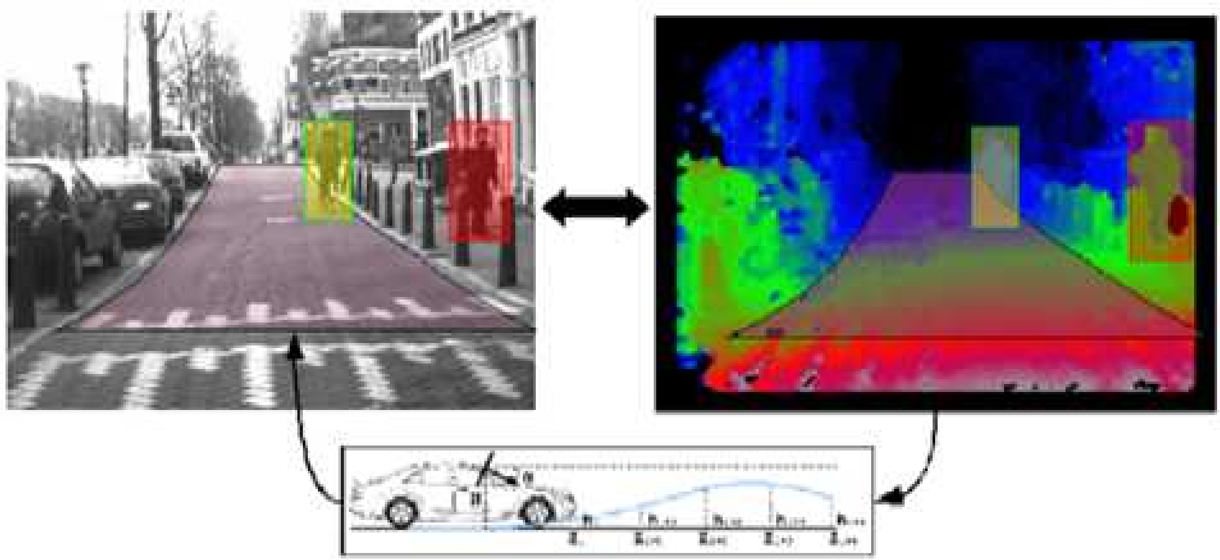


Fig. 1: Dense stereo-based pedestrian detection system comprising dense stereo computation, pitch estimation, corridor computation, B-Spline road profile modeling and multiplexed depth maps scanning with windows related to minimum and maximum extents of pedestrians.

We present the results of a dense stereo vision-based scheme used for obstacle detection in pedestrian protection applications from a moving vehicle. Dense disparity maps allow an accurate estimation of the camera height, vehicle pitch and vertical road profile, leading to more precise detection of generic obstacles which will be passed to subsequent verification stages.

Background and Goals

Vision-based pedestrian detection is a key problem in the domain of intelligent vehicles. Common stereo-based obstacle detection schemes assume that everything above the ground is an obstacle. Most systems assume the installed camera to have a static pitch and height. Additionally the road is viewed as a planar surface. These assumptions may lead to false detections, especially on hilly or undulating roads. This work demonstrates the advantages of using dense disparity maps instead of sparse ones when detecting generic obstacles in the early stage of a pedestrian recognition system.

Methods and Results

Our system uses the available dense stereo information to compute the pitch and height of the camera. The next step consists in computing a corridor of a pre-defined width using the vehicle velocity, the yaw rate, the camera height and the camera tilt angle. The road profile is represented as a parametric B-Spline surface which is fitted to the 3D measurements. Tracking improves the robustness of the estimation road surface. With the additional road surface estimation the system can refine the search regions for pedestrians. This leads to a reduction of necessary computations and improves the overall system performance.

The proposed dense stereo-based attention mechanism was tested on a sequence recorded from a moving vehicle in the inner city of Amsterdam (Netherlands). Because of the undulated road, many small hills and several speed bumps the sequence is challenging for the road profiling system. Additionally the large number of pedestrians and the complexity of the scene challenges the pedestrian detection system. A performance improvement by a factor of five can be observed compared to a system using static camera position and planar road surface model.

Outlook & Future Work

The presented system showed the advantages of using dense stereo for pedestrian detection. Further work will focus on extending the use of dense stereo as attention mechanism and pedestrian tracking.

Funding: Daimler AG

An Adaptive Variational Approach to Fluid Flow Estimation

F. Becker, C. Schnörr

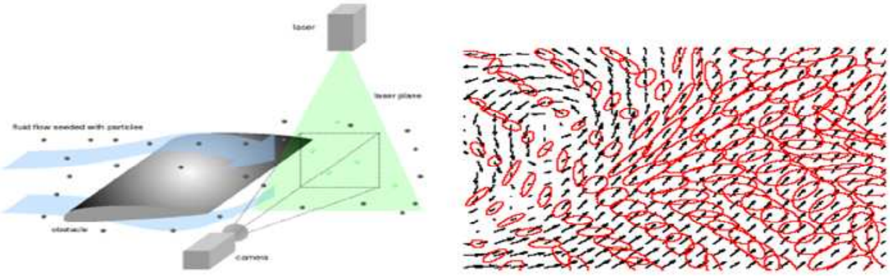


Fig. 1: Left: Illustration of a Particle Image Velocimetry setup. The fluid flow near an obstacle is rendered visible by seeding the gas or liquid with small particles and illuminating them by a laser. The analysis of the recorded image sequence allows to draw conclusion on the fluid movement. Right: Result of the analysis of a real image sequence using our approach. The arrows indicate the measured velocity of a turbulent flow. The red ellipses visualize the correlation windows which adapt to the flow with the aim to increase accuracy.

A variational approach to fluid motion estimation, based on cross-correlation, is presented. Furthermore, we formulate a sound criterion for the adaption of the incorporated correlation windows, with the aim to increase accuracy of the velocity measurements.

Background and Goals

Particle Image Velocimetry (PIV) is an important measurement technique for industrial fluid flow questions. Small particles are introduced into liquids or gases and act as indicators for the movement of the investigated substance around obstacles and in mixing zones. A 2D plane is illuminated by laser light rendering the particles in there visible to a camera which records two images of the highlighted area within a short time interval. The analysis of the image pair allows to determine the movement of particles and with this to measure the speed, turbulence or other derived mechanical properties of the fluid. For this purpose, we investigate a variational approach to the motion estimation task. Furthermore, we propose a window adaption scheme which directly formulates the aim to improve the accuracy of the displacement measurement method.

Methods and Results

State-of-the-art methods for the analysis of PIV image pairs select a patch from the first image and match it to the second one. Cross-correlation is used as dissimilarity measure which is maximized using discrete search. The optimal displacement describes the movement of the flow in this area. In our work, we formulate the maximization of the cross-correlation measure as a variational problem and solve it continuously. Special care is taken to avoid local maxima of this highly nonconvex and non-linear function. The usually employed square correlation window which selects the incorporated image data is replaced by a Gaussian weighting function whose shape (size, anisotropy and orientation), can be continuously controlled. An error function models the expected error that is caused by data disturbances (sensor noise, low particle seeding etc.), gradients in the motion field and the choice of the window shape. The adaption of the correlation window is then formulated as the minimization of the error model function. The problem of motion measurement and window adaption are interconnected through the window parameters and the displacement vectors. Thus, we resolve this interdependency by formulating a joint optimization problem which simultaneously computes the velocity and the window shapes.

Approved multiscale optimization methods are employed to solve this problem which has non-linear and non-convex objective function in both its sub-problems. Experiments showed that our method can handle synthetic benchmark data as well as turbulent real world flows. Comparison to approved correlation implementations showed that window adaption improves accuracy both in situations with homogeneous motion and large velocity gradients. This work was partially published in [1] with the focus on image processing, while in [2] we investigate our approach from the fluid mechanic point of view.

Outlook & Future Work

For both the displacement estimation as well as the window adaption we did not incorporate any spatial regularization terms, although the variational formulations allows to do so. In this way, physical priors on the fluid flow, such as incompressibility, can be added to further improve accuracy. The definition of the error model used for the window adaption can be refined by adding expert knowledge on the data, such as local particle seeding density or image noise level which can be measured a priori.

Funding: FLUID project (FP6-513663) in the Sixth Framework Program of the European Community

References:

[1] F. Becker, B. Wieneke, J. Yuan, and C. Schnörr. A Variational Approach to Adaptive Correlation for Motion Estimation in Particle Image Velocimetry. In Pattern Recognition – 30th DAGM Symposium, vol. 5096 of LNCS, pp. 335–344. Springer Verlag, 2008.

[2] F. Becker, B. Wieneke, J. Yuan, and C. Schnörr. Variational Correlation Approach to Flow Measurement with Window Adaption. In 14th International Symposium on Applications of Laser Techniques to Fluid Mechanics, p. 1.1.3, 2008.

Parallel Computation of Large Variational Problems

F. Becker, J. Yuan, C. Schnörr

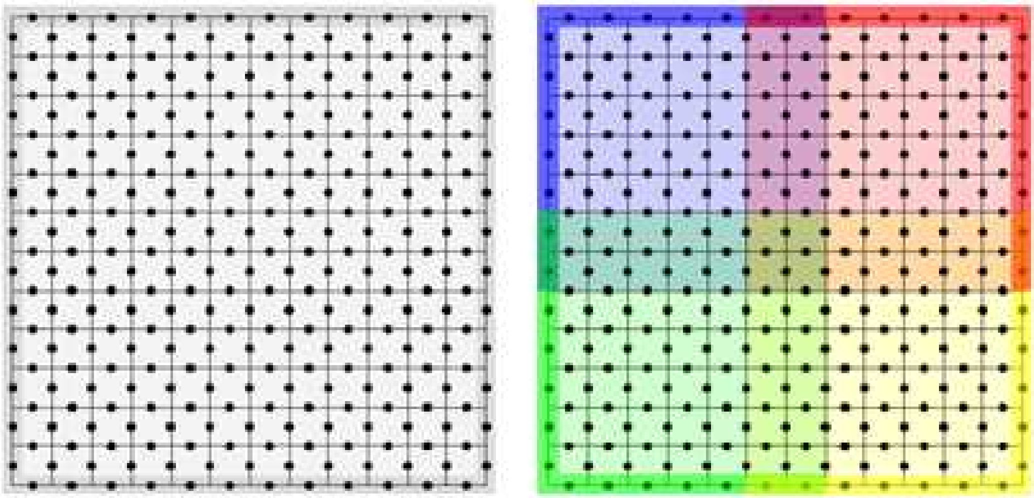


Fig. 1: Left: Structure of a (very small) discretised variational problem. Variables and pixels of the problem image data are represented by dots and the square boxes, respectively. Shaded regions represent boundary terms. For large problems, i.e. around 1 million variables or more, the problem description exceeds the memory limitations of standard hardware. Right: Coloration indicates the decomposition into four smaller, slightly overlapping subproblems, which can be distributed to parallel hardware. However, variational problems incorporate knowledge on variable interconnections, which disallows to solve the subproblems independently and thus has to be respected to ensure that we find a solution to the original problem.

A decomposition method for a general class of optimization problems is developed with the aim to distribute large variational problems to parallel hardware.

Background and Goals

Variational approaches are nowadays routinely used in many image processing applications. However with increasing sensor resolution and in 3D applications, the resulting problem representations can not be handled within the working memory of standard PCs any more. This necessitates to investigate problem decomposition that can process in parallel large-scale problems with o_-the-shelf hardware.

Methods and Results

In our work we consider the fairly general class of convex quadratic optimization problems, which includes for example motion estimation problems with higher order regularization. Our aim is the decomposition into smaller easy-to-solve subproblems, that communicate to compute provably the unique global solution. We propose a method to decompose the objective function of any instance of the considered class into a sum of still convex sub-functions. The initial problem can then be solved as several smaller independent convex problems and computationally cheap synchronization steps using dual decomposition. An extensions is described that allows to improve numerical properties of the underlying problem without altering the overall objective, hence improving convergence rate. Furthermore, we can give general results on convergence rate and conditions of the overall problem with respect to the decomposition parameters. We verified the theoretical results by means of three relevant variational problems from image processing. The results were partially published in [1].

Outlook & Future Work

Next steps include further analysis of the convergence properties as well as the extension to other classes of optimization problems.

Funding: FLUID project (FP6-513663) in the Sixth Framework Program of the European Community

References:

[1] F. Becker and C. Schnörr. Decomposition of Quadratic Variational Problems. In Pattern Recognition – 30th DAGM Symposium, vol. 5096 of LNCS, pp. 325–334. Springer Verlag, 2008.

Variational Representation and Decomposition of Image Flows

J. Yuan, C. Schnörr

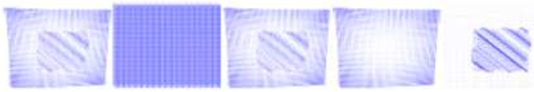


Fig. 1: The first graph shows the given non-rigid flow f . The 2nd and 3rd photos show the decomposition of f by the classical totalvariation based regularizar. The last two was the decompostion result based on the suggested convex regularizar, which obviously gives the correct decomposition of nonrigid flows.

In this paper, we focus on vector-valued data and derive from the Hodge decomposition of image flows a definition of TV regularization for vector-valued data that extends the standard componentwise definition in a natural way. We show that our approach leads to a convex decomposition of arbitrary vector fields, providing a richer decomposition into piecewise harmonic fields rather than piecewise constant ones, and motion texture. Furthermore, our regularizer provides a measure for motion boundaries of piecewise harmonic image flows in the same way, as the TV measure does for contours of scalarvalued piecewise constant images.

Background and Goals

The analysis and estimation of non-rigid image flows, especially piecewise smooth non-rigid flows, is a challenge problem in many real applications such as meteorology, climatology, oceanography. Recently the variational-based method can formally give us a powerful multi-scale decomposition tool of given 2-D flow fields $f := (f_1, f_2)^t$, just by minimizing the following energy functional

$$\min_u E(u) := \frac{1}{2}\|u - f\|^2 + \alpha R(u)$$

Where $R(\cdot)$ is some convex penalty function, mostly nonsmooth so as to capture flow boundaries. This optimization approach often results in a multi-scale decomposition of f depending on the scale selection parameter _. However, the common-used regularizars, which are borrowed from regularizing the scalar fields directly, were proved not effectively. The flow structures are mostly oversmoothed, especially for piecewise smooth non-rigid flows. In this project, we suggest the convex Hodge regularizar [1]

$$R(u) := \int_\Omega \sqrt{(\mathrm{div}u)^2 + (\mathrm{curl}u)^2}\, dx\,; \qquad (1)$$

which is just the nonsmooth first-order div-curl regularizar and a counterpart of the classical total-variation regularizar in the decomposition of image functions.

Methods and Results

The classical Hodge decomposition proposes the orthogonal decomposition of a given 2D flow u as:

$$u = \nabla\phi \oplus \nabla^\perp\psi \oplus h\,, \ \phi_{\partial\Omega} = 0\,, \ \psi_{\partial\Omega} = 0\,;$$

where h is the harmonic flow, i.e. both div and curl free. Such orthogonal decomposition basically gives rise to an equivalent representation of 2D nonrigid flows f such that:

$$f(:= (f_1, f_2)) \iff (\phi, \psi, h)\,. \qquad (2)$$

With this equivalent representation (2), it is obvious that minimizing the energy functional combined with the regularizar (1) and the L2 data term just supposes one nonsmooth multiscale decomposition of the given nonrigid flow f such that

$$f := (0,0,h) \oplus ((\phi_s, \psi_s, 0) + (\phi_t, \psi_t, 0))$$

i.e.

$$f = h \oplus ((\nabla\phi_s + \nabla^\perp\psi_s) + (\nabla\phi_t + \nabla^\perp\psi_t))$$

where the flow component $(0,0,h)$ gives the most smooth background flow, i.e. pure harmonic background flow h and the flow component $u := (\phi_s, \psi_s, 0)$ expresses the large-scale part of f. And the last component flow $v := (\phi_t, \psi_t, 0)$ represents the small-scale part of f , which is just the projection of f to the convex set S_α , i.e.

$$v := \arg\min_{v \in S_\alpha} \frac{1}{2}\|v - f\|^2$$

where S_α is the set of $v := \nabla\phi + \nabla^\perp\psi$ such that

$$\sqrt{\phi(x)^2 + \psi(x)^2} \le \alpha,\ (\phi, \psi) \in (H_0^1(\Omega))^2\,. \qquad (3)$$

Then a multi-scale flow representation of

$$f := (\phi, \psi, h) = h + u + v$$

is constructed depending on the parameter $\alpha > 0$, which is called the *convex hodge decomposition*.

Outlook & Future Work

In this project, the multi-scale convex Hodge decomposition is suggested based on the novel nonsmooth regularized optimization problem, which can be well-adapted for the decomposition and estimation of highly nonsmooth fluid flows, such as turbulent flows, multi-phase flows, clouds and ocean flows etc. In furture works, it can be suggested into the variational estimation framework of nonrigid flows through image sequences, and the most recent proposed model of physicsconsistent flow extraction.

Funding: German Science Foundation (DFG), grant Schn 457/9-1

References:

[1] J. Yuan, C. Schnörr, and G. Steidl. Convex Hodge Decomposition and Regularization of Image Flows. J. Math. Imag. Vision, 33(2):169–177, 2008.

Graphical Models for Object Recognition

J. Kappes, R. Karim, S. Schmidt, C. Schnörr

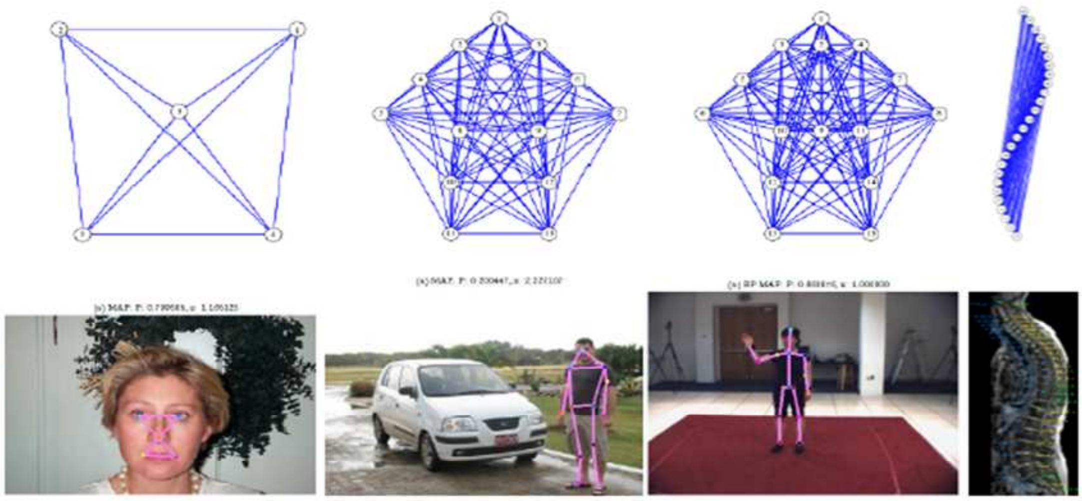


Fig. 1: Top: Graphical models for different object categories. Bottom: Detected configurations of object parts. The datasets are Face (left), Human (middle-left), the HumanEva benchmark (right-right), and human spine (right). All cases are handled by our approach in a uniform manner.

A new inference-technique for Markov Random Fields (MRF) is developed and applied on part-based object recognition. In contrast to state of the art algorithms the optimization is done directly on the relaxed objective function and guaranteed convergence to local minima. Experimantal results show that this method is at least as good as state of the art methods.

Background and Goals

Graphical models constitute a major class for learning and object recognition in computer vision. We focus on graphs with high connectivity and investigate the inference problem for this difficult case, with a wide range of potential applications. The nodes of the graph correspond to parts of an object and the edges represent dependencies between the parts, e.g. geometric relation. Example are shown in Fig. 1.

Finding the most probable configuration is than finding for each part a candidate in the image so that the energy for this configuration is minimal. The energy for a configuration x is given by J(x).

$$J(x) = \sum_{i\in V} \psi_i(x_i) + \sum_{ij\in E} \psi_{ij}(x_i, x_j)$$

Minimizing J(x) is very hard for models with non-treestructures. On the other hand tree structured models are often not powerful enough to model difficult problems. We focus on novel techniques to overcome this problem. Our main application are human bodies, but our model can be easily used for other scenarios, as shown for faces and the human spine.

Methods and Results

Exact inference is only applicable for moderate problem sizes, and standard approaches like Belief Propagation get often stuck in bad solutions and are not satisfying from a mathematical point of view. We relax the combinatorial optimization problem to a none-convex quadratic program. The noneconvex
objective function is divided into the difference of two convex functions and optimized by the difference of convex function algorithm (DCA). The DCA solves the none-convex problem by a serial of convex approximations and guaranteed to converge to a local optima of the relaxed function. Experiments has shown that this new technique is at least comparable to state of the art methods [1].

Outlook & Future Work

The current work introduces a new class of MRF-inference algorithms. First further steps relating calculation time are done. Perhaps this framework can also be used for other MRF-problems and it is currently not clear if better convex decompositions exist. For the part-based object recognition we are working on inference techniques which can handle hyper-edges. This enables as to include factors of orders higher than two into our model. This is useful to build for example rotation and scale invariant models for object recognition.

Funding: Marie-Curie Research Training Network (MRTNCT- 2004-005439) and Philips Research Europe (Hamburg)

References:

[1] J. Kappes and C. Schnörr. MAP-Inference for Highly-Connected Graphs with DC-Programming. In Pattern Recognition – 30th DAGM Symposium, vol. 5096 of LNCS, pp. 1–10. Springer Verlag, 2008.

The 2D and 3D Physically Consistent and Efficient Variational Reconstruction of Image Fluid Flow Estimates

A. Vlasenko, C. Schnörr

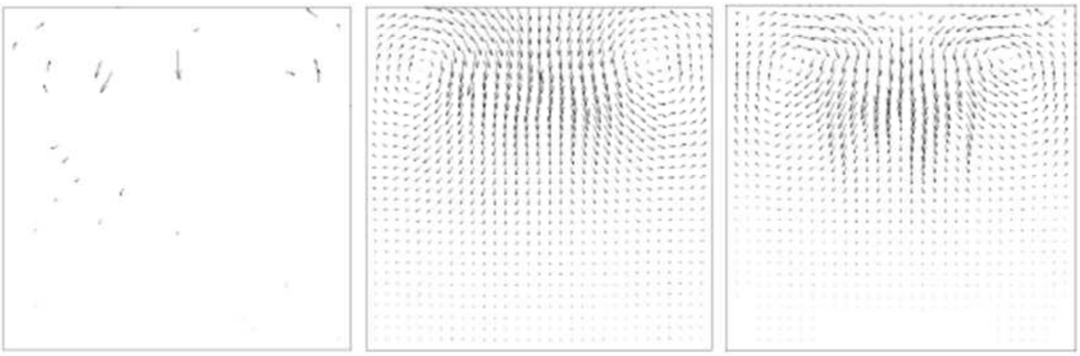


Fig. 1: The example of reconstruction of sparse and noisy 2D vectorfields. Left: Sparse and noisy vector field. Middle: Restored vectorfield. Right: Ground truth.

High-speed image measurements of fluid flows is an important part of experimental fluid mechanics and related areas of industry. Numerous competing methods have been developed for both 2D and 3D applications. However, due to various deficiencies of the image processing fluid flow velocity estimates are often corrupted which makes their physical interpretation questionable. We present here an algorithm that accepts as an input vector data set from a wide variety of experimental techniques and returns a denoised version of it which is consistent with the laws of continuum mechanics. Our approach enforces the physical structure and does not rely on particular models of noise. As a result, the algorithm performs well for different types of noise and estimation errors.

Background and Goals

The knowledge of velocity distribution in gaseous and liquid media plays a crucial role in investigations of hydrodynamic phenomena, such as turbulence. Particle image velocimetry (PIV) and Particle Tracking Velocimetry (PTV) are two most powerful velocimetry techniques which are used in gas and fluid investigations on a regular basis. The idea of both methods is as follows: special tiny luminous particles are seeded in the moving medium, this medium is illuminated with high-frequency laser pulses and the position of all particles is recorded with a high-speed camera which is synchronized with the laser pulses. Analyzing the positions of the particles obtained at two close moments of time one can estimate the velocity of the particles.

As any other velocimetry method, the PIV and PTV introduce unavoidable errors in the output data set. In case of PIV these errors are often associated with spurious vectors, biases, or wrong estimates. In case of PTV the output vector field is usually sparse. All these types of corruption presented in the measured vector fields make their further analysis and interpretation quite problematic.

Methods and Results

Previously we elaborated two- and three-dimensional (2D and 3D) approaches for reconstruction of fluid flow estimates obtained from any experimental fluid velocity measurements. They accept a wide variety of corrupted 2D and 3D velocity vector fields as input data sets and remove the noise in a physically plausible way. In addition, the methods allow to increase the resolution of vector fields and recover missing data fragments. The example of such vector field recovery is presented on Fig. 1. This approach essentially exploits the physical properties of incompressible fluid flows and does not rely upon any particular model of noise. It comprises the following successive reconstructive steps:

Step 1: Solenoidal projection. The decomposition of the input data field d into divergent r_ and divergent-free v components, i.e.

$$\mathbf{v} = \mathbf{d} - \nabla\phi \in \mathbf{V}_{sol}\,.$$

Step 2: Gaussian filtering. Spectra denoising is performed by application of the Gaussian filter g_σ:

$$\mathbf{v}_g = g_\sigma * \mathbf{v}\,.$$

Step 3: Vorticity rectification.

$$\omega - \nu\Delta\omega = \omega_g - \mathbf{e}(\mathbf{v}_g),$$

here

$$\omega_g = \nabla \times \mathbf{v}_g, \text{ and } \mathbf{e}(\mathbf{v}_g) = \mathbf{curl}\left((\mathbf{v}_g \cdot \nabla)\mathbf{v}\right)\,.$$

This step enforces the physical structures in the flow in terms of the vorticity transport equation (VTE), where $\mathbf{e}(\mathbf{v}_g)$ is the left hand side of the VTE.

Step 4: Velocity reconstruction. This step converts the vorticity denoised at the previous step into velocity by application of the procedure:

$$\mathbf{u} - \beta\Delta\mathbf{u} = \mathbf{v}_g - \beta\nabla \times \omega$$

The vector field u is the denoised output. Note that although the method implements the VTE which is nonlinear, the algorithm itself is presented by four linear partial differential equations and Gaussian filtering. The developed algorithm performs well and robust for different types of noise and estimation errors.

The performance of the announced denoising algorithm has some limitations: if the signal-to-noise ratio is lower than some certain value, the vector field can not be reconstructed efficiently. The error reduction properties of the algorithm was investigated analytically, and the dependence between the input and output signal-to-noise ratios was determined. The critical value of the signal-to-noise ratios of the input signal at which the reconstruction procedure is still possible has been also estimated. These results were tested and justified by a number of numerical runs. The error analysis along with with the results obtained from previous years reported in [1– 4] were summarized in a PhD thesis.

Outlook and Future Work

As expected, the announced method can efficiently be used in some TomoPIV applications. In short this procedure runs as follows: the particle motion is recorded during PIV experiment by a number of cameras oriented at different angles to light plane. Using these images obtained by several cameras,

the positions of particles in an experimental domain can be reconstructed afterwards. However, due to imperfectness of the PIV technique mentioned above, the position of some particles can not be accurately computed. The procedure of the fluid flow denoising developed here can detect and exclude such particles from the analysis, or they can be used as a ’particle position predictor’ for the next stage of computations. Thus, the combination of TomoPIV and vector field reconstruction technique becomes a promising issue for future work.

Funding: DFG priority program “Bildgebende Messverfahren für die Strömungsanalyse”

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Adaptive Cuts for Image Segmentation

J. Wagner, C. Schnörr

Fig. 1: Left: original image, Right: image segmented by means of iterative optimisation of the continuous graph cut segmentation and the appearance model in feature space based on the RGB colours

The research work proposed here focuses on extensions of mathematically well understood variational approaches to image segmentation (continuous graph cuts) in order to widen their scope in view of object category recognition and weakly supervised learning.

Background and Goals

A common property of most image segmentation approaches is the considerable complexity of the resulting systems. Although benchmark comparisons are carried out on publicly available data sets, differences of few percent between recognition rates deliver only limited insights into strengths and weaknesses of different architectures. Another observation concerns the poor quality of figure-ground segmentations provided by systems that currently achieve the best recognition rates. On the other side of the spectrum, tight convex relaxations have been worked recently for the basic Potts model and slight variations and extensions thereof. While the scope of these approaches to segmentation is more narrow, they yield mathematically sound algorithms with almost no tuning parameters and reproducible results. In this context, the research work proposed here focuses on extensions of mathematically well understood variational approaches to image segmentation [1] in order to widen their scope in view of object category recognition and weakly supervised learning. Emphasis is placed on precise mathematical definitions, algorithm design and on minimising the number of hidden tuning parameters involved.

Methods and Results

The iterative ansatz of alternatingly optimising the segmentation u and the appearance model in feature space represented by the parameters p in form of adaptive graph cuts

$$p^{k+1} = \inf_{p} \left\langle d(p), u^k \right\rangle , \qquad (4)$$

$$u^{k+1} = \operatorname*{argmin}_{u \in B} \{ \left\langle d(p^{k+1}), u \right\rangle + \alpha \mathrm{TV}(u) \} \qquad (5)$$

yields good results, as can be observed in Fig. 1, when comparing the original image, on the left, and its segmentation (background pixels are shown in black) on the right.

Outlook and Future Work

Future work to be pursued is to tackle the joint optimisation problem, which is highly non convex and non linear so that mathematical statements regarding the convergence of the algorithm can only be made on a local basis and for a restricted class of initial conditions.

Funding: Heidelberg Graduate School of Mathematical and Computational Methods for the Sciences

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Learning Based Object Detection in Medical Imaging

S. Schmidt, C. Schnörr

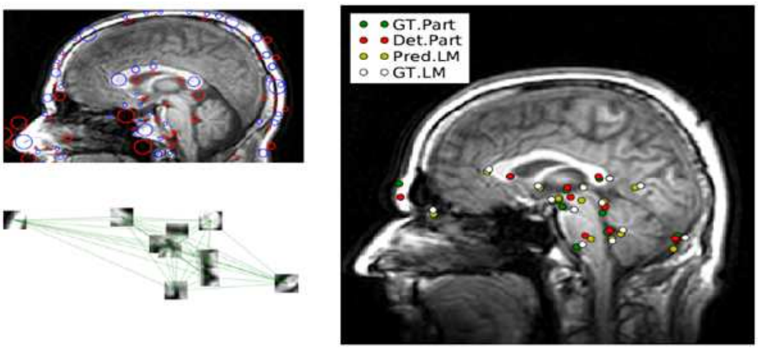

Fig. 1: Left panel: Starting with interest points detected a set of registered images (top image shows example of pos./neg. Lindeberg interest points), our method clusters, builds candidate part classifiers and then simultaneously selects a subset to enter a parts-based graphical model (bottom shows sample).
Right panel: Test image annotated with ground truth anatomical target landmarks (white dots), automatic localization of feature points using learned graphical model (red dots), expected position of feature points using ground truth TPS warp (green dots), and prediction of anatomical landmarks using TPS interpolation with the automatic landmarks (yellow dots).

A method for constructing a part-based graphical model for object detection and localization from example image data is developed. It is applied to the problem of localizing anatomical landmarks in medical images.
The part-based graphical model approach seems particularly suited for obtaining robust initializations for other registration or segmentation approaches based on local optimization, because exact probabilistic inference allows to obtain globally optimal model fits.
Our approach is to select good parts from a pool of candidate features such that they cover a region of interest, or — if target landmarks are known — are spatially close to these, to allow a good prediction of their position after the model is fit.

Background and Goals

Our goal is the automatic modeling of the stable image parts which are shared by a set of example images, and relevant for the task of localizing anatomical structures of interest, after co-registering the input images to a common reference frame. A variant of our group-wise registration scheme was published in [2]. Here, we focus on the modelling and learning part.
As the part-based model should, for computational efficiency, only include interesting image parts, i.e. those that are related to a given region of interest or a set of anatomical target landmarks, we are faced with a combinatorial feature selection problem.
Here, we investigate a novel selection scheme for extracting the graphical model from training data, akin to the facility location problem from the field of operations research. With this problem formulation, we can take into account the spatial distribution of the parts as well as their individual saliency.

Methods and Results

The detector model we use in this context has been introduced in [1, 4]. It consists of a part-based graphical model, representing object geometry by pairwise relations as well as the appearance of the parts, which is captured using randomized tree classifiers. In [4], we demonstrated the applicability of the model to the task of automatically annotating the intervertebral discs of the human spine in MR images.
We assume that the training data has been previously registered to an atlas coordinate space and that a target region of interest is available. This region can either be given as a set of anatomical landmarks that are to be localized or as a (weighted) mask covering one or several image regions, in which the interesting image structure is present. The latter case is relevant if — as in the context of an automatic ROI selection system such as [3] — the anatomical loci of interest are learned later by incorporating user preference, and we only have rough information where the model should be able to predict well by means of a mask specifying interesting foreground.
To summarize, we give an algorithmic overview of our part selection and model generation approach:

1. Detect interest points in each image

2. Map interest points to atlas space (via known registration)

3. Form part candidates by clustering interest points spatially

4. Design part classifier for each candidate

5. Test part classifiers on hold-out data to assess their local performance

6. Select subset of part candidates using facility location model

7. Construct graphical model from selected parts
   - Extract geometry model from marginal statistics of pairwise inter-part relations
   - Learn feature weights of graphical model using a max-margin approach (structured SVM)

Facility location is a well-known problem in operations research, that is underlying the question of where to open a set of facilities (e.g. factories, storage, fire stations) to serve a set of clients with fixed locations and given demands, at minimal cost. By analogy, we select parts i (the facilities) that perform well on their own (low local costs f_i as well as serving well to predict the location of the target landmarks j (the clients). For the latter, we assume that spatial proximity enables accurate prediction, hence we assign costs c_{ij} according to the distance. The Simple Facility Location model with unlimited facility capacities and unit demands yields the optimization problem

$$\begin{aligned} \min_{y,X} \quad & f^\top y + \mathrm{trace}(C^\top X) && && (6) \\ \text{s.t.} \quad & X_{ij} \leq y_i \; \forall j && X^\top e = e \\ & y \text{ integer} && 0 \leq X_{ij} \leq 1 \; \forall i, j \end{aligned}$$

where the decision variables are: $y_i \triangleq$ select i;
$X_{ij} \triangleq$ fraction of j's demand supplied from site i.

This is an mixed-integer LP that for practical instance sizes can be solved using standard Branch&Cut methods. The selected parts as indicated by y then become part of the graphical model, which is trained as outlined above. To predict anatomical landmarks in new images, we apply the graphical model detector to find the locations of the automatically determined parts. Then, we either use these to condition a joint Gaussian of both anatomical and automatically selected features, or simply use a thin-plate spline (TPS) parameterized by the parts to interpolate the anatomical landmarks.
The method has been tested on small image databases of mid-sagittal MRI images of very low resolution (scout scans). The preliminary evaluation based on 20 images shows that the overall methodology can be applied to construct interesting graphical models which take account of several localization target points or regions. However, its predictions are not very accurate. The obtained position estimates however could serve as input to robustly initialize finer-grained models based on local search. Quantitative results for larger image databases will be reported in a future publication.

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Convex Models and Global Optimization for Image Segmentation and Labeling

J. Lellmann, D. Breitenreicher, J. Kappes, F. Becker, C. Schnörr

Fig. 1: Application of the proposed approach for finding optimal partitions.
Left: Original image. Center: Selection of seed regions by the user.
Right: Histogram-based multiclass segmentation. The originally combinatorial problem is relaxed to a convex problem and solved globally optimal using specialized algorithms. The spatially continuous framework avoids discretization-based artifacts and allows to obtain solutions with sub-pixel accuracy.

In this project, we study approaches to construct convex formulations of variational problems in image processing. We focus on problems that can be approximated by convex partitioning problems on continuous image domains. Using specially developed algorithms, these problems can be globally optimized even for very general data terms, which allows to clearly separate modeling and optimization effects.

Background and Goals

One of the key problems in image analysis is the partitioning problem. Here one seeks to decompose a given image domain $\Omega \subseteq \mathbb{R}^d$ into several regions according to some data consistency and spatial coherency constraints.

Classical applications include image- or 3D volume segmentation and 3D reconstruction. In many cases the resulting problems can be formulated as convex optimization problems, which allows to solve them to global optimality. Any undesired or unexpected results can thus be attributed to the model, which is a clear advantage for model development.

Moreover, using a lifting technique [1], many originally non-convex variational problems such as image registration and optical flow can be reduced to higher-dimensional convex partitioning problems.

In this project, we focus on deriving convex relaxations for partitioning problems and developing efficient numerical solvers.

In contrast to grid- or graph cut-based methods, we consider the problem in the functional-analytic framework and from a spatially continuous perspective, i.e. we regard the image domain as a connected set rather than a finite set of individual points. In contrast to "discretize first" approaches, this "analyze first" approach allows to get a deeper insight into the underlying problem, obtain sub-pixel accurate solutions, and abstract from inaccuracies caused by the discretization.

Methods and Results

The task of segmenting the image $\Omega \subseteq \mathbb{R}^d$ into several regions $P_1, \ldots, P_l$ can be posed as finding a labeling function $u : \Omega \to \{1, \ldots, l\}$ minimizing

$$\inf_{u:\Omega \to \{1,\ldots,l\}} \int_\Omega \langle u(x), s(x) \rangle dx + J(u), \qquad (7)$$

where $s : \Omega \to \mathbb{R}^l$ constitutes the local data fidelity term, and the regularizer $J(u)$ ensures a certain smoothness of the boundaries.

A way to solve this originally combinatorial problem is to allow intermediate solutions, i.e. to relax the constraint set to $u : \Omega \to \Delta_l$, where Δ_l is the l-dimensional unit simplex. By a suitable extension of the regularizer J to this enlarged feasible set, one obtains a relaxed problem. From the solution of the relaxed problem, an approximate – and, in the case of two labels, exact – solution of the original problem can then be recovered.

This is particularly appealing in cases where J can be extended in a convex way, since then the overall problem can be solved to global optimality without potentially getting stuck
in local minima [4].

It is therefore of central importance to characterize regularizers for which such extensions exist, and to provide ways to construct such extensions. We focus on a class of regularizers where jumps between labels are penalized differently according to an interaction potential d, i.e. boundary length weighted by some scalar $d(i, j)$ depending on the labels i and j of the adjoining regions (Fig. 2). In [2] we considered the special class of Euclidean distances, which are naturally handled by the above model. Non-Euclidean distances can still be approximated by offline solving an auxiliary convex problem.

Under several reasonable assumptions on the regularizer, we showed that any interaction potential must be a metric [5]. In addition, we extended an existing result [1] to show how a regularizer can be constructed for any such interaction potential. This completely characterizes the class of interaction potentials.

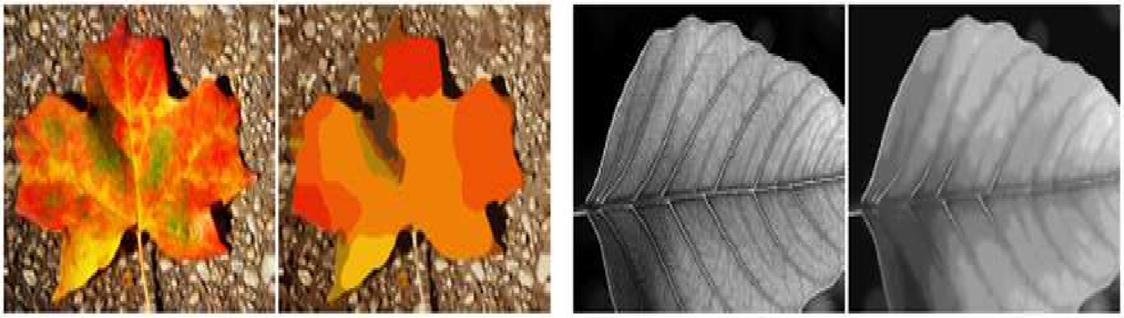

Fig. 2: Left: Effect of choosing nonstandard interaction potentials. The original image (left) is segmented into 12 regions corresponding to prototypical colors vectors. By modifying the interaction potential, the regularization strength is selectively adjusted to suppress foreground structures while allowing for fine details in the background. Such non-standard regularizers require special tehniques in order to formulate them in a convex way.
Right: Mumford-Shah denoising of a grayscale image (left) using a nonconvex regularizer to remove fine structures while preserving hard edges (right). Using a lifting technique, many similar variational problems can be formulated and solved in the considered framework.

Regarding optimization, the model (7) can be posed as a (convex-concave) saddle-point problem. We studied several methods to solve such problems, with a special focus on primal-dual methods that allow to solve the problems to a prescribed accuracy and provide optimality certificates [5]. Compared to existing methods, the proposed Douglas-Rachford method is robust and works on many synthetical and real world problems without further parameter tuning. When combined with an improved rounding technique, the approach allows to recover very good solutions of the original combinatorial problem with sub-pixel accuracy, and without the staircasing artifact commonly encountered with graph-based methods.

The quality of the segmentation can be further improved by employing tighter relaxations of the regularizer. These pose a problem for existing methods, as they require to iteratively solve inner problems at each step. In [3] we demonstrate how this can be avoided, increasing numerical robustness and speed at the same time. The proposed technique also works for a large class of general image processing problems that can be formulated in saddle-point form (Fig. 2).

Outlook and Future Work

A promising direction is to study how the recovery of true discrete segmentations from the solution of the relaxed problems can be improved. In contrast to the binary case, there are no known approximation results for the multi-class formulation in the continuous framework.

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Relaxation and Inference for Discrete Graphical Models

J.H. Kappes, C. Schnörr

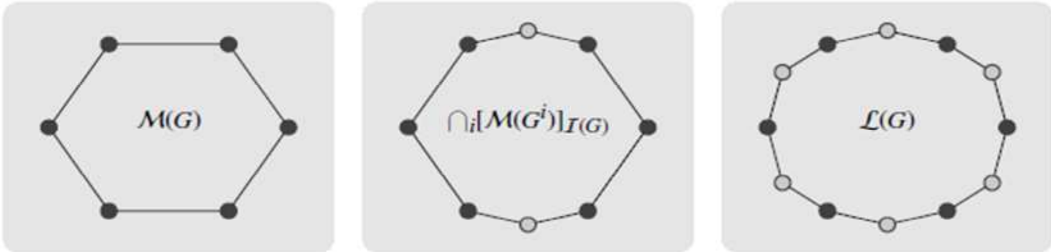

Fig. 1: Highly idealized illustration [1] of the polytopes of linear programming relaxations of the integer problem. **(Left)** The marginal polytope $\mathcal{M}(G)$ leads to an exact relaxation of the corresponding integer problem, but the number of integer vertices (black) of the polytope grows exponential with the number of variables. **(Right)** The local polytope $\mathcal{L}(G)$ on the other hand can be represented by a polynomial number of constraints but contains additional fractal nodes (grey). **(Middle)** To reduce the number of fractal vertices we construct methods using tighter polytopes, which are constructed as the intersection of lifted simpler polytopes.

Discrete graphical models can be used to conveniently represent many real world problems. Inference based on such models leads to combinatorial optimization problems that are NP-hard in general. Suitable relaxations leads to problems that facilitate inference yet closely approximate the original problem. Our current research concerns the derivation of such relaxations by decomposing the inference problem into a set of simpler subproblems, and the design of corresponding algorithms. In many research areas graphical models are an important tool for the mathematical description of problems. They represent statistical relations and assumptions in a convenient form and express dependencies between quantities of interest in comprehensible way. Computational inference using such models is often quite complicated, however.

Tree types of inference problems are from mayor interest,

i) Marginalization:

$$p(x_A|\theta) = \sum_{x' \in X, x'_A = x_A} p(x'|\theta) \quad \forall A \subset V$$

ii) Learning:

$$\theta^* = \arg\max_\theta \prod_i p(x^i|\theta)$$

iii) Calculation of Modes:

$$x^* \in \arg\max_{x \in X} p(x|\theta) \text{ or}$$
$$x^* \in \arg\min_{x \in X} J(x|\theta).$$

The objective functions, $p(\cdot)$ or $J(\cdot)$ parametrized by the vector_, factorize according to a graph G = (V, E) through subset C(G) of the powerset $\mathcal{P}(V)$ into

$$p(x|\theta) = \prod_{C \in C(G) \subset \mathcal{P}(V)} g_C(x_C|\theta)$$
$$J(x|\theta) = \sum_{C \in C(G) \subset \mathcal{P}(V)} f_C(x_C|\theta).$$

The main focus our work lies on the minimization task in the third problem. For more details and applications see [2].

Even if exact inference is theoretically out of reach, mathematically sound approximations can often be derived, leading to bounds for the unknown solution of the original problem and, in turn, possibly certificates for global optimality solution to approximate problems.

While inference on second order models, that are models for which each $C \in C(G)$ contains not more than two elements, are standard nowadays, inference algorithms for higher order models are rare. This might be caused by lack of suitable representations of such models as well as the larger computational complexity. We developed a C++-library (openGM) [1], which is able to deal with arbitrary discrete energy or density functions and provides inference algorithms for such models. Arbitrary in this context means that we are neither limited to the number of states of each variable nor to the order of the potential functions.

[1] The true topology of high dimensional polytopes can not be illustrated linear depended, which will not be true in higher dimensions.

Methods and Results

In previous work [2] we introduced an A_-search method for exact inference, which for larger problems becomes too time consuming, however. We therefore decompose the problem to accelerate inference.

Moreover, an approximation to the intractable inference problem can be formulated in terms of a two-level optimization procedure, where at the lower level inference on tractable substructures is carried out, while the master program at the upper level combines these partial solutions via dual variables.

Additionally, the objective value obtained at the upper level yields a bound of the original (intractable) objective function, whose optimization through dual variables possibly meets the value of some locally computed optimum, thus providing a certificate that this optimum is indeed a global one.

It is well known, that the integer program can be reformulated into a linear program

$$\min_{x \in X} J(x|\theta) = \min_{\mu \in \mathcal{M}(G)} \langle \varphi(\theta), \mu \rangle$$

where $\mathcal{M}(G)$ contains an intractable number of linear constraints in general. In the standard relaxation the marginal polytope is replaced by the local polytope which can be represented by a polynomial number of linear constraints, but contains additional fractal vertices. If the solution of this relaxed LP is integer the global optimal solution of the integer problem is found, otherwise this gives only a lower bound on the minimal energy and rounding schemes have to be applied to obtain a integer solution.

A major difference of our work [3] to related research is that we can deal with particular cyclic subproblems. This leads to tighter approximations than those commonly applied in the literature.

As illustrated in Fig. 1 the corresponding polytopes contain less fractal nodes and increase the probability to end up in a integer solution. However, as we show [3] a suitable choice of the decomposition is often more promising than just using more complex subproblems.

Outlook and Future Work

As so far decompositions are manually selected, we currently working on full-automatic selections based on the structure and/or the objective function of the model.

The mayor drawback of sub-gradient methods used in [3] is that a suitable choice of the stepsize is none-trivial but essential for fast convergence. Therefore we will investigate alternative methods for stepsize/update calculation

In another line of research we are looking for algorithms, which consider also tighter relaxations but avoid solving the non-smooth dual problem.

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Discrete Tomography for Particle Image Velocimetry

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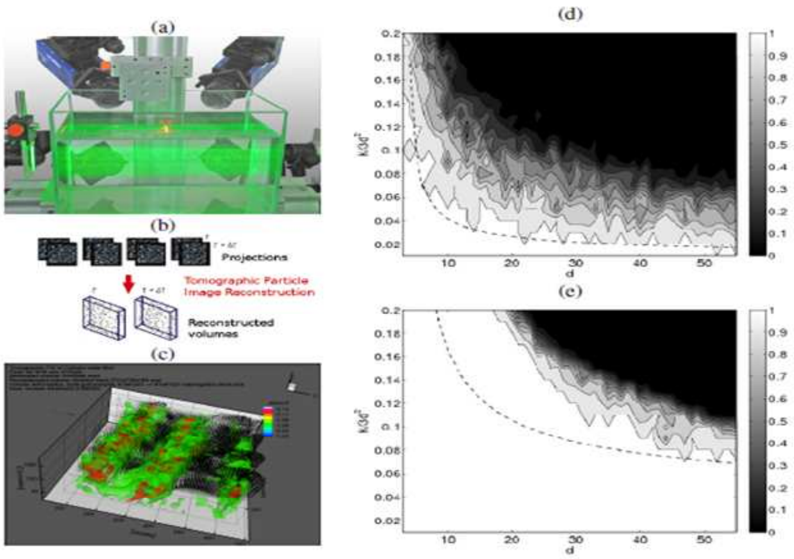

Fig. 1: Left: The working principle of TomoPIV; (a) Seeding particles within the measurement volume are illuminated by a pulsed light source, and the scattered light pattern is recorded simultaneously from several viewing directions using CCD cameras. (b) The 3D particle distribution (the object) is reconstructed as a 3D light intensity distribution from its projections (2D images) on the CCD arrays. (c) The particle displacement (hence velocity) within the interrogation volume is then obtained by the 3D cross-correlation of the reconstructed particle distribution at the two exposures.
Right: Recovery via a standard TomoPIV measurement system (d) versus recovery via the improved measurement system (e). (d) Success and failure empirical phase transition for the standard measurement system along with the phase transition for the optimal measurement system from the viewpoint of CS (the Gaussian ensemble) scaled by factor 0:1 (dashed curve). (e) Success and failure empirical phase transition for the improved measurement system along with the phase transition for the Gaussian measurement ensemble scaled by factor 0:4 (dashed). The results indicate that at least a three times better reconstruction performance is obtained within the considered range of image resolution. For the analytical phase transitions for arbitrary high resolution (parameter d) see [2, 3].

We study the discrete tomography problem in Experimental Fluid Dynamics – Tomographic Particle Image Velocimetry (TomoPIV) – from the viewpoint of Compressed Sensing (CS). The problem results in an ill-posed image reconstruction problem due to undersampling. Ill-posedness is also intimately connected to the particle density. Higher densities ease subsequent flow estimation but also aggravate ill-posedness of the reconstruction problem. A theoretical investigation of this trade-o_ is studied in the present work.

Background and Goals

Among the different 3D techniques presently available for measuring velocities of fluids, Tomographic Particle Image Velocimetry (TomoPIV) has recently received most attention, due to its increased seeding density with respect to other 3D PIV methods. This, in turn, enables high-resolution velocity field estimates of turbulent flows by means of a cross correlation technique. TomoPIV is based on a multiple camerasystem, three-dimensional volume illumination and subsequent 3D reconstruction, see Fig. 1. TomoPIV, in contrast to medical imaging, employs only few projections due to both limited optical access to wind and water tunnels and cost and complexity of the necessary measurement apparatus. As a consequence, the reconstruction problem becomes severely ill-posed, and both the mathematical analysis and the design of algorithms fundamentally differ from the standard scenarios of medical imaging. Our research work addresses two major open problems:

1. A crucial parameter for 3D fluid flow estimation from image measurements is particle density (sparsity). The ill-posedness of the reconstruction problem is aggravated by higher particle densities. On the other hand, higher densities are desirable since they increase the resolution and measurement accuracy. A thorough theoretical investigation of this trade-o_ phenomenon is studied by the authors in [2, 3].

2. Another major issue concerns problem size and computation time. 3D problems and, in particular, timedependent 3D problems require considerable computational resources. Sparsity enforcing optimization criteria and algorithms are investigated by the authors in some detail to reveal pros and cons from the perspective of TomoPIV, see e.g. [1].

Methods and Results

The reconstruction of particle volume functions from few projections can be modeled as finding the sparsest solution of an underdetermined linear system of equations, since the original particle distribution can be well approximated with only a very small number of active basis functions relative to the number of possible particle positions in a 3D domain. In general the search for the sparsest solution is intractable (NPhard), however. The newly developed theory of Compressed Sensing shows that one can compute via `1-minimization or linear programming the sparsest solution for underdetermined systems of equations provided that the measurement ensemble (the coe_cient matrix) satisfies certain conditions. Testing these conditions on generic matrices is often harder than solving the underlying combinatorial `0-problem as it also implies solving a combinatorial problem which is intractable given the huge dimensionality of the measurement matrix within the TomoPIV setting. However, we showed in [2] that all currently available recovery conditions predict an extremely poor performance of the TomoPIV measurement ensemble when we restrict to a simple but realistic setup geometry. On average, such matrices perform approximately ten times worse than the Gaussian ensemble which is optimal in the sense that it allows maximal sparsity such that for all less sparse vectors exact recovery is still guaranteed. However, when we slightly perturb the entries of such a degenerate measurement matrix we can boost both worst case and expected reconstruction performance. Then the particle density can be increased by a factor of three while preserving the number of measurements.

Outlook and Future Work

We currently study the tomographic problem of reconstructing particle volume functions from the general viewpoint of compressed sensing. In a nutshell, we show that the TomoPIV problem is quite degenerate from the viewpoint of compressed sensing, thus leading to poor performance guarantees. On the other hand, the probabilistic analysis of [2] yields average performance bounds that back up current rules of thumb of engineers for choosing particle densities in practice. Moreover, simulations demonstrate that slight random perturbations of the TomoPIV measurement matrix considerably boost both worst-case and expected reconstruction performance. This finding is interesting for CS theory and for the design of TomoPIV measurement systems in practice. Our work aims at pointing out connections between the fields of compressed sensing and discrete tomography in order to stimulate further research.

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Model-Based Multiple 3D Object Recognition in Range Data

D. Breitenreicher, C. Schnörr

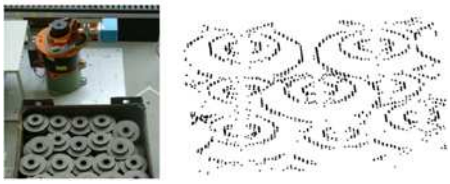

Fig. 1: Visualization of an industrial scenario motivating our work (left). A laser scanner is mounted on a linear axis and records the scene containing multiple objects randomly assembled in a bin. Substantial self-occlusion, noise, and unstructured sparse measurements render the task of multiple object detection and registration difficult (right).

We study an approach to detect and align multiple instances of industrial 3D objects in unstructured noisy range data. This approach is based on a two-stage procedure, where the first non-local processing stage takes all data into account and computes in parallel multiple localizations of the object along with rough pose estimates while the second stage calculates accurate registrations for all detected object instances individually by using local optimization. Both stages are designed using advanced numerical techniques, large-scale sparse convex programming, and second- order geometric optimization on the Euclidean manifold, respectively.

Background and Goals

We focus on computer vision techniques for industrial tasks as illustrated in Fig. 1. Multiple instances of an arbitrary, rigid 3D object are randomly assembled in a bin. A laser scanning device acquires unstructured and noisy point measurements. The objective is to detect reliably and to determine accurately the pose of the object instances in terms of rigid body transformations for subsequent tasks, such as picking individual objects by a robot. In this context, we focus on the following requirements:

- The approach should not rely on properties of specific objects, such as the geometry of flat disks, for instance. Rather, we only require as input a sparse point sample of the object's surface, obtained from a CAD model if available or by direct measurements if not. This enables flexible adaption to novel scenarios by nonexperts as user.
- Numerous ambiguities due to object symmetries and occlusion require a non-local contextual first processing stage in order to reliably detect multiple object instances and rough pose estimates. The latter should be sufficiently accurate to avoid problems with local minima of subsequent pose estimation which is an intrinsically non-convex problem.
- The subsequent numerical pose estimation should adequately take into account the geometry of the manifold of Euclidean transformations so as to minimize the number of iterations while having a large basin of attraction to the correct local minimum.

Methods and Results

Given point measurements of the scene, we wish to detect in parallel object instances O_{Y_l} and determine rough estimates of their poses $Y_l,\ l = 1, 2, \ldots$ as input for the subsequent registration stage refining these estimates. To this end, we adopt the basis pursuit approach based on convex programming. The "dictionary" in our case corresponds to a sample S of the Euclidean manifold and the corresponding object instances O_{Y_l} , $Y_l \in S$. Formally, this dictionary becomes quite large. Yet, it can be shown that by inspecting the optimality condition beforehand, the convex optimization problem can be considerably reduced such that applying a state-of-the-art solver computes the solution in a few seconds only. The approach delivers a sparse solution that effectively resolves conflicting object hypotheses due to mutually overlapping supports while obtaining both the number of detected objects and an estimate of their pose [1]. As these estimates are related to the finite set S of samples of the Euclidean manifold, their accuracy is necessarily limited. Consequently, we refine these estimates in a subsequent second processing step. Specifically, based on the initializations, we optimize each pose individually by continuous geometric optimization on the Euclidean manifold SE(3), using an objective function that does not rely on explicit point correspondences [2]. We employ second-order approximations for fast convergence while providing a sufficiently broad basin of attraction that enables to converge to the correct local minimum [1].

Outlook and Future Work

Although the presented approach is designed to handle single rigid models, it can be extended to cope with multiple rigid object models straightforwardly. Further work includes to work out criteria for selecting the discretization of the pose space automatically. Too coarse discretization yields inaccurate initial pose estimates for the subsequent geometric optimization procedure. Too fine discretization leads to unnecessarily large problem sizes. A convenient feature for the user therefore would be to derive this parameter from given object models directly.

Funding: VMT Vision Machine Technic Bildverarbeitungssysteme GmbH

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Recent Advances in Multi-Cue Pedestrian Classification

M. Enzweiler, C. Schnörr

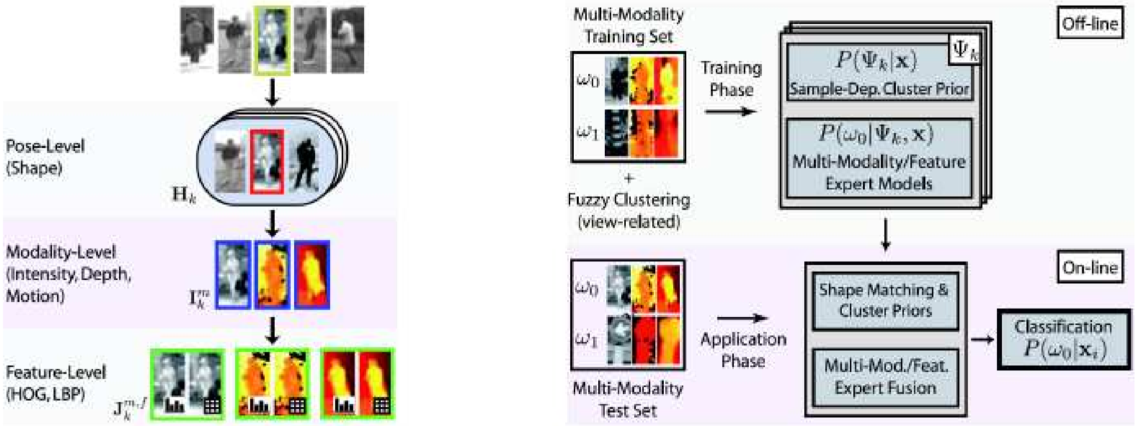

Fig. 1: Mixture-of-Experts framework overview. (left) Multi-level object representation comprising Mixture-of-Experts on pose-level, modality-level and feature-level. (right) K view-related models specific to fuzzy clusters Ψ_k are used for classification. The models consist of sample-dependent cluster priors and multi-modality / feature discriminative experts which are learned from pedestrian (class ω_0) and non-pedestrian (class ω_1) samples x.

This work addresses the problem of recognizing pedestrians in images acquired from a moving camera in real-world environments. We propose a multi-level Mixture-of-Experts framework which involves local pose-specific expert classifiers operating on multiple image modalities and features. In terms of modalities, we consider gray-level intensity, depth cues derived from dense stereo vision and motion cues arising from dense optical flow. We furthermore employ shape-based, gradient-based and texture-based features.

Background and Goals

In recent years, a multitude of (more of less) different feature sets has been used to discriminate pedestrians from nonpedestrian images, see [2]. Most of these features operate on intensity contrasts in spatially restricted local parts of an image. In human perception however, depth and motion are important additional cues to support object recognition. In particular, the motion flowfield and surface depth maps seem to be tightly integrated with spatial cues, such as shape, contrasts or color.

Methods and Results

To that extent, we present a Mixture-of-Experts framework for pedestrian classification that combines four modalities (shape, intensity, depth and motion) and three features, i.e. Chamfer distance, HOG (histograms of oriented gradients) and LBP (local binary patterns) [2, 4]. The Mixture-of-Experts model involves several classifiers, the experts, which are each restricted to a local subspace of the problem and make a combined decision. We follow a multi-level approach by utilizing expert classifiers on pose-, modality- and feature-levels, see Fig. 1. The local experts are integrated in terms of a probabilistic model based on fuzzy view-related clustering and associated sample-dependent cluster priors. A number K view-related models are trained in an o_-line step to discriminate between pedestrians and non-pedestrians. These models consist of sample-dependent cluster priors and multi-level (multimodality / multi-feature) expert classifiers. In the on-line application phase, cluster priors are computed using shape matching and used to fuse the multi-level expert classifiers to a combined decision, see Fig. 1.

For pedestrian classification, our goal is to determine the class label ω_i of a previously unseen sample x_i. We make a Bayesian decision and assign x_i to the class with highest posterior probability:

$$\omega_i = \operatorname{argmax}_{\omega_j} P(\omega_j|x_i) \qquad (8)$$

We decompose $P(\omega_0|x_i)$, the posterior probability that a given sample is a pedestrian, in terms of the K clusters Ψ_k as:

$$P(\omega_0|x_i) = \sum_k P(\Psi_k|x_i)P(\omega_0|\Psi_k, x_i) \qquad (9)$$

$$\approx \sum_k w_k(x_i)H_k(x_i) \qquad (10)$$

$P(\Psi_k|x_i)$ represents a sample-dependent cluster membership prior for x_i. We approximate $P(\Psi_k|x_i)$ using a sampledependent gating P function $w_k(x_i)$, with $0 \leq w_k(x_i) \leq 1$ and $\sum_k w_k(x_i) = 1$, which is derived from shape matches [3, 4]. $P(\omega_0|\Psi_k, x_i)$ represents the cluster-specific probability that a given sample xi is a pedestrian. Instead of explicitly computing $P(\omega_0|\Psi_k, x_i)$ we utilize an approximation given by a set of multi-modality / multi-feature discriminative models H_k. The classifier outputs $H_k(x_i)$ can be seen as approximation of the cluster-specific posterior probabilities $P(\omega_0|\Psi_k, x_i)$.

Our approach has a number of advantages compared to fusion approaches using a joint feature space. First, our individual expert classifiers operate on a local lower-dimensional feature subspace and are less prone to overfitting effects. We do not need to apply dimensionality reduction techniques to robustly train our classifiers. Compared to multi-feature boosting approaches, we also do not require techniques to map the multi-dimensional features to a single dimension.

Second, our Mixture-of-Experts framework alleviates practical problems arising from the use of large and high-dimensional datasets. Some authors reported that classical machine learning techniques do not scale-up (on practical terms) to the use of many tens of thousands of high-dimensional training samples, due to excessive memory requirements. In contrast, the local expert classifiers in our framework are trained on a lower-dimensional subspace alleviating memory requirements. As a result, more complex classifiers and / or a larger amount of training samples can be used.

A third issue is training time, which can be on the order of weeks on current hardware, particularly for boosting approaches. In our approach, training times are usually faster, given the lower dimensionality and inherent parallelism of training multiple local experts independently at the same time.

Our experiments are designed to evaluate the different levels of the proposed Mixture-of-Experts framework, see Fig. 1, both in isolation and in combination, to quantify the contribution of the individual cues to the overall performance. We use the publicly available Daimler Multi-Cue Pedestrian Classification Benchmark dataset (intensity, dense depth and dense motion samples), as introduced in [1].

Our results show a significant performance boost of up to a factor of 42 in reduction of false positives at constant detection rates over a state-of-the-art intensity-only classifier using HOG features and linear SVM classification. We identified the use of multiple modalities (intensity, dense depth and dense motion samples) as the most benefiting factor for overall performance.
An extension of the proposed Mixture-of-Experts framework involves applying the pose-specific nature of the model towards single-frame estimation of pedestrian body orientation. Unlike previous work which addressed classification and orientation estimation separately with different models, our method involves a probabilistic framework to approach both in a unified fashion. We use the set of view-related expert models not only for classification as in , but also to approximate the probability density of pedestrian orientation. Sample-dependent priors are integrated in a Bayesian fashion and the approach scales-up to the use of multiple cameras, see [3].

Additionally, the multi-modality representation can be exploited for partial occlusion handling of pedestrians. Occlusions manifest in discontinuities in depth and motion space. This representation involves a set of component-based expert classifiers trained on features derived from intensity, depth and motion. To handle partial occlusion, we compute expert weights that are related to the degree of visibility of the associated component. This degree of visibility is determined by examining occlusion boundaries in depth and motion space. Occlusion-dependent component weights then focus the combined decision of the classifier on the unoccluded body parts, see [1].

Funding: Daimler AG

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[5] C. G. Keller, M. Enzweiler, M. Rohrbach, D. F. Llorca, C. Schnörr, and D. M. Gavrila. The Benefits of Dense Stereo for Pedestrian Detection. Intelligent Transportation Systems, IEEE Transactions on, 2011. ISSN 1524-9050.

Pedestrian Path Prediction and Action Recognition

C. Keller, C. Schnörr

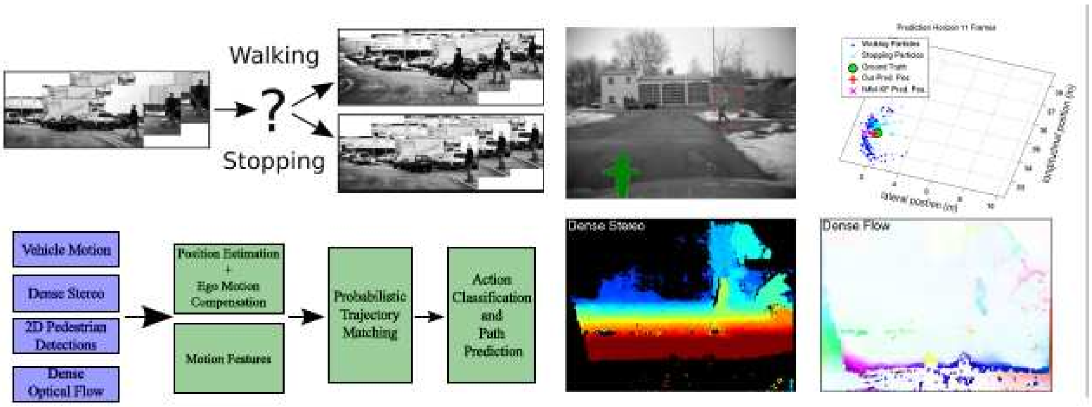

Fig. 1: Pedestrian path and action prediction. (left/top) Will the pedestrian stop or walk. (left/bottom) Overview of the proposes system using motion features and a probabilistic trajectory matching to predict the action and future position of a pedestrian. (right) System output illustrating the available input data and system derived decision.

Future vehicle systems for active pedestrian safety will not only require a high recognition performance, but also an accurate analysis of the developing traffic situation. In this work a system for pedestrian action classification (walking vs. stopping) and path prediction at short time intervals (< 1 s) is presented. Apart from the use of positional cues, obtained by a pedestrian detector, we extract motion features from dense optical flow. These augmented features are used in a probabilistic trajectory matching and filtering framework.

Background and Goals

Strong gains have been made over the years in improving pedestrian recognition performance. However, the initation of a emergency vehicle maneuvre requires a precise estimation of the current and future position of the pedestrian with respect to the moving vehicle. A deviation of, say, 25 cm in the estimated lateral position of the pedestrian can make all the difference between a “correct” and an “incorrect” maneuver initiation. One major challenge is the highly dynamic behavior of pedestrians, which can change their walking direction in an instance, or start/stop walking abruptly. As a consequence, prediction horizonts for active pedestrian systems are typical short; even so, small performance improvements can produce tangible benefits. Accident analysis shows that being able to initiate emergency braking 0.16 s (4 frames @ 25 Hz) earlier, at a Time-to-Collision of 0.66 s, reduces the chance of incurring injury requiring hospital stay from 50% to 35 %, given an initial vehicle speed of 50 km/h.

Methods and Results

We present a system for pedestrian action classification (walking vs. stopping) and accurate path prediction from a moving vehicle, at short time intervals Fig. 1. Features are extracted from dense stereo and dense optical flow data computed over the bounding box returned by a pedestrian detector. Lateral and longitudinal position of the pedestrian is obtained with the center of the detector box and median disparity values inside the box, respectively. Vehicle ego motion is compensated by rotation and translation of positions to a global reference point using velocity and yaw-rate measurements from onboard sensor data. Motion features involve a low-dimensional histogram representation of optical flow. Measured pedestrian positions and motion features are subsequently used in a trajectory matching and filtering framework. From the filter state and information about the class labels of the matched trajectories, a future pedestrian position and action is derived.

To capture motion differences between torso and legs the detector box is split into an upper and lower sub-box. For each sub-box the median box motion is removed to compensate the pedestrian ego motion. Resulting orientation vectors $v = [v_x, v_y]^T$ are assigned to bins $b \in [0, 7]$ using their $360°$ orientation. Bin contributions are weighted by their magnitude $|v| = \sqrt{v_x^2 + v_y^2}$ and resulting histograms are normalized with the number of contributions. A feature vector is formed by concatenating the histogram values and the median flow for the lower and upper box. The first three PCA dimensions with the largest eigenvalue are used as final histograms of orientation otion (HoM) features.

Pedestrian trajectories X are represented using the ordered tuples $X = ((x_1, t_1), \ldots, (x_N, t_N))$. For every timestamp t_i the state x_i consists of the lateral and longitudinal position of the pedestrian with respect to the vehicle and additional features extracted from optical flow. For two trajectories A and B the QRLCS metric $\mathrm{dist}_{\mathrm{QRLCS}}(A, B) \in [0, 1]$ is used to find the (partial) translation and rotation parameters for the optimal assignment and matching distance. Given a motion history $M_{1:t}$ up to the current time step t, the probability that a future pedestrian state ϕ_T at $T = t + \Delta T$ occurs is computed by

$$p(\phi_T|M_{1:t}) = \eta\, p(M_{1:t}|\Psi_t) \int p(\Psi_t|\Psi_{t-1})\, p(\Psi_{t-1}|M_{1:t-1})\, d\Psi_{t-1}$$

with a normalisation constant η and the current state Ψ_t which represents a sequence of trajectory points including position, optical flow features and its history over a temporal sliding window with a manually defined number of time steps d. $p(\phi_T|\Psi_t)$ is the probability of observing a future state ϕ_T , and is determined from the motion database. The distribution $p(\phi_T|M_{1:t})$ is represented by a set of samples or particles $\{\Psi_t^{(s)}\}_S$, which are propagated in time using a particle filter. Therefore, each particle $\Psi_t^{(s)}$ represents a sub-trajectory for the current state. From a training trajectory database a binary search tree is constructed using keys derived from motion features. Predicting the particle filter state is performed by a probabilistic search in the binary tree and a lookup for the next state in the trajectory database.

The distribution $p(M_{1:t}|\Psi_t)$ represents the likelihood that the measurement trajectory $M_{1:t}$ can be observed when the model trajectory is given. In the context of particle filters, this value corresponds to the weight of a particle and is computed by the QRLCS value $\mathrm{dist}_{\mathrm{QRCLS}}$ normalized to a weight

$$w^{(s)} = 1 - \mathrm{dist}_{\mathrm{QRCLS}}$$

for each particle $\Psi_t^{(s)}$. Each particle is a representation of the assumed current pedestrian state with an assigned likelihood. An estimated state $\Phi_T^{(s)}$ representing the pedestrian state in the future is derived by looking ahead on the associated trajectories for the current state $\Psi_t^{(s)}$. This results in many hypotheses which are compensated using the mean-shift algorithm. Local densities of a predicted state $\Phi_T^{(s)}$ are estimated by constructing a kernel over each state and iteratively

shift the states towards higher densities using the mean shift vector

$$m_{h,g}(\phi_T^{(s)}) = \frac{\sum_{i=1}^{S} \phi_T^{(i)} w_p^{(s)} g(||\frac{\phi_T^{(s)}-\phi_T^{(i)}}{h}||^2)}{\sum_{i=1}^{S} w_p^{(s)} g(||\frac{\phi_T^{(s)}-\phi_T^{(i)}}{h}||^2)} - \phi_T^{(s)}$$

with $w_p^{(s)} \sim p(\Phi_T^{(s)}|M_{1:t})$ as the weight of a particle, the kernelfunction G(x) with its derivative

$$g(x) = -G'(x)$$ and

the kernel width h. Here we use a Gaussian kernel

$$G(x) = \exp[-\tfrac{1}{2}x^2].$$

By applying the shifting procedure until no particle moves any longer, new cluster centers are derived from the re-weighted members. The hypotheses with the highest weight is chosen as the final predicted state Φ_T^* . The trajectory database contains two classes of trajectory snippets, the class C_s in which the pedestrian is stopping and the class C_w where the pedestrian continues walking. For the predicted object state Φ_T^* derived using cluster members $L = \{\Phi_t^{(l)}\}$ and the corresponding weight $w_p^{(l)}$ the stopping probability is approximated using:

$$p(C_s|L) \approx \frac{\sum_{\Phi_t^{(l)} \in C_s} w_p^{(l)}}{\sum_{\Phi_t^{(l)} \in C_s} w_p^{(l)} + \sum_{\Phi_t^{(l)} \in C_w} w_p^{(l)}}.$$

Performance of the proposed system has been compared to a Interacting Multiple Model Kalman Filter (IMM-KF) and human test subjects. Human estimates of the pedestrian action class outperforms current methods. The proposed system dominate the classification accuracy compared to IMM-KF at all times. An accuracy of 0:8 in classifying the correct pedestrian’s action is reached 570 ms before a possible standstill by the human and 180 ms by the proposed system; it is only reached after the possible standstill with IMM-KF baseline method. Regarding the path prediction accuracy, our system leads to a siginificant lower position error, especially for large prediction horizons, compared to the IMM-KF.

Funding: Daimler AG

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Generative Modeling of Appearance and Shape for Medical Image Analysis

F. Rathke, S. Schmidt, C. Schnörr

The project focuses on classes of image data given by partitions with randomly varying geometry and fixed topology, and with class-specific appearance of each component of the partition. Variational methods will be studied for learning generative model parameters from examples and for tractable inference based on the interaction of respective model components. The application scenario concerns 3D OCT scans of the retina.

Funding: DFG RTG 1653

Variational Models for Image Segmentation with Shape Priors

B. Schmitzer, C. Schnörr

Prior knowledge about the shape of objects constitutes an important cue for image segmentation. Statistical models of shape range from elementary PCA-based models of closed contours to sophisticated shape manifolds that encode shapes in a more invariant way by abstracting from non-intrinsic shape variations. Complementing data-driven approaches to segmentation with shape priors typically result in highly non-convex models that are difficult to handle from the optimization point-of-view. The project will focus on recent progress concerning convex variational relaxations of the segmentation problem and on the inference and learning problem in connection with suitable shape priors represented by graphical models.

Funding: DFG RTG 1653

Research Groups

Advanced Computer Architecture

Application Specific Computer

Accelerated Scientific Computing

High Speed Short Range Interconnects

New Detectors for Scientific and Medical Applications

Next Generation Network Interfaces

Process Control

Dependable Robotics

Virtual Patient Analysis

Advanced Computer Architecture

Holger Fröning[1], Heiner Litz[1], Sven Kapferer[1], Alexander Giese[1], Christian Leber[1], Maximilian Thürmer[1], Federico Silla[2]

[1] University of Heidelberg, Germany *[2] Technical University of Valencia, Spain*

Today's computing landscape is driven by the demand for more computing power together with a trend towards data-intensive computing. Despite the fact that technological advances and architectural improvements steadily increase the amount of computing power, the demands of many applications still cannot be satisfied. Applications like particle physics, biology, genetics, quantum chemistry, fluid mechanics, meteorology or climatology are still computationally bound. Data-intensive applications on the other hand are not primary dependent on computing power, but rather on storage and memory solutions to handle a vast amount of data. The complete computing landscape will become more data-centric and the sheer amount of data demands new techniques to handle this trend. Example applications include Facebook, Twitter, Amazon or Ebay, and many more from the area of scientific computing.

This research group focuses on new and innovative techniques to provide solutions for both compute- and data-intensive applications. In particular we have identified that global address spaces might improve state-of-the-art technologies significantly. However, today architectures either completely aggregate or disaggregate all resources, in particular resources like computing cores and main memory. Message passing systems are prominent examples for overall disaggregation, and coherent shared memory architectures for overall aggregation. Instead, we propose to decouple resources aggregation in a way that the kind of aggregation can be chosen depending on the application. For instance, data-intensive applications might choose to aggregate only main memory, and not computational cores. Another aspect of current research is relaxing consistency in a way that the overhead for coherency protocols can be reduced. This allows to replace current message-passing programming paradigms with shared-memory ones, for an easier programming and more efficient use of parallel computers.

As simulation of large-scale parallel systems quickly results in excessive run times, we gear to rapid prototyping using demonstrators based on commodity parts, but enriched with reprogrammable for customization purposes. We were able to set up a 64-node cluster at the Technical University of Valencia, which incorporates an FPGA-based network including custom network interfaces (Fig. 1). Currently, this cluster serves for experiments in the following research areas:

- Data-intensive applications like in-memory databases
- Techniques to support the Partitioned Global Address Space (PGAS)
- Relaxed consistency models for scalable shared memory systems
- Device-to-device communication
- Low-overhead remote memory allocation and revocation to reduce over-provisioning in datacenters

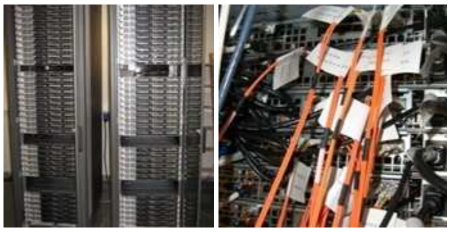

Fig. 1: The 64-node, 1024 core, 1TB prototype cluster with custom interconnection network

First results show the impact of this architecture to memory-constraint applications, in particular to speed up data-intensive calculations dramatically [1] [2] but also to increase the performance of databases by relying on global shared memory without any capacity constraints.

As the research areas of the two involved universities overlap only partially, the research group's expertise covers a broad range, from digital hardware design over interconnection networks, OS and middle-ware software to applications. Thus, the collaboration allows entering new research fields, and to investigate other opportunities to apply research. Furthermore, having a large prototype system is crucial for comprehensive results, offering insights in effects like scalability, congestion and locality.

Supported by grants: Spanish MEC and MICINN, European Comission FEDER funds (CSD2006-00046, TIN2009-14475-C04), Cooperation: Technical University of Valencia

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Application Specific Computers

W. Gao, T. Gerlach, A. Kugel, N. Schroer, A. Wurz

ATLAS is one of four high-energy physics experiments that are operated at the LHC at CERN. The research group is involved in this experiment since 1989 and has developed and built a central component (ROBIN) of the data acquisition system (DAQ) and is presently developing parts of a new readout system for the IBL subdetector [2].

The performance of both PCI and PCIe ROBIN variants are better than the design requirements, however even more performance would be required for new trigger menus, involving e.g. inner-detector scans at high rates.

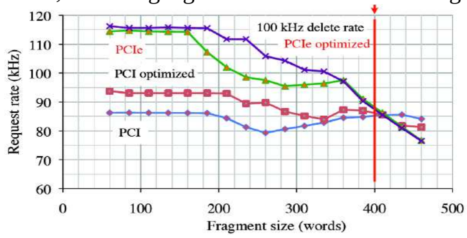

Fig. 1: ROBIN performance (design performance ~ 65 kHz)

A modified design using a 4-lane PCIe interface device has been evaluated, using vendor prototyping hardware. The DMA bandwidth measured when transferring data to the PC is in the order of 800MB/s, sufficient to copy the entire input volume of up to 4 input channels. The decision to build a demonstrator was postponed.

For IBL [1], the detailed design of the ROD/BOC architecture [2][3] was finalized and an initial implementation using commercial prototyping hardware (Fig. 2) was performed.

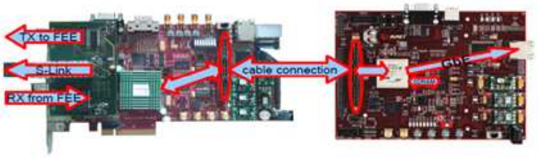

Fig. 2: IBL prototyping hardware

The Active Buffer board (ABB) for the CBM DAQ system has been built up and run in real DAQ environment stably. Subsequent development upon the existed DMA engine includes DPR (dynamic partial reconfiguration) in Virtex5 FPGA, Epoch-Marker indexing and DMA read performance improvement.

DPR is further realized with PlanAhead 12, targeting Virtex5 FPGA. The design flow has been much improved and the experiment is succeeded. An ICAP control program is added to the test library and ICAP_Virtex5 is accessible via software so that the applications can reconfigure the dynamic modules within the top-level framework, as the ChipScope snapshot in Fig. 3. In the new DPR procedure, bus-macros are deprecated and the JTAG configuration cable is not necessary. Boundary decoupling is strongly recommended instead, which still demands pipeline reorganization in the original logic code.

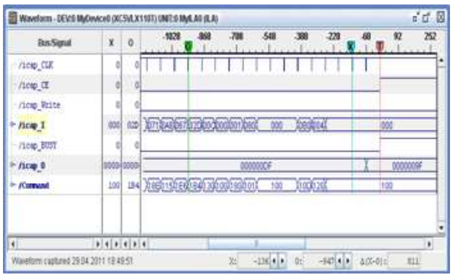

Fig. 3: ICAP access via software

The readout system of the XFEL DSSC detector uses 10G-Ethernet links to send data from the detector to the back-end DAQ system. A prototype card (Fig. 4) was developed to test the basic 10G operation of an FPGA Ethernet solution.

Fig. 4: 10G-Ethernet mezzanie

ATLAS is supported by: BMBF (05H09VHA), Cooperations: CERN, Wuppertal University, NIKHEF (NL), RHUL (UK), INFN Bologna (I)

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Astrophysical Simulations with Special Hardware

Guillermo Marcus, Andreas Kugel, Dzmitry Razmyslosvich

Smoothed Particle Hydrodynamics is a particle method to simulate fluids. The method is based in averaging local density of the fluid into point particles, and computing the interacting forces between neighboring particles. In astrophysics, it is used to simulate gas dynamics and contributes to the system as pressure force and heat. This approximation is very useful with NBODY simulations, which also use particle approximations. After the computation of gravitational forces, gas dynamics are the second most demanding computational task in a simulation, and as such a good candidate for acceleration with special hardware. We developed a library that allows the use of different technologies, like FPGAs and GPUs, to accelerate this task. Compared to a workstation, an FPGA provides 6- 11x speedup, while a GPU provides 24x speedup under the same conditions.

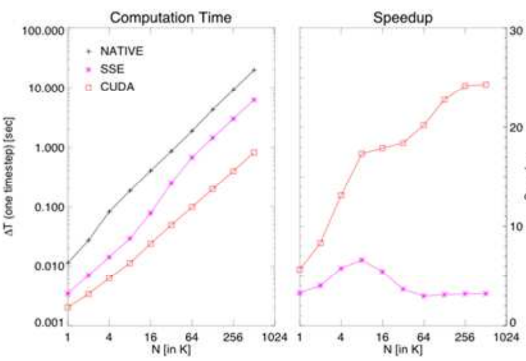

Fig. 1: Computation time and speedup of the SPH fraction for the serial version

In order to make the integration of FPGAs and GPUs into other applications as easy as possible, a set of libraries was developed, providing an abstraction layer to the expected behaviour of the hardware. This layer hides all language- and hardware-specific optimizations, but provides interfaces in C, C++ and FORTRAN for the application level. Hardware-specific optimizations include all supporting libraries to access FPGA specific operations like the *mprace* and *bufmgr*, while language-specific ones cover the coding in CUDA and C++ as well as SSE.

In hardware-related developments, the project include the development of a custom computing board based on FPGAs, the MPRACE2, a floating point library for FPGAs with customizable precision and a pipeline generator for the automatic assembly of complex formulae into pipelined designs. In addition, the necessary software stack for its use was developed for use in Linux systems.

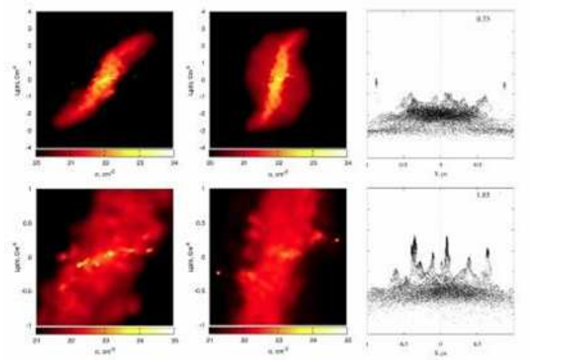

Fig. 2: Sample snapshots from simulations accelerated with special hardware

The project involves strong cooperation with astrophysicists in order to integrate the accelerators into their existing applications like VINE and NBODY6++. In its current extension, the project is focusing on the development of a computing framework for astrophysical applications, with the goal to provide mechanisms and infrastructure for the development of efficient applications in exascale systems.

Supported by: VWF, Cooperations: ARI, ITA, NAS (China), UC-Berkeley (USA). Rainer Spurzem, Peter Berczik, Ralf Klessen, Robi Banerjee, Ingo Berentzen, Hemant Shukla

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Optical high-speed short-range interconnects

D. Wohlfeld, F. Lemke, S. Schenk, H. Fröning, F. Merchán, K.-H. Brenner, U. Brüning

There is a continuously growing demand for optical high-speed, short-range interconnects in applications like networking for high performance computing (HPC) and data centers. One example is the Active Optical Cable (AOC), which combines the advantages of optical transmission and electric connection, encapsulating the electrical-optical conversion inside the connector housing.

The research project focuses on two new methods to couple light from active components into fibers including optimization of the complete fabrication chain to enable low-cost high-volume production. Both methods are based on an integrated 45° mirror and a fiber guide, which is positioned directly above the active component. Figure 1 shows the principle of light coupling: light coming from the VCSEL is deflected from the mirror and coupled into a multi-mode fiber (fig. 1).

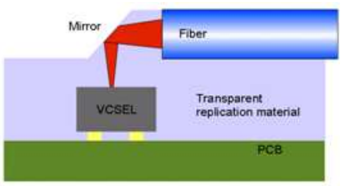

Fig. 1: Light deflection using total internal deflection to couple light from a VCSEL into a multi-mode fiber.

The first coupling method, for which a patent was filed, uses a new direct replication process on top of the active components and total internal reflection [1] while the second approach is based on a replicated micro-coupler with a reflective coating, which is aligned above the active components [2]. Both methods allow compact fiber coupling with high coupling efficiencies. The masters for the replication are fabricated either by UV deep lithography or high precision machining in metal. Using PDMS and UV adhesive, the master form is replicated with high accuracy.

For prototyping, the integrated optical modules were tested directly on FPGA boards, fig. 3, and on a small interposer for an AOC version of the mini-HT connector, fig. 2. The mini-HT connector is specified for up to 150 Gbps using 12 bidirectional links offering two times the area transfer density of a CXP connector and is therefore very attractive for HPC. The interposers were assembled using flip chip technology by the group of Thomas Blank from the KIT. Challenges here were the 50 µm tracks on the interposer and the flip-chip technology using a ball grid array pitch of only 125 µm with two rows of balls. Both requirements are at the edge of FR4 PCB manufacturer and assembler.

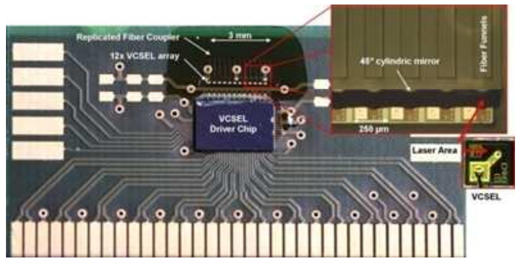

Fig. 2: High-density AOC interposer for the mini-HT connector with a bidirectional bandwidth of 150 Gbps

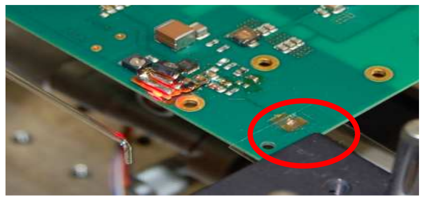

Fig. 3: Micro-coupler alignment above a PCB for video processing

Eye patterns for the optical transmission have been measured up to 3.25 Gbps due to restrictions in the measurement equipment, while all electrical components are specified for up to 12.5 Gbps per channel. A high volume production of mini-HT AOC is planned for the near future.

Supported by: BMBF (03VWP0002), Cooperation: KIT Thomas Blank

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Novel Monolithic Pixel Detectors in HV CMOS Technologies

I. Perić

The implementation of monolithic active pixel sensors (MAPS) for high-energy particles in standard CMOS technologies has gained in popularity. Mechanically simple, relatively cheap pixel detectors with excellent spatial resolution and nearly 100% fill-factor have been designed.
MAPS sensors in its original form have a few limitations, particularly, the charge collection by diffusion is relatively slow and radiation tolerance poor. Further, only NMOS
transistors can be used inside pixels, which limits the in-pixel electronics.
The novel detector concept - high-voltage monolithic detector is implemented in a high-voltage CMOS technology. These technologies are extensively used in industry. The main applications are power management circuits for mobile phones, automotive bus transceivers, printer head-, LCD display- and motor drivers as well as dataline drivers for high speed internet or ”Voice over IP”. High-voltage CMOS technologies allow both the implementation of special transistors capable to generate high-voltage signals (up to 120V) and the integration of standard low-voltage transistors usually used to control the
high-voltage devices.
Especially interesting for our application is the ”floating logic” structure. A group of PMOS and NMOS transistors can be electrically isolated from lightly doped p-type substrate by a high-voltage deep n-well.
Depending on technology used, the deep n-well/p-substrate junction can sustain reverse bias of up to 120V. Typically in
the case of 100V reverse bias a depleted zone of 14 μm thickness is formed. The signals generated in the 14 μm-thick depleted zone are in most cases high-enough for particle detection.
The novel detector is based on two main ideas. The first idea is to use the deep nwell as the signal collection region and the depleted p-substrate/n-well junction as sensor. The second idea is to implement the entire pixel electronics with both PMOS and NMOS transistors inside the deep n-well.
The detectors structure is shown in fig. 1. Since the signal electrons experience strong electric field, they will be collected very fast and a high radiation tolerance can be expected. In this way, using a commercial technology, we implemented a radiation tolerant monolithic detector with the possibility to use both p- and n-channel transistors inside pixels.
Therefore the novel detector concept eliminates almost all drawbacks of the state of the art monolithic CMOS detectors. We will name the novel detector concept: ”Smart Diode Array” or ”SDA”.
In the first project stage, 2006-2009, the development of monolithic detectors in high-voltage technology has been financed by Landesstiftung Baden-Württemberg. The project goal was the proof of the principle. We have designed three test detector matrices and obtained the following experimental results:

Typical MIP single pixel signal is in the range from 1100 e (21 μm × 21 μm pixels) to 1800 e (50 μm × 50 μm pixels) which is typically several times better than in the case of standard MAPS (single pixel signal of 220 e).
Radiation tolerance of up to 50Mrad and 10^{15} neq/cm^2 has been demonstrated, typically by two orders of magnitude better than in the case of standard MAPS.
We have also performed three successful test-beam measurements (DESY and CERN). Detection efficiency was about 98%, spatial resolution around 3 μm (RMS) and seed pixel SNR of 30 (fig 2.).
The results have been published in 6 papers and presented on various conferences and workshops. The detector technology has especially drawn attention in particle physics community and recently (since 2010) we have the first application - the pixel detector for μ -> eee decay experiment at Paul Scherrer Institute in Switzerland. The development of the detector is supported since 2011 by the Enable fund of the Faculty for Physics and Astronomy, University of Heidelberg. Within this project we have successfully tested a detector in new 180nm technology.
Together with our colleagues from CERN we are also evaluating the use of the detector technology for LCH detectors.

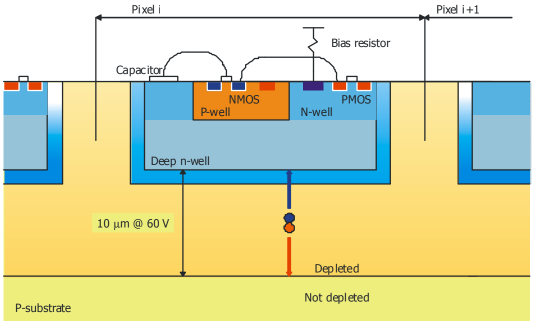

Fig. 1: Smart diode array.

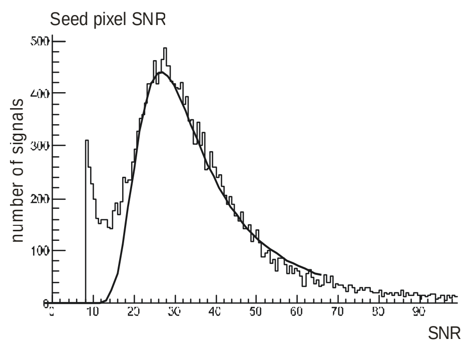

Fig. 2: MIP Spectrum.

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Next Generation Network Interfaces

M. Nüssle, N. Burkhardt, B. Geib, B. Kalisch, A. Giese, C. Leber

In modern computing an increasing amount of parallelisation on all levels from chips to clusters can be observed. The bi-annual list of the 500 fastest computers of the world (www.top500.org) illustrates this. Because of this development, interconnection networks and network interface architectures become increasingly important for modern parallel computer architectures.

The research group "Next Generation Network Interfaces" focuses on a holistic approach to advance the architecture of interconnect solutions in the HPC space. Several activities were conducted within the last year, mainly for the EXTOLL network architecture, which has been developed at the Computer Architecture Group of the ZITI.

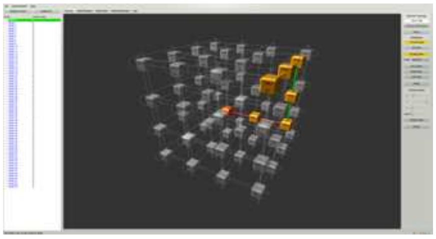

Fig. 1: EXTOLL Management software MEXS.

Within the group, Linux driver software, API libraries, MPI integration and management software for the EXTOLL prototype were developed. Figure 1 shows the managements software MEXS, which enables efficient managing of a 3-d torus EXTOLL network. The software environment and the pre-existing EXTOLL R1 prototype hardware combined within the PEAC cluster (Figure 2) were used to perform extensive performance analysis of the first EXTOLL implementation. To this end well-known benchmark programs like the Intel MPI-Benchmarks, the HPCC Benchmark suite, the SPEC MPI2007 Suite and the Weather Research Forecast (WRF) codes were used. These cover the whole space form micro-benchmarks to complete, complex application codes. Figure 3 shows the performance of WRF in Gigaflop/s for a 12 hour simulation of the continental USA with a spatial resolution of 12 km. The performance of a 128 core cluster with the EXTOLL network and with a commercially available HPC network are shown.

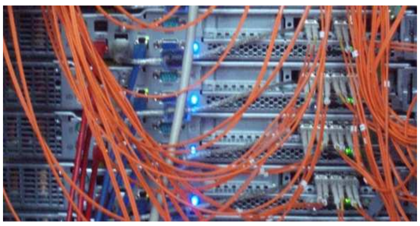

Fig. 2: Detail of some 4 nodes of the PEAC experimental cluster

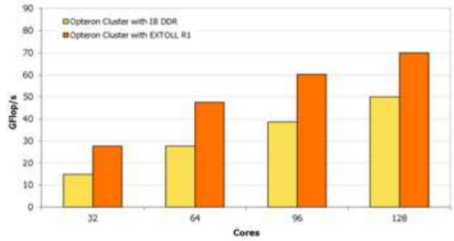

Fig. 3: Weather Research Forecast (WRF) Performance

The results of the performance analysis led to the specification of revision two of EXTOLL after an extensive design space analysis. To optimize performance further the data path has been doubled to 64 bit for the FPGA version and quadrupled for an ASIC version that is currently in development. The Remote-Memory-Access-Unit (RMA) has been completely reworked. Enhancements incorporated include pipelining to decouple the address translation from the packet processing and to reach higher frequencies. Furthermore handling of atomic lock transactions has been vastly improved and new features like byte transfers, a new unified interrupt mechanism and the ability to cross 4kB page boundaries have been added to improve compatibility with a wide range of industry wide used software.

Because of the complexity of the EXTOLL design, a custom verification environment was developed. The environment is based on the Universal Verification Methodology (UVM). UVM offers a complete infrastructure for complex verification projects. Constrained random testing and automatic checking of EXTOLL enabled to find bugs early in the design process. The verification environment also includes a regression suite.

Finally, the group also performed some work in the area of High Frequency Trading (HFT), which has received a lot of attention over the past years and has become an increasingly important element of financial markets. The term HFT describes a set of techniques within electronic trading of stocks and derivatives, where a large number of orders are injected into the market at sub-millisecond round-trip execution times. Within the group work was done to reduce latency as far as possible, as a result the reception of UDP packets can be performed in ~2 us, less than one fourth of the conventional approach. Additional hardware enables processing of complex protocols commonly used in the HFT-ecosystem. In summary, a solution was developed that exhibits world-class performance metrics for HFT applications.

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Process Control Research Group (ProCon)

A. Gambier, A. Kandil, M. Wolf, T. Miksch, Y.G. Lee

Abstract – ProCon is a research group founded in June 2010 with the objective of carrying research in the field of Process Control. In the current year intense efforts have been performed in order to advance the state of the art in at least three main streams. The work was very fruitful. Research activities have been materialized in ten contributions to international conferences, in a website for information interchange and intense review activities.

1. Introduction

The Process Control Group (ProCon) is a research group is dedicated to the modelling, control, supervision and optimization of industrial processes. It was established in the framework of the Institute of Computer Engineering, which has been founded in the Mannheim located division of the Heidelberg University. Its relevant objectives are:

- to develop, experiment and disseminate methods and procedures for the analysis, control and supervision of process control applications, as well as to establish their applicability area. Real problems from industry will be studied, solved and tested, as well.
- to apply for regional, national and international grants in order to support research activities.
- to establish an international cooperation network in order to exchange knowledge, human resources and to apply jointly for international research grants.

The general structure of ProCon is summarized in Fig. 1.

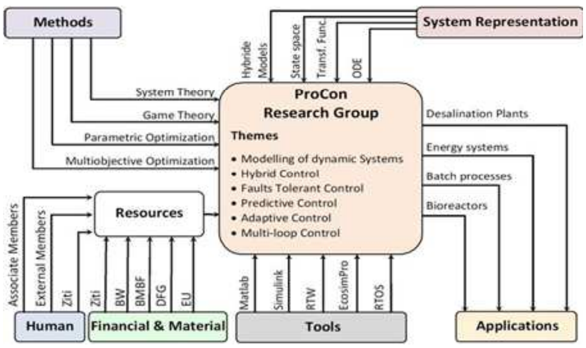

Fig. 1. General structure of the research group ProCon

Thus, the rest of this report is devoted to describe the research activities of the group in its first year of life.

2. Research activities

Research activities of ProCon can be divided in three main streams: Application of multi-objective optimization methods to the control system design (MOOC), Fault-tolerant Control (FTC) and finally, modelling and control of desalination plants powered by renewable energies, i.e. water-energy-cogeneration. In the following, research works in the mentioned areas are presented separately.

2.1 Multiobjective Optimal Control

The increasing requirements of quality for new products and consequently the natural needs of more advanced control systems have led to the introduction of several coupled performance indices. These cost functions have to be fulfilled simultaneously, which in turn involves sophisticated techniques for Multi-Objective Optimization (MOO). All these design techniques are collected together in order to constitute the Multi-objective Optimal Control (MOOC) field. In order to specify this new field proposed by ProCon, an introductory paper was internationally presented ([1]). MOO methods, which can be suitable for control, have been investigated and the results are summarized in [2]. Finally, the concept is successfully applied to design a robust PID controller ([3]).

2.2 Fault-tolerant control system (FTCS) design

A FTCS is defined here as a control system that can work stably with an acceptable degree of performance even though in the presence of component faults. FTCS should detect and accommodate faults avoiding the occurrence of failures, i.e. irrecoverable damages at the system level.

A Model Predictive Controller (MPC) has been developed by using a multi-objective lexicographic optimization algorithm in order to adjust actuator constraints in case of faults. The control algorithm is presented in [4] and applied to control a reverse osmosis desalination plant in [5] and in [6].

2.2 Modelling and control of desalination plants

Water production and power generation are two activities that have to be combined in areas affected by desertification. How to combine water desalting with power generation based on renewable energies was also studied in the group und the results are reported in [8], [9] and [10]. Advanced control systems design requires a dynamical model of the plant. These modelling activities were developed by an external member of the group, who in two opportunities was working in Mannheim supported by the DAAD. This work is summarized in [7].

3. Other activities

In addition to research efforts, other activities are also carried out. In particular a website has been set up not only for inform about ProCon but also as internal support for the research group. The site can be consulted at http://www.rzuser. uni-heidelberg.de/~i56. Moreover, several conferences and journals have been supported by means of review activities. The group provided support to the project Open-Gain (www.open-gain.oeg) organizing the 6th project meeting in Mannheim and writing the final reports, as well.

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Dependable Robotics (DeBot) Group Annual Report 2010

A. Wagner, A. Kandil, S. Rady, L. Zouaghi

This report summarizes the results of the Dependable Robotics Group from June to December 2010, which have been worked out together with partners from universities and industry.

One field of research within the group is concerned about the monitoring of control systems[1]. An approach for hybrid monitoring of lower level actions for dependable (mobile) control systems including closed-loop control was worked out in [1]. The method is based on the consideration of both discrete and continuous aspects within a single unified framework by combining Petri-net and numerical filter theory. The model uses a specification of the desired system behaviour during the system design in order to deliver an on-line estimation of the current system state. To show the feasibility of the results, the method was applied to an intelligent wheelchair as an example of a mobile robot platform. Such system can be best represented by hybrid models and presents a number of interesting new challenges for dependability monitoring and diagnosis methodologies, which could be easily generalized to any autonomous mobile robot.

In [2], a generic system architecture for dependable interactive systems has been proposed[1]. The architecture is an extension of the behavior-based recursive control structure, which has already been applied successfully to robotic applications. The interaction between multiple robots or between a human user and robotic systems takes place on multiple behavioral levels providing fixed interfaces. A complex system is decomposed into levels according to the dynamics of behaviors and bandwidth of the interfaces. Signals from and to multimodal interface devices are processed according to the behavior-related information contents and fused within the behavior levels. The usage of the generic system architecture is demonstrated on the example of a semi-autonomous flying robot.

Environmental modelling and hierarchical robot localization have been investigated in a further project [3, 4]. Hierarchical localization provides both topological and quantitative metric solutions, with faster performance for the latter since the searchable space is minimized. The first [4] hierarchical localization approach primarily focuses on the efficiency of the topological module. The approach utilizes a minimal set of qualitative entropy-based local features, which achieves both speed and localization accuracy. The abundant features are triangulated in a next step using a photogrammetric projective model to obtain a metric solution. The metric localization selects only the correct matches by regarding a simple yet efficient distance measure to overcome problems of data association and environment dynamics (fig. 1).

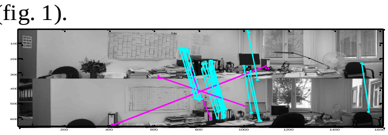

Fig. 1: Detection of mismatches and environment dynamics through spatial layout.

The information-theoretic environment modelling approach was validated using the COLD database [4], a recent specific benchmarking database for robotic topological mapping and localization. The evaluation has proved the efficiency in obtaining accurate localization with less complexity.

In the project CYCLOBOT[2], the control of a bone mounted surgical robot based on epicyclic kinematics (fig. 2) has been investigated. First results related to the 6-degrees-of- freedom position control of the functional EPIZACTOR prototype have been published in [5]. Test trajectories demonstrate the feasibility of the construction according to the requirement of complex task in orthopedic surgery.

Fig. 2: Functional prototype EPIZACTOR of the epicyclic surgical robot.

[1] *Project ECOMODIS – Efficient Component-Based Design of Dependable Computing Systems, Ministry for Science, Research and Art, Baden-Württemberg..*

[2]*Project CYCLOBOT- Erforschung des Gesamtverhaltens einer neuen Hybridkinematik in einem robotischen Werkzeug für knochenchirurgische Anwendungen, German Research Foundation.*

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Medical Training Simulators Based on Virtual Reality

F. Beier, N. Hüsken, O. Schuppe, E. Sismanidis

Surgical operations are often complex and potentially dangerous procedures. Only well trained and experienced surgeons are able to perform these interventions successfully. Surgical skills are usually acquired by assisting and by operating under the supervision of more experienced surgeons. Another possibility to improve surgical skills is the training on plastic models, on animals, or cadaver preparation. However, these methods lack realism or endanger patients' lives. Consequently, there is an urgent need for an efficient training environment that is realistic but does not depend on human beings or animals.

Virtual reality (VR) can be used in order to implement such a training system. Apart from the fact that VR simulators do not involve human beings, they offer several advantages: Surgical tasks are reproducible and can be trained at any time, even if the medical case is rare. The surgeons' skills are measured objectively and the result can be compared to other users.

Fig. 1: NeuroSim

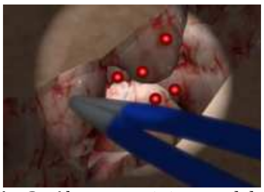

Fig. 2: Abstract training module

In order to implement a medical training simulator, several requirements have to be met: The interface between the user and the simulator has to be as native as possible in order to generate immersion. The simulation of biological tissue and medical instruments has to be realistic. Everything has to be done in realtime, leading to huge demands on the hardware as well as on the algorithms.

Current research of the ViPA group focuses on two simulators: NeuroSim for cerebrovascular surgery and MicroSim for microsurgical interventions.

NeuroSim uses original instruments and a real surgical microscope (see figure 1). The microscope is tracked by an optical tracking system. For the tracking of the instruments, a sensorfusion between inertial and optical tracking methods is used. The first training module features an abstract task in order to train basic skills (see figure 2). The software design is modular, so further tasks like aneurysm clipping can be added. The simulator was introduced at MMVR18 [1] in 2011. Current research focuses on a medical training module in order to simulate the clipping of a brain aneurysm.

Fig. 3: Simulated thread

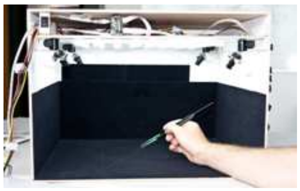

Fig. 4: Tracking system

MicroSim is a simulator for microsurgical tasks that are done by using a microscope. Original instruments are used and tracked by an optical tracking system (see figure 4). A markerbased setup is implemented [2], a markerless approach is in development. The simulation of virtual tissue and vessels uses realtime mass-spring algorithms and is based on tetrahedron models. Methods for tearing and cutting as well as algorithms for the simulation of suture material (see figure 3) have been developed [3]. As a first training module, the preparation and the suturing of blood vessels is currently being developed.

Both simulators are developed in cooperation with the VRmagic GmbH in Mannheim. NeuroSim is supported by Leica Microsystems GmbH and developed in cooperation with the Department of Neurosurgery (Medical Faculty Mannheim, University of Heidelberg). MicroSim is supported by the BMWI (2351202SS9).

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Data

Members and Staff

Third Party Funded Projects

Project Partners

Publications

Patents

Colloquia and Conferences

Members and Staff

Professors

Last Name	Name	Chair
Badreddin	Essameddin	Automation
Brenner	Karl-Heinz	Optoelectronics
Brüning	Ulrich	Computer Architecture
Fischer	Peter	Circuit Design
Männer	Reinhard	Computer Science
Schnörr	Christoph	Computer Vision, Graphics and Pattern Recognition

Secretaries

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Feldmann	Marlis	Computer Architecture
Fischer	Ursula	Automation
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Seeger	Andrea	Computer Science V
Volk	Sabine	Optoelectronics
Wilhelm	Evelyn	Computer Vision, Graphics and Pattern Recognition
Wunsch	Beate	Circuit DesignCircuit Design

Ph.D. Candidates and Research Assistants

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Alexopoulos	Alexander	Automation
Armbruster	Tim	Circuit Design
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Auer	Johannes	Computer Science V
Bakulina	Alena	Computer Science V
Bartolein	Christian	Automation
Becker	Florian	Computer Vision, Graphics and Pattern Recognition
Beier	Florian	Computer Science V
Berentzen	Ingo	Computer Science V
Bickel	Martin	Computer Architecture
Blecher	Wolf	Computer Science V
Böttcher	Patrick	Computer Science V
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Breitwieser	Oliver-Julien	Computer Science V
Brock	Alexander	Automation
Burkhardt	Niels	Computer Architecture
Buschlinger	Robert	Optoelectronics
Del Galdo	Andreas	Automation
Diederich	Stephan	Computer Science V
El-Shenawy	Ahmed	Automation
Enzweiler	Markus	Computer Vision, Graphics and Pattern Recognition
Erdinger	Florian	Circuit Design
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Gambier	Adrian	Automation
Ganter	Axel	Circuit Design
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Geppert	Dina	ZITI

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Gosch	Christian	Computer Vision, Graphics and Pattern Recognition
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Hepp	Sebastian	Computer Science V
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Kandil	Amr	Automation
Kapferer	Sven	Computer Architecture
Kappes	Jörg	Computer Vision, Graphics and Pattern Recognition
Karim	Rezaul	Computer Vision, Graphics and Pattern Recognition
Keller	Christoph	Computer Vision, Graphics and Pattern Recognition
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Krupitzer	Christian	Automation
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Kurz	Steffen	Computer Architecture

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Lehmann	Lars	Circuit Design
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Leys	Richard	Computer Architecture
Leys	Richard	Computer Architecture
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Yuan	Jing	Computer Vision, Graphics and Pattern Recognition
Zouaghi	Leila	Automation

Third-party-funded Projects

Research at ZITI is funded by various national and international programs and sponsors. On an average, ZITI obtained more than € 2.5mn funding per year between 2008 and 2010.

Funding by	Project Title	Funding Amount	Funding Period	Chair
AIF	Pro INNO ITD Moscot	61.000 €	2006 - 2009	Automation
AIF	Pro INNO ITD Moscot	80.029 €	2008 - 2010	Computer Science V
Altera, AMD, SRC	Forschung und Entwicklung von Referenzdesign für HTX3 Connector mit neuartigem HT 3.0 core	11.234 €	2008 - 2009	Computer Architecture
AMD	HyperTransport Center of Excellence	186.365 €	2006 - 2009	Computer Architecture
BMBF	ATLAS Experiment - Physik auf der TeV-Skala am Large Hadron Collider	367.320 €	2006 - 2009	Computer Science V
BMBF	ATLAS: Betrieb, Wartung und Entwicklung von HLT/DAQ-Komponenten	338.722 €	2009 - 2012	Computer Science V
BMBF	FAIR-CBM: Front End Electronic	565.000 €	2006 - 2009	Computer Science V
BMBF	ViroQuant	187.121€	2007-2011	Optoelectronics
BMBF	CBM Data Acquisition at FAIR	245.000 €	2009 - 2012	Computer Architecture
BMBF	DEPFET - Pixeldetector für ILC	331.320 €	2006-2009	Circuit Design
BMBF	FORSYS-VIROQUANT - Systembiologie von Virus-Zell-Interaktionen	296.240 €	2007-2011	Circuit Design
BMBF	SUPER BELLE - Auslesechips und Bumping für den DEPFET Vertexdetektor bei SuperBelle	290.360 €	2009-2012	Circuit Design
BMBF	FAIR-CBM - Front End Elektronik	260.000 €	2009-2012	Circuit Design
BMBF GSI	FAIR-CBM - Front End Elektronik	274.454 €	2006 - 2009 2007-	Circuit Design

			2009	
BMBFG	Viroquant	181.183 €	2008 - 2010	Computer Science V
BMWi	HD - Active-Optical-Cable	38.979 €	2010 - 2011	Computer Architecture
BMWi	Entwicklung eines auf Virtueller Realität basierenden Trainingssimulators für mikrochirurgische Eingriffe (MicroSim)	175.000 €	2009 - 2011	Computer Science V
BMWi	EXIST Forschungstransfer: EXTOLL - Innovative skalierbare Hochleistungs-Rechnersysteme	383.856 €	2010 - 2012	Computer Architecture
Daimler AG	Sensorbasiertes Fahrerassistenzsystem zur vorausschauenden Erkennung und Verfolgung von Fußgängern und Radfahrern	25.000 € + vat	2010 - 2010	Computer Vision, Graphics and Pattern Recognition
Daimler Chrysler	Sensorbasiertes Fahrerassistenzsystem zur vorausschauenden Erkennung und Verfolgung von Fußgängern und Radfahrern	210.000 € + vat	2007 - 2010	Computer Vision, Graphics and Pattern Recognition
Daimler Chrysler	Sensorbasiertes Fahrerassistenzsystem zur vorausschauenden Erkennung und Verfolgung von Fußgängern und Radfahrern	127.750 €	2006 - 2010	Computer Vision, Graphics and Pattern Recognition
DESY / ESRF	XNAP - Development of an APD 2D Pixel Array Detector	256.400 €	2009 - 2011	Circuit Design
DESY / MPE	XFEL-Projekt DESY/DAQ	100.562 €	2009 - 2012	Computer Science V
DFG	Cyclobot	171.000 €	2009 - 2011	Automation
DFG	Mercator	123.146 €	2010 - 2011	Automation
DFG	Komponentenbasierte konvexe Trennung und Schätzung von Bewegungen in Bildfolgen	1 BATIIa/E13 (100 % pos.) 1 student assistant	2007 - 2009	Computer Vision, Graphics and Pattern Recognition

		for 8 h/week		
DFG	Globale Variationsansätze zur Vektorfeldberechnung mit physikalischem Vorwissen	1 BAT IIa/E13 (100 % pos.) 4.000 €	2007 - 2009	Computer Vision, Graphics and Pattern Recognition
DFG	3D-Tomographie mit wenigen Projektoren in der experimentellen 3 D-Strömungsmessung	1 BAT IIa/E13 (100 % pos.) 3.600 €	2007 - 2009	Computer Vision, Graphics and Pattern Recognition
DFG	3D-Tomographie mit wenigen Projektoren in der experimentellen 3 D-Strömungsmessung	1 BAT IIa/E13 (100 % pos.) 25.900 €	2010 - 2012	Computer Vision, Graphics and Pattern Recognition
DFG	Graduiertenkolleg 1653/1Spatio/Temporal Graphical Models and Applicationsin Image Analysis	585.000 €	2010 - 2014	Computer Vision, Graphics and Pattern Recognition
DFG + Industrie	Heidelberg Collaboratory for Image Processing (HCI)	1.675.589 €	2008 - 2012	Computer Vision, Graphics and Pattern Recognition
Dolphin Numascale	High Performance Computing and Cluster Interconnects	75.474 €	2007 - 2010	Computer Architecture
EU	Open-Gain	1.300.000 €	2007 - 2010	Automation
EU	Visiontrain	292.206 €	2005 - 2009	Computer Vision, Graphics and Pattern Recognition
EU	FutureDAQ	22.640 €	2008	Computer Science V
EU	EUDET - Detector R&D Towards the International Linear Collider	87.760 €	2006-2010	Circuit Design
EU	HYPERImage - Hybrid PET-MR system for concurrent ultra-sensitive imaging	645.185 €	2008-2011	Circuit Design

EU	SUBLIMA - SUB nanosecond Leverage In PET/MR ImAging	1.000.250 €	2010-2014	Circuit Design
Google Inc.	Efficient high speed flash memory without flash translation layer overhead	41.747 €	2010 - 2011	Computer Architecture
GSI	Front End Elektronik, schnelles Kommunikationsnetzwerk	161.648 €	2008 - 2010	Computer Science V
Helmholtz-Gemeinschaft / DESY	Physics Terrascale	60.000 €	2010-2014	Circuit Design
IMC Trading B.V.	Accelerated Computing using FPGAs	264.803 €	2009 ongoing	Computer Architecture
Jäger, MSC, Kuroda	Test und Inbetriebnahme von HTX-Boards (Anwendung gesicherter Erkenntnisse - AgE)	51.105 €	2009 ongoing	Computer Architecture
Land BW	Ecomodis	101.076 €	2008 - 2009	Computer Science V
Land BW	Xenon	33.930 €	2008 - 2009	Computer Science V
Landes-stiftung BW	Eliteprogramm für Postdoktoranden Monolithischer Pixeldetektor	39.000 €	2006-2008	Circuit Design
Philipps	Extraktion robuster invarianter Bildmerkmale aus gr.Datenbanken mediz. Bilddaten (MRI) CT)	1 BAT IIa/E13 (100 % position) + 5 % overhead	2005 - 2008	Computer Vision, Graphics and Pattern Recognition
Schooner	Forschung zu Hochgeschwin-digkeitsnetzwer-ken und nicht-flüchtigen Speichermedien	450.000 €	2007 - 2009	Computer Architecture
Landes- stif-tung BW	Ecomodis	1.200.000 €	2006 - 2010	Automation
SUN	Entwicklung Clustersystem mit einer Kommunikationsrichtung mit sehr geringer Latenz	370.276 €	2007 - 2009	Computer Architecture
Technische Universität Valencia	High performance, reliable architectures for data centers and internet servers	127.194 €	2007 - 2010	Computer Architecture
VMT	Bildverarbeitungsalgorithmen im Zusammenhang mit der Steuerung u. Regelung von Robotern in der industriellen	66.600 €	2006-2009	Computer Vision, Graphics and Pattern Recognition

	Produktion			
VW	GRACE	66.891 €	2008	Computer Science V
VW	GRACE II	60.000 €	2009 - 2010	Computer Science V
XFEL GmbH	XFEL - Development of a Large Format X-ray Imager with Mega-Frame Readout Capability based on the DEPFET Active Pixel Sensor	1.024.600 €	2009-2012	Circuit Design

Project Partners

Company/Institution	Location	Chair
AAST (Arab Academy of Science and Technology)	Alexandria / Ägypten	Automation
American University of Beirut (AUB)	Beirut / Libanon	Automation
Belle-II Collaboration	KeK / Japan	Circuit Design
Bonn University	Bonn	Circuit Design
CERN	Geneva / Switzerland	Circuit Design
Daimler AG	Sindelfingen	Automation
DESY	Hamburg	Circuit Design
ESRF	Grenoble / France	Circuit Design
Diverse europäische Universitäten im Rahmen des EU-Projekts IntelliCIS		Automation
Fondazione Bruner Kessler	Trento / Italy	Circuit Design
Fraunhofer-Institut für Nachrichtentechnik Heinrich-Hertz-Institut	Berlin	Optoelectronics
GSI	Darmstadt	Circuit Design
Honda Research Institute Europe GmbH	Offenbach	Automation
IBM	Böblingen / Zürich	Optoelectronics
IFIC, University of Valencia	Valencia / Spain	Circuit Design
King's College	London / UK	Circuit Design
Klinik für Neurochirurgie, Medizinische Fakultät der Universität Heidelberg	Mannheim	Computer Science V
KSB AG	Frankenthal	Automation
Kyoto University	Kyoto / Japan	Automation
LEONI Fiber Optics GmbH	Waghäusel	Optoelectronics
MPI Semiconductor Laboratory	Munich	Circuit Design
MWM GmbH	Mannheim	Automation
Otto Bock Mobility Solutions GmbH	Königsee	Automation

Philips Medical	Aachen	Circuit Design
Polytechnico di Milano	Milano / Italy	Circuit Design
SMOS-Smart Mikrooptical Solutions	Walldorf / Mannheim	Optoelectronics
Technical University Delft	Delft / The Netherlands	Circuit Design
Technische Universität	Chemnitz	Computer Architecture
Technische Universität	Karlsruhe	Computer Architecture
Technische Universität Valencia	Valencia / Spanien	Computer Architecture
University of Castilla-La Mancha	Castilla-La Mancha/ Spanien	Computer Architecture
VRmagic GmbH	Mannheim	Computer Science V

Publications

Chair for Automation

2010

- Gambier, A., T. Miksch and E. Badreddin, Fault-tolerant supervisory control of a reverse osmosis desalination plant powered by renewable energies. Proceeding of the22nd European Modeling and Simulation Symposium (Simulation in Industry), (EMSS 2010), Fes, October 13-15, 2010.
- Gambier, A., T. Miksch and E. Badreddin, Fault-tolerant Control of a small reverse osmosis desalination plants with feed water bypass. Proceeding of the American Control Conference, 3611-3616, Baltimore, June 30-July 2, 2010.
- Jipp, M., S. Kloess, M. Wolf and E. Badreddin, Comparative performance assessment of path-planning for autonomous mobile robots using structured intelligence. Proceeding of the 2009 IEEE Conference on Control Applications (CCA 2010), 1251-1256, Yokohama, September 8-10, 2010.
- Kandil, A., W. Wagner, A. Gotta and E. Badreddin, Collision avoidance in a recursive nested behaviour control structure for unmanned aerial vehicles. Proceeding of the IEEE International Conference on Systems, Man, and Cybernetics, SMC2010, 4276-4281, Istanbul, October 10-13, 2010.
- Kandil, A., A. Gambier and E. Badreddin, Optimal design for water and power co-generatin in remote areas using renewable energy sources and intelligent automation. Proceeding of the 22nd European Modelling and Simulation Symposium (Simulation in Industry), (EMSS 2010) 165-167, Fes, October 13-15, 2010.
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- Lee, Y. G., A. Gambier, E. Badreddin, und J. H. Kim: “A dynamic model for the control of a seawater reverse osmosis desalination process Proceeding of the EuroMed 2010 Conference, Tel Aviv, October 3-6, 2010.
- Miksch, T., A. Gambier and E. Badreddin. Fault-tolerant control of a reverse osmosis plant basedon MPC with lexicographic multiobjective optimization. Proceeding of the 2009 IEEE Conference on Control Applications (CCA 2010), 1045-1050, Yokohama, September 8-10, 2010.
- Rady, S., A. Wagner and E. Badreddin, Building efficient topological maps for mobile robot localization: An evaluation study on COLD benchmarking database. Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS10), 542-547, Taiwan, October, 2010.
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- Rady, S., and E. Badreddin, Information-theoretic environment modeling for efficient topological localization. Proceedings of the 10th IEEE International Conference on Intelligent Systems Design and Applications (ISDA10), 1042-1046, Cairo, November 29 - December 1, 2010.

- Wagner, A., M. Jipp, A. Kandil, C. Eck and E. Badreddin, Generic system architecture for dependable interactive systems: A flying robot example. Proceedings of the IEEE International Conference on Systems, Man and Cybernetics, Istanbul, October 10-13, 2010.
- Zouaghi, L., A. Wagner and E. Badreddin, Hybrid, recursive, nested monitoring of control systems using Petri nets and particle filters. Proceedings of the 40th Annual IEEE/IFIP International Conference on Dependable Systems and Networks (DSN 2010), 73-79, Chicago, June 28 - July 01, 2010.

2009

- Bartolein, C., A. Wagner, M. Jipp and E. Badreddin, Dependable design for assistance systems: Electrical powered wheelchairs. Extended abstract in Workshop on the Design of Dependable Critical Systems, Hamburg, 2009.
- Gambier, A., A. Wellenreuther, E. Badreddin, Control system design of reverse osmosis plants by using advanced optimization techniques. Desalination and Water Treatment. Vol. 9, in press, 2009.
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- Gambier, A., T. Miksch and E. Badreddin, A reverse osmosis laboratory plant for experimenting with fault-tolerant control. Proceeding of the2009 American Control Conference, 3775-3780, Saint Louis, June 10-12, 2009.
- Gambier, A., and E. Badreddin, Control of small reverse osmosis desalination plants with feed water bypass. Proceeding of the 2009 IEEE Conference on Control Applications, 800-805, Saint Petersburg, July 8-10, 2009.
- Jipp, M., C. Bartolein, A. Wagner and E. Badreddin, The impact of individual differences in fine motor abilities on wheelchair control behavior and especially on safety-critical collisions with objects in the surroundings. Extended abstract in Workshop on the Design of Dependable Critical Systems, Hamburg, 2009.
- Jipp, M., C. Bartolein and E. Badreddin, The role of task and situational characteristics on the dependability of human-technology interaction. Extended abstract in Workshop on the Design of Dependable Critical Systems, Hamburg, 2009.
- Kandil, A. A., E. Badreddin, A new method for direct and point-to-point robot trajectory planning in narrow spaces. Proceeding of the 3rd IEEE Multi-Conference on Systems and Control, Saint Petersburg, 1738-1743, July 8-10, 2009.
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- Zouaghi, L., A, Wagner and E, Badreddin, Hierarchical hybrid monitoring for autonomous systems, extended abstract, accepted by Workshop on the Design of Dependable Critical Systems, Extended abstract in Workshop on the Design of Dependable Critical Systems, Hamburg, 2009.
- Zouaghi, L., M. Koslowski, A. Alexopoulos, F. Barth, M. Jipp, R. Fajardo, Y. Luo, A. Wagner and E. Badreddin, Dependable component-based design on the Example of a Heating Control System. Extended abstract in Workshop on the Design of Dependable Critical Systems, Hamburg, 2009.

2008

- Bartolein, C., Wagner, A., Jipp, M., & Badreddin, E. (2008). Easing wheelchair control by gaze-based estimation of intended motion. Proceedings of the IFAC World Congress, 17, 9162-9167.
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- Frank Lemke, David Slogsnat, Niels Burkhardt, Ulrich Bruening A Unified DAQ Interconnection Network with Precise Time Synchronization IEEE Transactions on Nuclear Science (TNS), Journal Paper, VOL. 57, No. 2, APRIL 2010.
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- Frank Lemke, David Slogsnat, Niels Burkhardt, Ulrich Bruening A Unified Interconnection Network with Precise Time Synchronization for the CBM DAQ-System 16th IEEE NPSS Real Time Conference 2009 (RT 09), May 10-15, Beijing, China.
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- Benjamin Kalisch, Alexander Giese, Heiner Litz, Ulrich Brüning HyperTransport 3 Core: A Next Generation Host Interface with Extremely High Bandwidth First International Workshop on HyperTransport Research and Applications (WHTRA), February 12th, Mannheim, Germany.
- Jose Duato, Federico Silla, Brian Holden, Paul Miranda, Jeff Underhill, Mario Cavalli, Sudha Yalamanchili, Ulrich Brüning and Holger Fröning Scalable Computing - Why and How HyperTransport Consortium White Papers, 2009.
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- David Slogsnat, Alexander Giese, Mondrian Nüssle, Ulrich Brüning An Open-Source HyperTransport Core ACM Transactions on Reconfigurable Technology and Systems (TRETS), Vol. 1, Issue 3, p. 1-21, Sept. 2008.

Patents

Name	Date of Submission	Chair
Über optische Verbinder und dessen Herstellung UHD07a, DE 10 2010 018 248.6	23.04.2010	Optoelectronics
Vorrichtung und Verfahren zur Strahlungskonzentration AZ PCT/EP2010/006070	05.10.2010	Optoelectronics
Erfindungsmeldung "Hardware Einheit für die Verarbeitung von Protokollen mit unabhängiger Fortschrittssteuerung"	14.12.2009	Computer Architecture
Patentanmeldung "Über optische Verbinder und deren Herstellung" Nr. 10 2010 018 248.6	23.04.2010	Computer Architecture
Method for generating and/or imprinting a retrievable cyptographic key during the production of a topographic structure US Patent Publication No. US2009/0304181 A 1		Circuit Design

Colloquia and Conferences

Title	Place	Date	Chair
Workshop Hardware, Software and Human Factors in Dependable System Design	Hamburg (SAFECOMP)	15.09.2009	Automation
Ecomodis-Workshop: Entwurf verlässlicher Computersysteme	Mannheim	04.11.2009	Automation
Open-Gain Workshop	Mannheim	14.-15.07.2010	Automation
European Conference of Computer Vision	Marseille, France	October 12-18, 2008	Computer Vision, Graphics and Pattern Recognition
International Conference of Computer Vision	Kyoto, Japan	September 29-October 2, 2009	Computer Vision, Graphics and Pattern Recognition
European Conference of Computer Vision	Crete, Greece	September 6-9, 2010	Computer Vision, Graphics and Pattern Recognition
Second Symposium of the HyperTransport Center of Excellence and the First International Workshop on HyperTransport Research and Applications	Institut für Technische Informatik (ZITI) in Mannheim	11. - 12.02.09	Computer Architecture
International Workshop on DEPFET Detectors and Applications	Heidelberg	10.-12.09.2008	Circuit Design