Electrical Energy Education and Research

Energy Curriculum

“From Matlab Simulink to Practical Results in Minutes”

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Introduction: Jens Onno Krah 1


- 1988 – 1993 Ph.D. – team of Prof. Holtz
- 1993 – 1996 Post Doc at University Wuppertal

Prof. Joachim Holtz
Introduction: Jens Onno Krah 2

- 2000 – 2004 R&D Manager: Danaher Motion

Permanent Magnet Motor
Advanced Kollmorgen Motor

Danaher Servo Drive
ServoStar 300
Introduction: Jens Onno Krah 3

Since 2004: Professor for control theory at the Cologne University
Research: Motor control & digital signal processing with FPGA

Team: 7 Eng., 2 Master thesis and 14 diploma thesis

8000 eng. Students
~ 90 % Bachelor (diploma)
~ 10 % Master
~ 1 % PH. D. (in Co.)
Germany: Students are striking

Diploma -> Bachelor & Master
Integrating Students in Research ... break down in small blocks.

All complex projects are more or less build by using modular building Bloks (like LEGO)
Building Bloc 1: Computing Algorithms

(Industrial)  
Personal  
Computer = [intel] + [AMD]  

+ Well known by every student  
+ Excellent – floating point – computing power per $  
– PC (was) not real time
Building Bloc 2: System Modulation and Simulation

+ Fast design entry
+ Excellent simulation
+ Most eng. students learn during their education
+ Real time workshop (with FPU)
  – Interface to hardware (was) expensive
Building Bloc 3: IGBT Inverter

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+ One control card from < 1 kW ... > 1 MW
+ 3 ~ closed loop hall current measurement
+ High volume manufacturer
+ Every student can install and set up

– Power stage (was) not free programmable
+ Most common Real Time Ethernet for Motion Control
+ Extremely fast (50µs) due to the summing frame structure
+ The **EtherCAT** slave devices read the data addressed to them while the frame passes through the node
+ Similarly, input data is inserted while the telegram passes through
+ up to 180 Mbit per second (full duplex fast Ethernet)
Building Bloc 5: EtherCAT® I/O Bus Terminal

+ The Beckhoff I/O system supports about 400 Bus Terminals
+ Extremely fast (50µs) due to the EtherCAT interface
+ The Beckhoff Bus Terminals have been tried and tested in a wide range of sectors worldwide, from machine construction to building management.
+ Beckhoff Bus Terminal technology makes design, wiring and maintenance of equipment very cost-effective.
Building Bloc 6: Field Programmable Gate Array (FPGA)

+ Extremely fast due to parallel computing (VHDL)
+ Processing of feedback units: Encoder / Resolver
+ 6 ~ Pulse Width Modulation (PWM)
+ 3–Level Inverter (Wind power – PV)
+ Fieldbus connectivity – EtherCAT IP
+ Handling of ΣΔ ADC
– Not much internal RAM
Building Bloc 7: TwinCAT \[\text{PC} \rightarrow \text{real-time controller}\]

+ TwinCAT turns almost any compatible PC into a real-time controller
+ open: utilizes compatible PC hardware
+ embedded IEC 61131-3 software PLC, software NC and software CNC in Windows NT/2000/XP/Vista, Windows 7, NT/XP Embedded, CE
+ programming and run-time systems optionally together on one PC or separated
+ data communication with user interfaces and other programs by means of open Microsoft standards (OPC, OCX, DLL, etc.)
  – Version 3.0: direct Matlab Simulink Interface (new)
Building a Motor Control System for University purposes - step 1

1. Take the Altera / EBV Cyclone III evaluation board (www.ebv.de)
2. Take off all parts we do not need (USB, CAN, 24 V I/O, …)
3. Add $\Sigma\Delta$ ADC1204 from Texas Instruments
4. Add Danfoss power stage interface
5. Design a PCB with the dimensions of the Danfoss control card
6. Add motor control VHDL IP (PWM, current measuring …)
7. Add EtherCAT (Real Time Ethernet) fieldbus IP
8. Replace the original control card of the frequency inverter
Building a Motor Control System for University purposes - step 2

Hardware Setup

1. Connect motor and drive
2. Connect fieldbus (EtherCAT)
   PC: second Ethernet adapter (for example Intel Pro)
3. Connect optional Input, Output & motor feedback

PC (for example Dell)  Danfoss Drive with FPGA control board from University Cologne

Beckhoff I/O

Motor (with feedback)
Building a Motor Control System for University purposes - step 3

Software Setup

1. Install TwinCAT
2. Install real time Ethernet adapter driver
3. Configure the system with the TwinCAT System Manager
4. Create control loop software …
Take advantage of the superior development environment

1. On-Line variable read and modify
2. Multi-channel software scope
3. Gflops computing power (Intel CPU)
4. Utilize Microsoft interface standards (OPC, OCX, DLL, etc.)
Building a Motor Control System for University purposes - EtherCAT Timing

- EtherCAT "Read I/O"
- TwinCAT Control Algorithm RT Task
- EtherCAT "Write I/O"
- DC Event Sync
  Read: S&H
  Write: Latch
- VHDL PWM

Request

8 MHz Clock Burst

Distributed Clock Offset

XFC EtherCAT Cycle Time (62.5 µs)
Building a Motor Control System for University purposes – Design flow

Real Time Workshop

Visual C++

TwinCAT IDE

TwinCAT real time Task

TwinCAT Soft Scope

MATLAB Simulink

Real Time Workshop

Visual C++

TwinCAT IDE

TwinCAT real time Task

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Building a Motor Control System for University purposes – Building Blocks

- TwinCAT
- EtherCAT
- MATLAB Simulink
- FPGA
- Real Time Workshop
- Visual C++
- TwinCAT IDE
- TwinCAT real time Task
- TwinCAT Soft Scope

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Automated table soccer (one side)
8 PM motors with PC / FPGA control
Build by 3 undergraduate students in 6 month
Conclusion:

- Standard power electronics with high computing power and Matlab Simulink tool chain interface
- Motor Control is going to be free programmable with reasonable effort
- High quality industrial components for reasonable cost
- Utilized building blocks:
  1. PC technology (Intel CPU + Windows XP)
  2. Matlab Simulink
  3. Danfoss frequency inverter (power electronics)
  4. EtherCAT the real time Ethernet Fieldbus
  5. Beckhoff I/O bus terminal technology
  6. Field Programmable Gate Array (FPGA) from Altera
  7. TwinCAT real time automation software system

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