Control System Architecture of the JCNS Neutron Instruments

September 25th, 2018 | Harald Kleines

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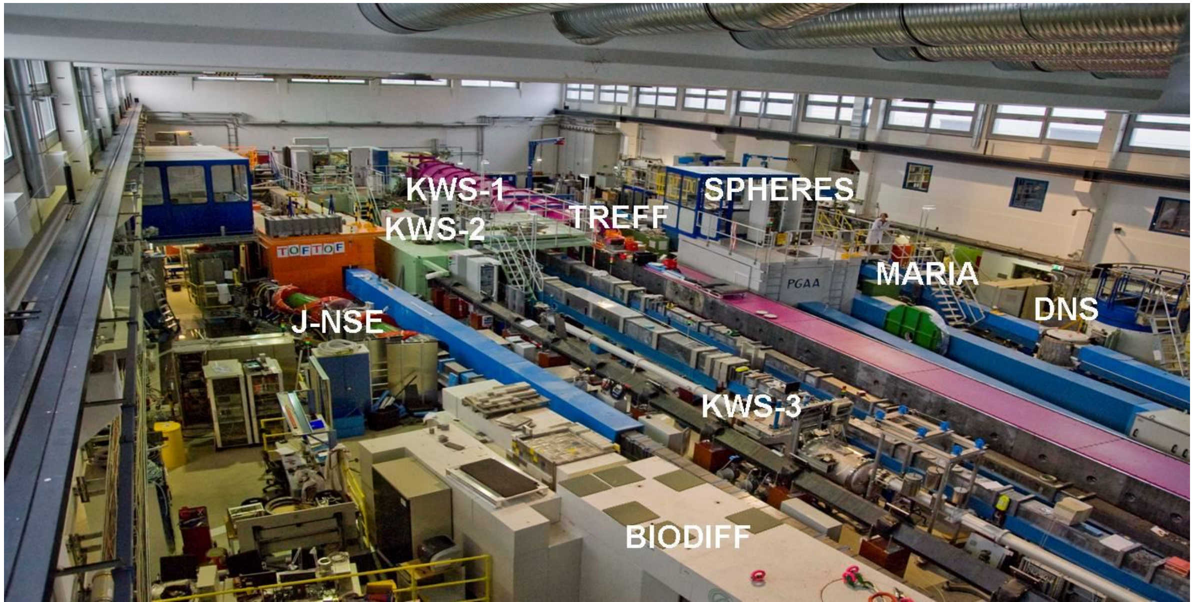
- Introduction to JCNS and Neutron Instrument Control
- TACO + TANGO + NICOS
- PLC based fronted end of JCNS instruments
- Examples

Jülich Centre for Neutron Science

- Forschungszentrum Jülich
  - Multi-disciplinary research institute, about 5800 employees
  - Research reactor FRJ-2 was switched off in 2006

⇒ Foundation of the JCNS in 2006

  - Central Divisions: JCNS-1, JCNS-2, (JCNS-3) in Jülich
  - Outstation at MLZ in Garching: 11 instruments at FRM-2
  - Outstation at ILL in Grenoble: 3 instruments in cooperation with CEA
  - Outstation at SNS in Oak Ridge: 1 instrument
  - Future activities: ESS (4 Instruments) + High Brilliance Source



Scope of Neutron Instrument Control

User Interface: definition/execution of scripts + GUI

Data Acquisition:	Motion Control	Personal safety system	Vaccum and cryogenic systems	Sample environment
starting, stopping, readout, synch. of detectors, monitors; meas. Time; ….	motors, encoders, switches, …..	access control, beam shutters (IEC 61508 / ISO 13849)	vacuum gauges, pumps, temperature sensors, valves, compressors,…	cryostats, heaters, magnets, …….

- **Data Acquisition:** Integrated into control system
  - Very moderate requirements compared to particle physics
  - Some recent detectors: fast data channels bypassing the control system

Status of Neutron Instrument Control

- Classically only Lab-wide standards,
  - Often proprietary or exotic HW and SW solutions
  - Trend to standardized middleware solutions (EPICS,…)
- Examples
  - ILL: MAD, NOMAD ; NIST: ICP
  - HFIR (Labview/Windows), SNS (pyDas mit python/Windows)
  - HZB: CARESS; SINQ: SICS
- In Jülich: Long history of proprietary solutions
  - PDP-11 + RSX-11 + Fortran + Unibus
  - VAX+ VMS + PASCAL+ QBUS/CAMAC
  - PC + Concurrent/DOS + Turbo PASCAL + ISA-Bus/SMP-Bus
  - ……
- Ca. 1995: Decision by Forschungszentrum Jülich and TU Munich on a common approach to neutron instrument control: **Jülich-Munich Standard**

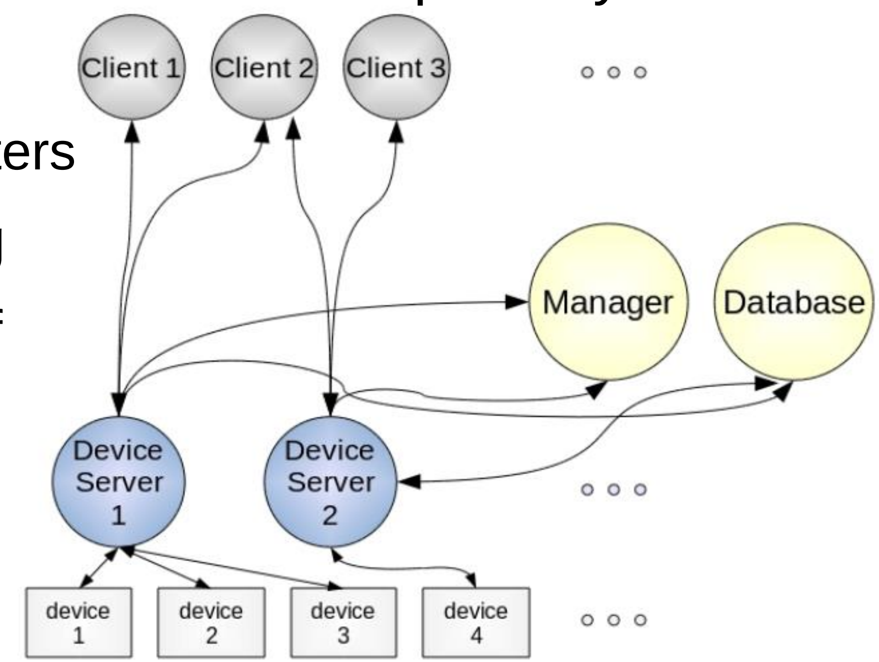
Original Jülich-Munich Standard

Application	Scripts: python	GUIs: Qt, C++
Middleware	**TACO**	
Experiment-Computer	PCs mit Linux (CompactPCI)	
Process communication	**PROFIBUS DP**	GPIB, serial IFs, Ethernet,..
Control layer	S7-300	● ● ●
Field layer	ET200S, ET200M, ASi-Modules,…	

- Core: TACO (ESRF)
  - compact, powerful
- JCNS frontend
  - Heavily PLC-based
  - Highly standardized
  - Differences to TUM
- Cooperation with TUM
  - JCNS started several years before TUM
  - At the beginning not very intense
  - Only a few device servers commonly used
  - improved with establishment of JCNS controls team at FRM-2
- Gradual evolution of the standard over 2 decades

TACO (Telescope and accelerator controls objects)

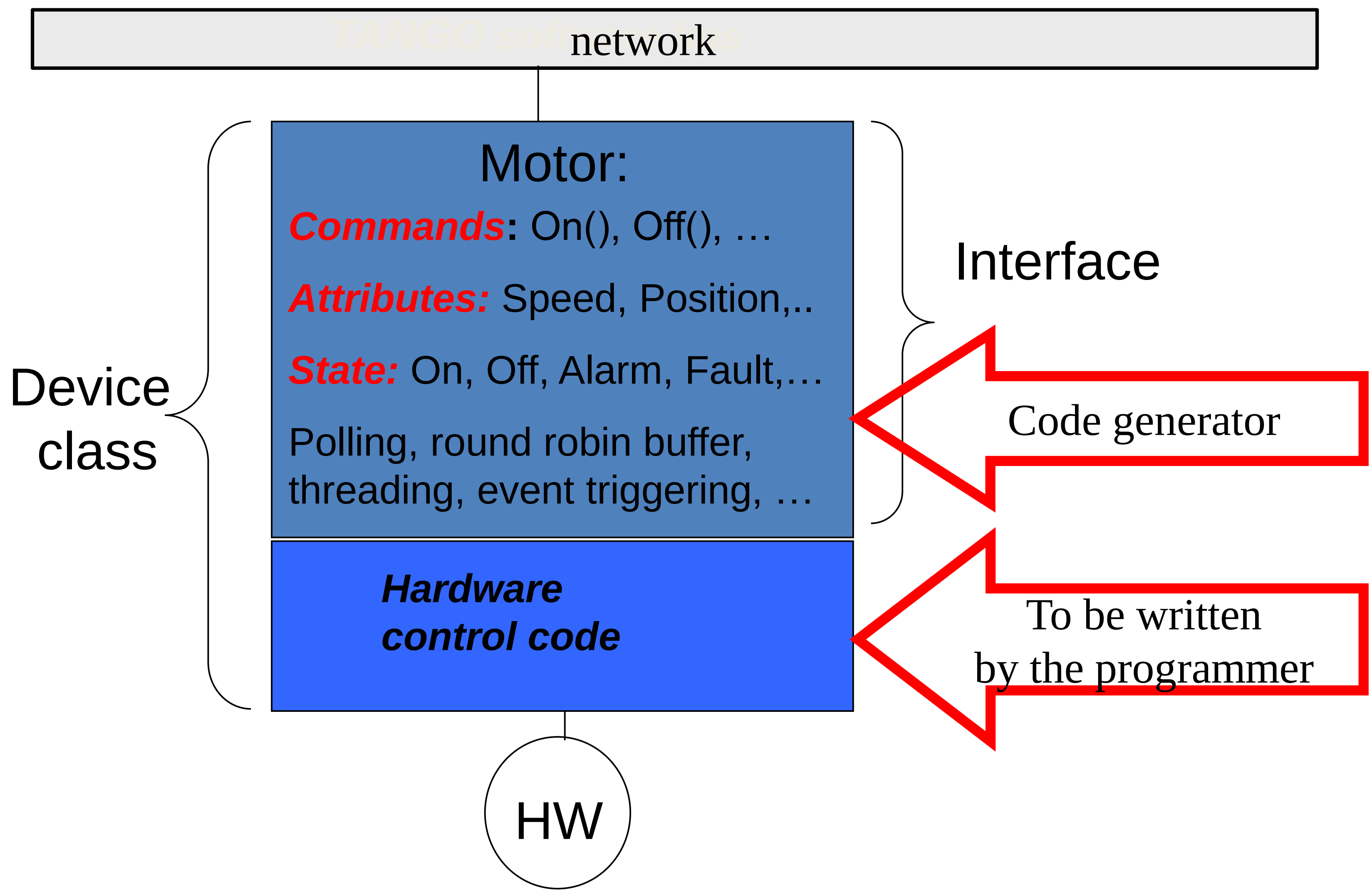
- Tool for the development of Control systems (ESRF, ca. 1990)
- Distributed client/server architecture (Sun-RPC)
- Device abstraction
  - *dev_putget(dev,cmd,argin,argin_type,argout,argout_type,error)*
  - Conceptional difference to “variable view” of EPICS
- Name-service: Taco manager => location transparency
- Database: dbm (+mysql)
  - TACO-configuration + parameters
- Not designed for multithreading
- Rudimentary implementation of asynchronicity (events,…)



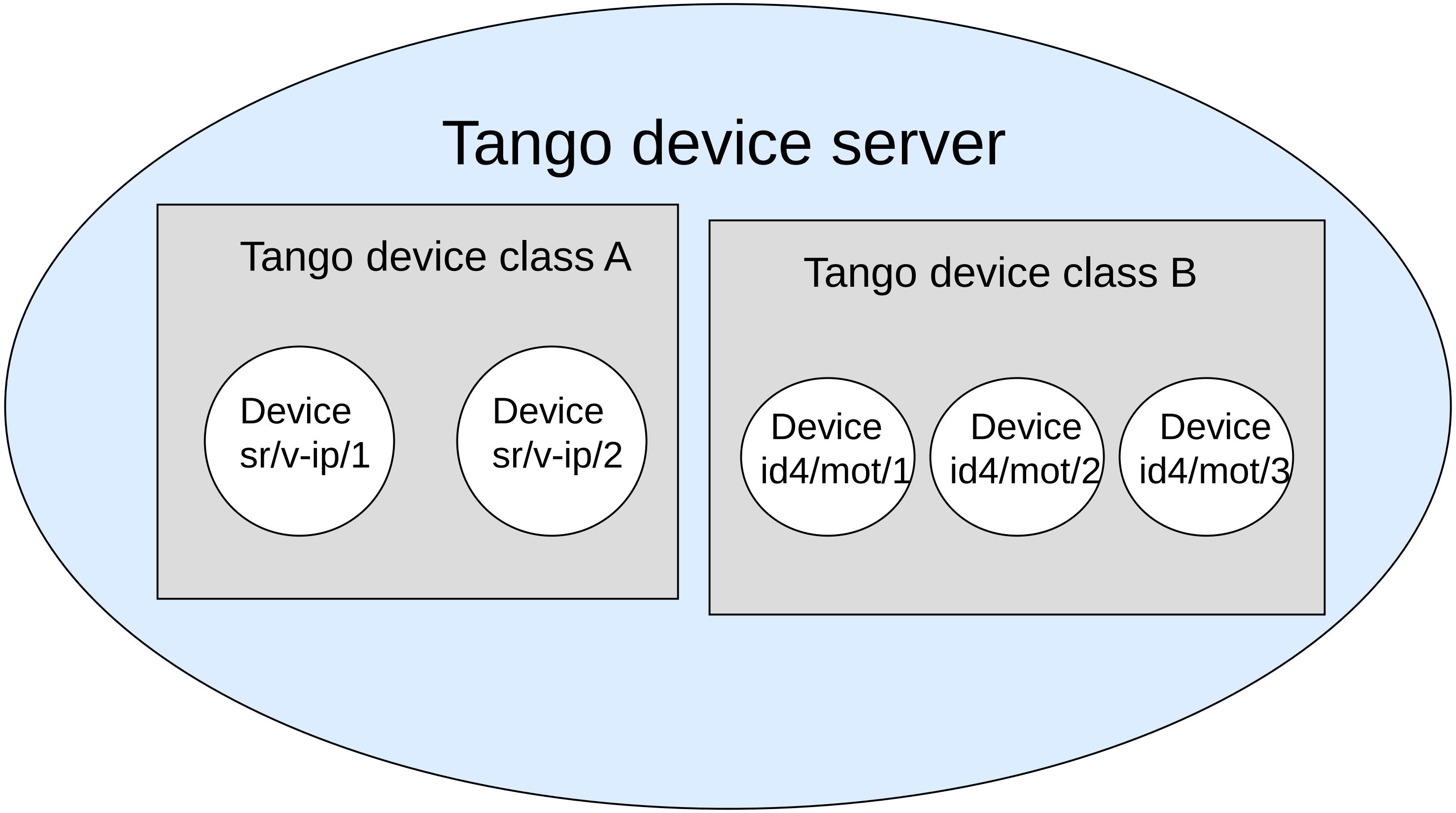
TANGO

- Object-oriented successor of TACO (ESRF, ca. 2000)
- Collaboration: ESRF, Elettra, Alba, Soleil, DESY, MAX-lab, MLZ,…
- Based on CORBA + ZeroMQ (object-oriented middleware systems)
- Device Objects
  - State (ON, OFF, FAULT, STANDBY, UNKNOWN….)
  - Attributes: value, state, timestamp, dimension
  - Methods: **out = dev.command_inout(“Cmd name”,in);**
- Language Bindings: Java, C++, Phython
- Operating systems: Linux, Windows, Solaris
- Event mechanism, data-caching, multithreading,…
- Standardized tools at the application layer:
  - process data archive, alarm system, synoptic editor,….

TANGO Device



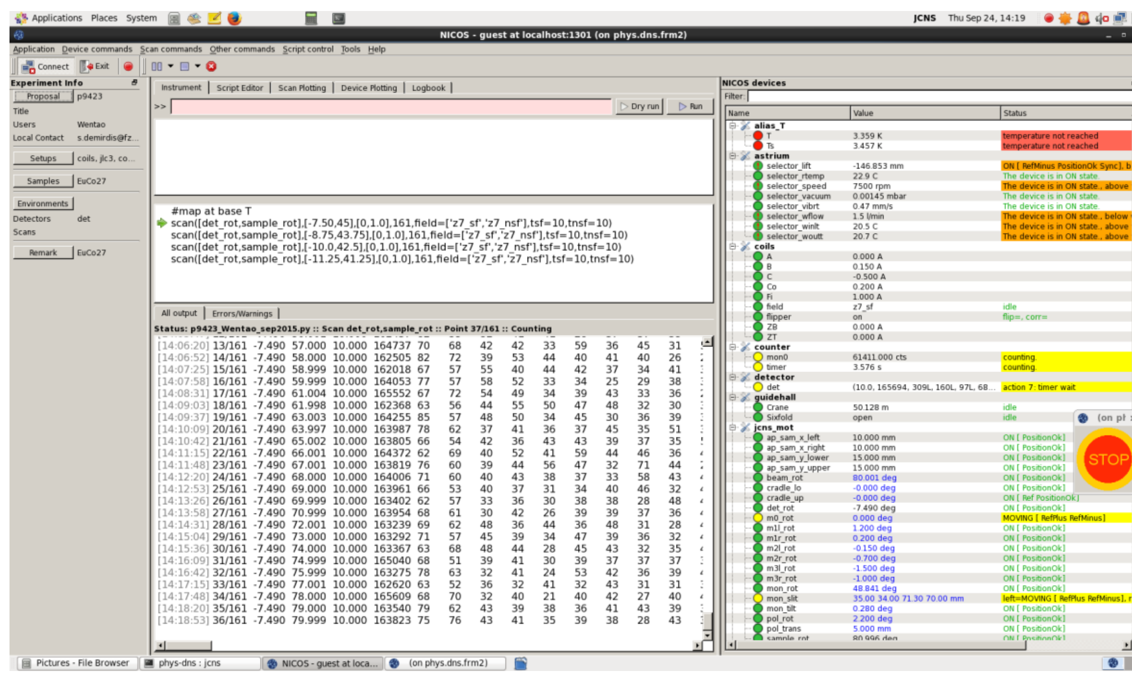
TANGO Server



- Server is an operating system process, multithreaded
  - New thread for each client connection

Measurement program NICOS

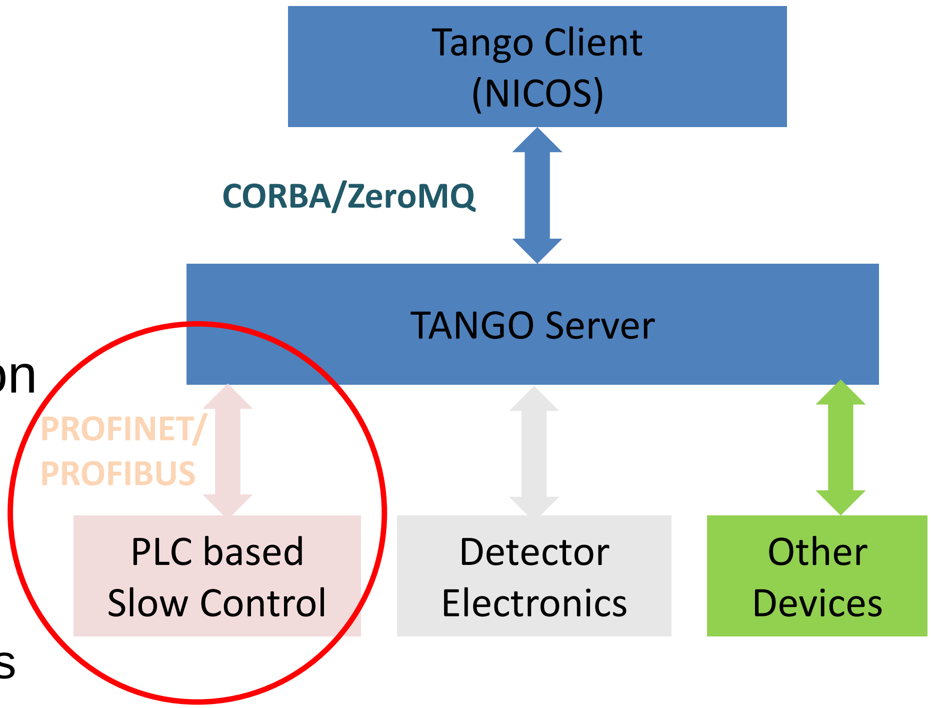
- Developed at MLZ (T. Unruh/ G. Brandl)
- Implemented with pyhton and pyQt
- Supports TACO and TANGO (and EPICS for use at ESS)
- Consistent, object-oriented device model (on top of TANGO!)
- Console + configurable GUI
- Single Server / Multiple Client
- Scripting
  - Python
  - Macro language
- History plots
- Data plots
- Electronic Logbook



Recent JCNS Instrument Control System structure

- Transition from TACO to TANGO straight forward
  - Careful: Multithreading!
- NICOS required additional standardization of device attributes + methods
- Slow Control at JCNS:
  - Based on industrial automation
  - Extremely standardized
    - Architecture
    - Products
    - Communication Mechanisms

  ⇒ Reduction of efforts for development and maintenance, spare parts,…..
  - Dominating task is **Motion Control**



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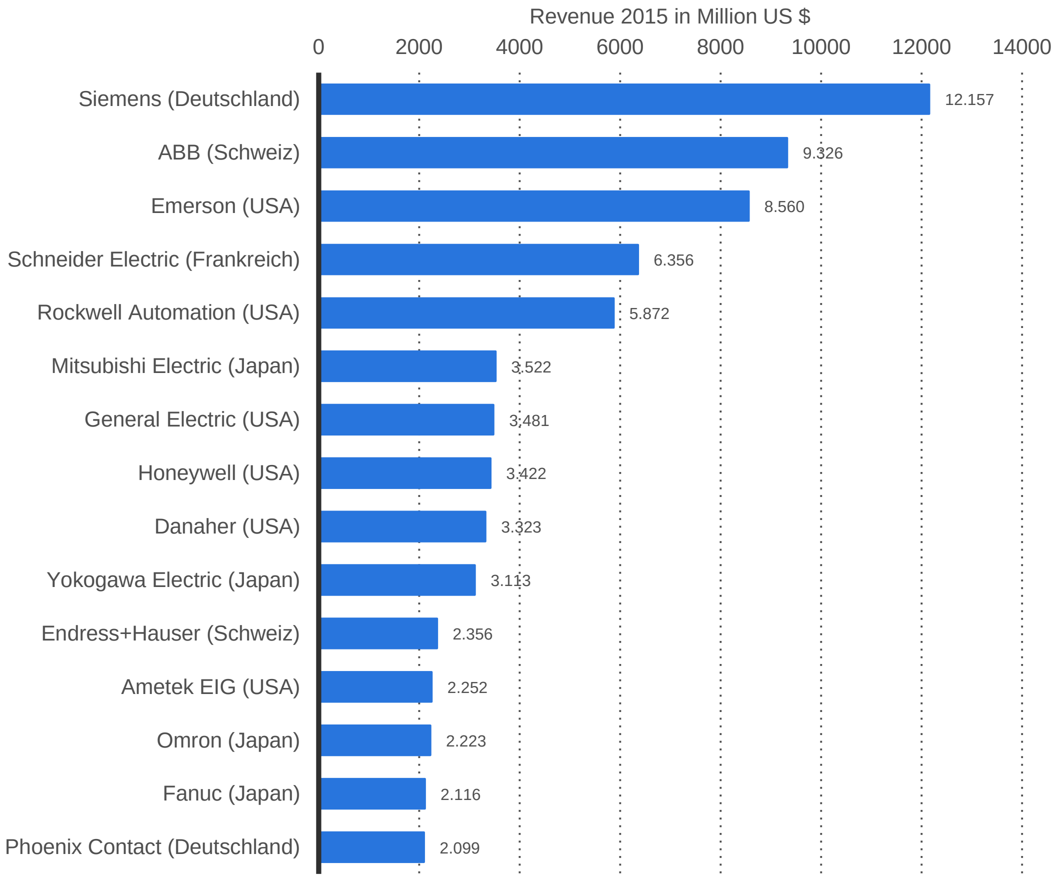
Industrial Automation technology

- Components/Systems:
  - Programmable Logic Controllers (PLCs)
  - Fieldbus systems
  - Decentral IO systems

$\Rightarrow$ **Common systems for motion, safety, vacuum,…..**

- Motivation:
  - Long term availability
  - Price
  - Robustness/Stability
  - Wide product range

Vendors in Automation



Beckhoff: ca. 600 Mio. $

- Extreme market segmentation
- Situation in Germany
  - Siemens absolute dominant (>60% market share)
  - Numerous medium sized vendors, especially for decentralized IO systems: Wago, Möller, Phoenix Contact, Weidmüller, Helmholz, Beckhoff, B&R,…..
- All required products offered by Siemens (quality, price,…)
- Already a de-facto standard in Jülich

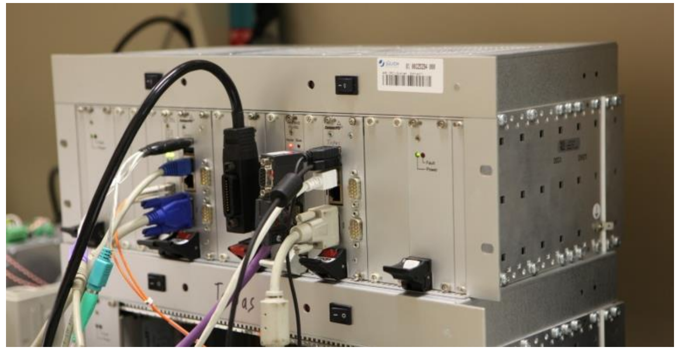
⇒ Decision for Siemens

- Decision against high end systems Sinumerik und Simotion

⇒ S7-300 + ET200S

Communication Architecture

Server Computers (only CPCI)



PLC gives homogeneous view on axes, independent of controller type, encoder,..

PROFIBUS DP, PROFINET IO

PLCs + Op. Panels

PROFIBUS DP, PROFINET, AS-Interface

Decentral Periphery

ET200S

ET200M

ET200pro

ASi

Decentral IO Systems in Protection class ≥ IP65

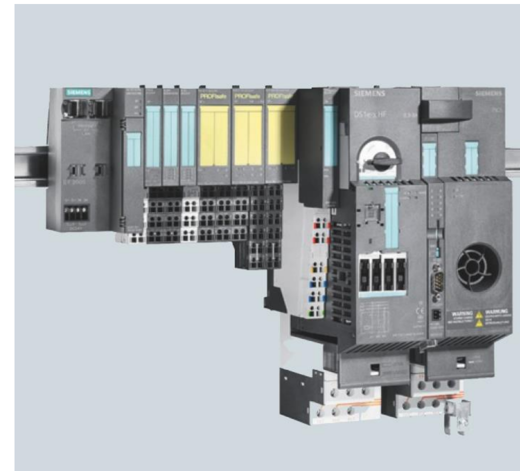
- Without cabinet in the field
- ASi-Module (IFM: Digital I/Os, pneumatic valves)

- Siemens ET200pro
  - PROFIBUS und PROFINET
  - Supports FESTO valve manifolds
  - Failsafe IO supported

- Festo CPX
  - PROFIBUS und PROFINET
  - Integrated valve manifolds

Decentral IO Systems for cabinets

- Siemens ET200S
  - IF modules for PROFIBUS + PROFINET
  - Digital + analog IOs
  - Motor controllers, encoder modules,…
  - Motor starters up to 5 kW



- Siemens ET200M
  - IF modules for PROFIBUS and PROFINET
  - S7-300 peripheral modules

- Integration of other vendors
  - Straight forward on base of GSD/GSDML files

Stepper motor controllers

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- **Almost exclusively used**

1STEP
-ET200S
-204 kHz
-Step/direction

Phytron 1STEP-Drive
-ET200S
-510 kHkz / 512 microsteps
-Integ. driver: 5A (peak) / 48V

- **Only a few axes (are being replaced)**

FM357
-S7-300
-4 axes trajectory control (NC)
-625 kHz oder Servo
- incremental + SSI encoders

Outdated!!

- **In Future**

Phytron
TM Step Drive
-ET200SP
-510 kHkz/
256 microsteps
-5A (peak) / 48V

TM PTO 4
- ET200MP
- 4 channel
- 1 MHz

Controllers for AC Motors

DS1-X

- ET200S
- Direct starter (also as soft starter) for 3 phase 400V
- Up to 5,5 KW

Sinamics S120

- Family of intelligent servo controllers
- Decentral (PROFINET + PROFIBUS)
- Distributed operation without PLC possible
- Dedicated engineering tool Startdrive integrated into TIA portal

- Many other optimized servo controller families available
- Easy integration of third party products via PROFIdrive standard

Encoder Readout

- Angle + linear-encoders from Heidenhain, Balluff, Renishaw, AMO,…
- Absolute, incremental (optical, inductive,….),
- Interfaces: SSI , EnDat (PB-Gateway), PROFIBUS, PROFINET, DRIVE-CliQ (only used for AC servo motors)
- ET200S modules 1SSI und 1Count (RS485 quadrature signals)
- Also a few resolvers (PROFIBUS Interface from AMCI) and potentiometers

PLC controllers (CPUs)

- Only Siemens products (very wide product range, common programming model)

High End: S7-400

ET200pro CPU

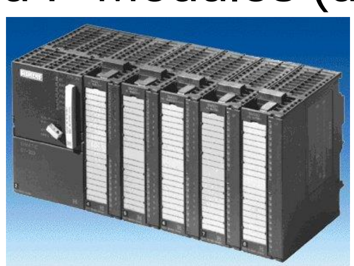
SoftSPS: WinAC

S7-mEC (Windows PC)

Simatic MP

- JCNS: Orignially exclusively S7-300 (CPU 315-2 PN/DP) and ET200S CPU (IM 151-7 CPU)
  - Single processor
  - Modular and scalable
  - Powerful Communication ⇒ decentral architecture
  - Failsafe operation (IEC61508 SIL3 and ISO 13849 Ple) with F-CPUs and F-Modules (distributed safety)

Mid Range: S7-300



Micro: ET200S CPU

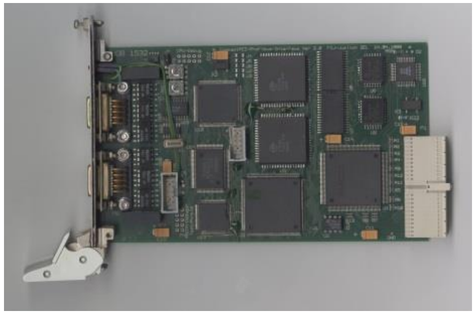
Recent Activities

- New PLC-Familiy S7-1500
  - Successor of S7-300
  - Decentral Periphery: ET200MP
    - Max. 30 Modules (12 with PROFIBUS)
  - SW-compatible low end family: S7-1200
    - Compact PLCs for around 200€

- Improved development environment: TIA-Portal
  - Programming changes required
  - JCNS SW framework was adapted successfully
- Integrated motion functionality based on PLCopen
    - Standardized function block interface
    - Independent of specific motor/controller type
- New decentral periphery System ET200SP
  - Hot swap of modules
  - Up to 64 modules (32 with PROFIBUS)

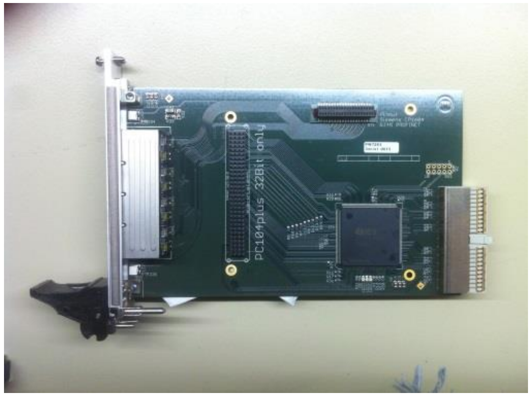
Communication with the control system

- Originally in house development of an PROFIBUS controller as CPCI module
  - with Linux device driver and configuration SW



PROFIBUS controller

- Now PROFINET: Development of PC104+ carrier
  - Mezzanine: Siemens CP1604
  - Configuration automatically by PLC configuration
  - Functionally similar to PROFIBUS
  - ⇒ simply a new library under Linux and different function calls on the PLC side



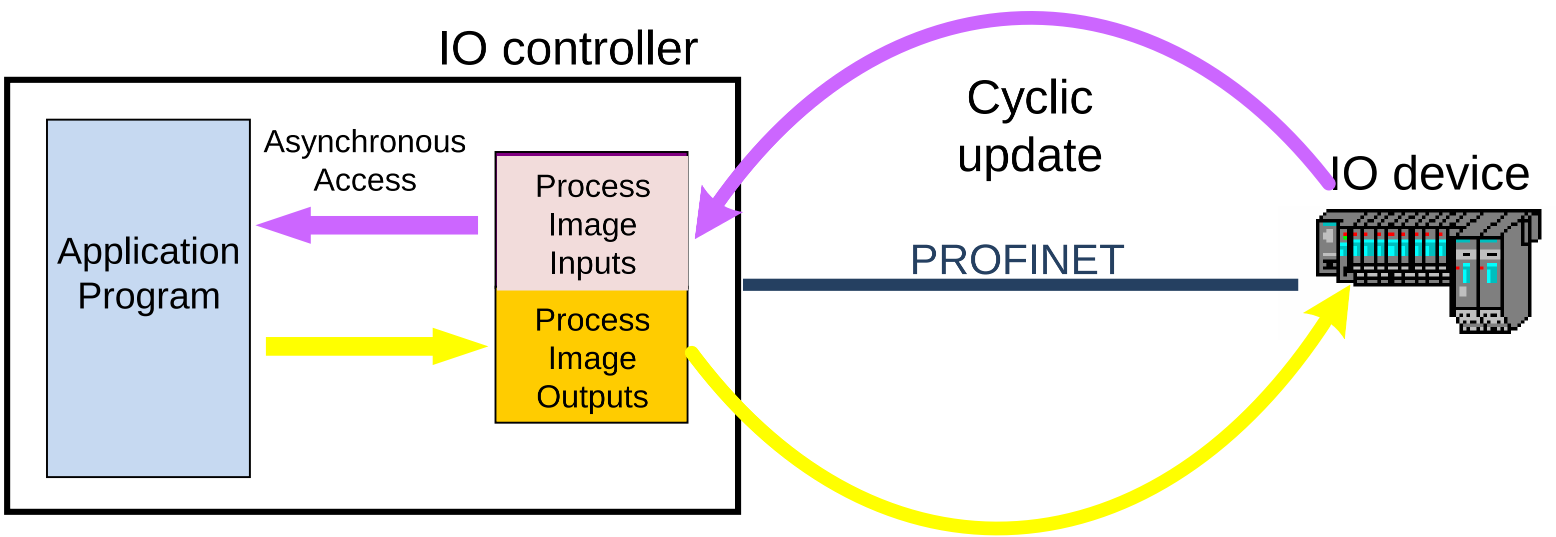
PC104+ Carrier

PROFINET Controller CP1604

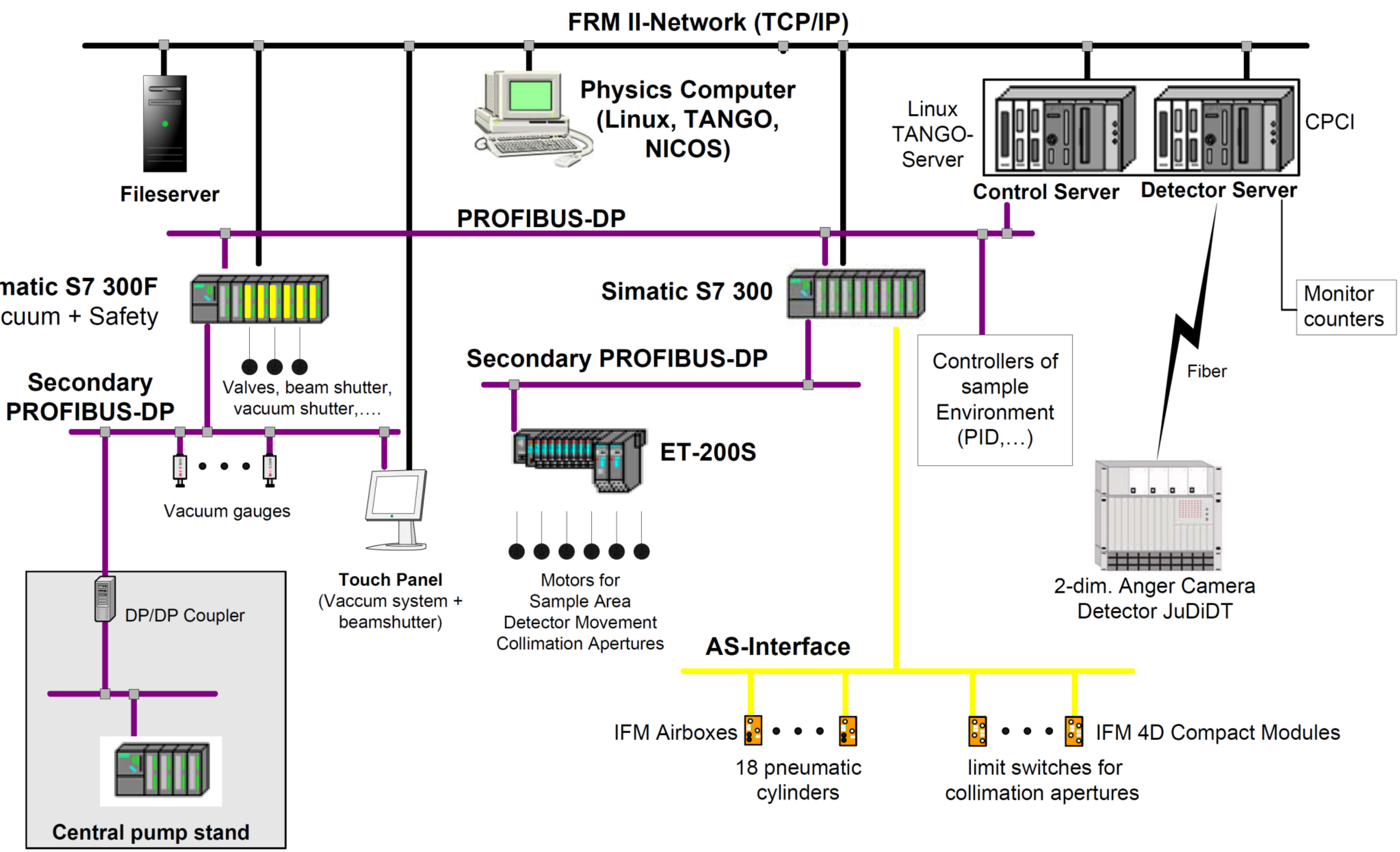
Application Protocol

- Abstract controller/axis modell (e.g for synchronized movement)
- Transactions for the execution of most commands
- Producer/Consumer model of PROFIBUS/PROFINET

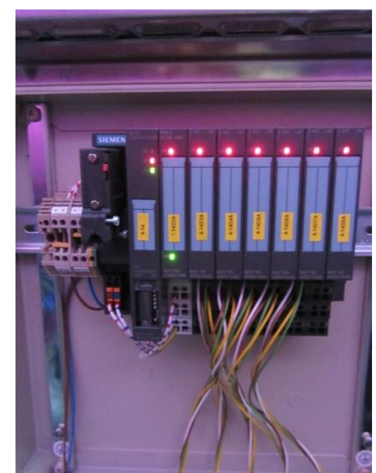
⇒Fast communication by directly mapped areas (e.g. for positions)



Example 1: Small Angle Instrument KWS1

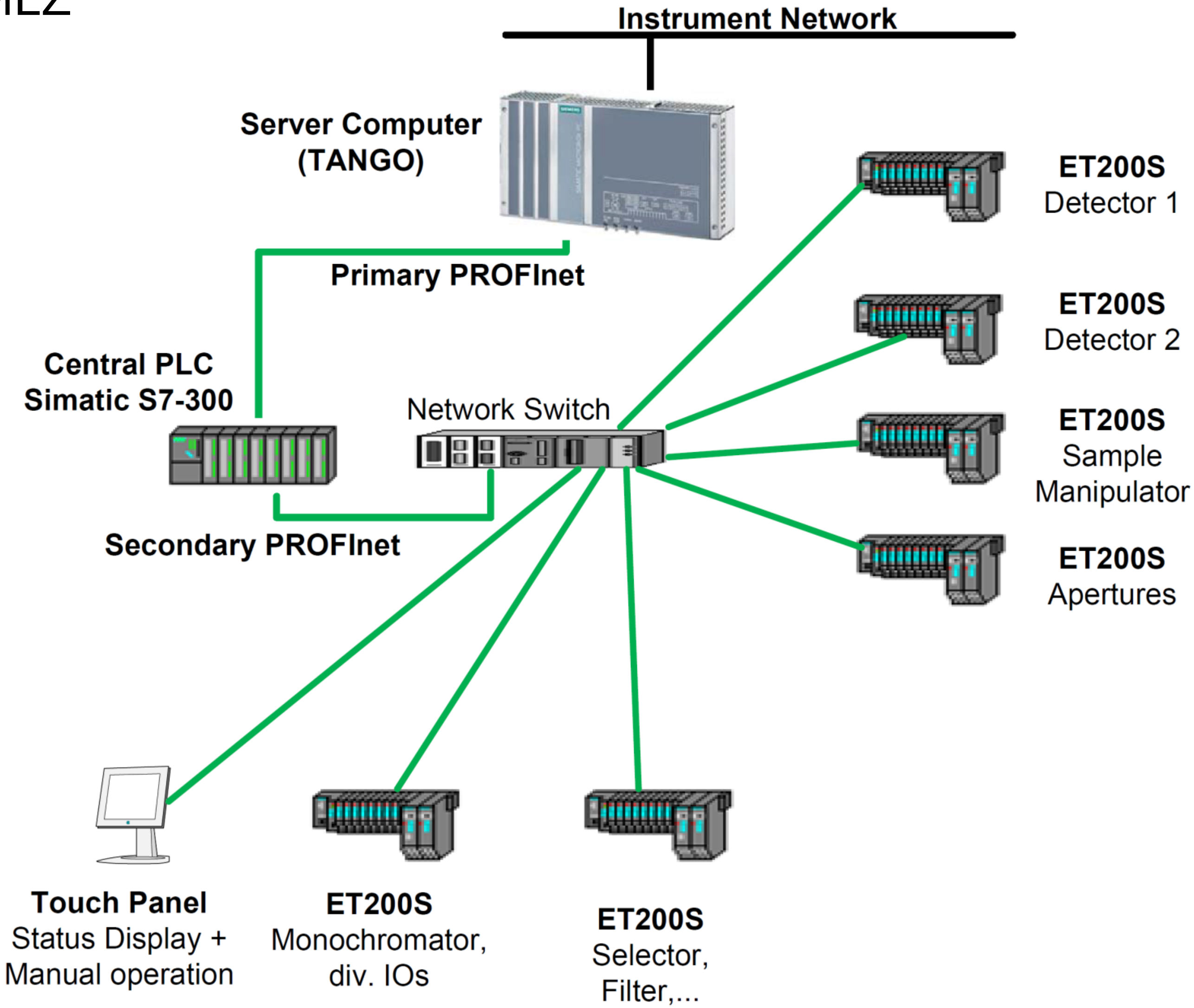


KWS1 Implementation

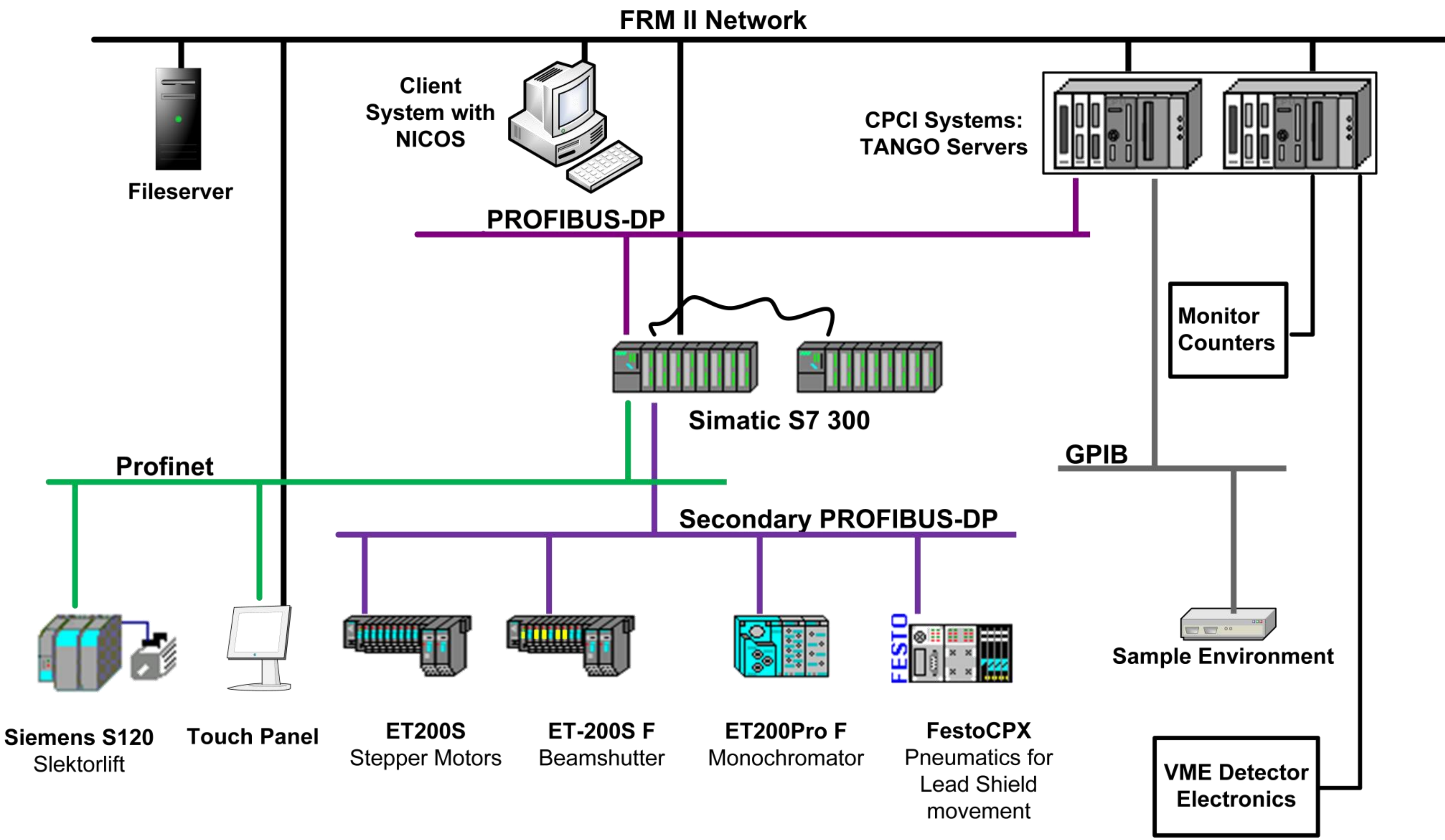


Example 2: Motion Subsystem of ANTARES

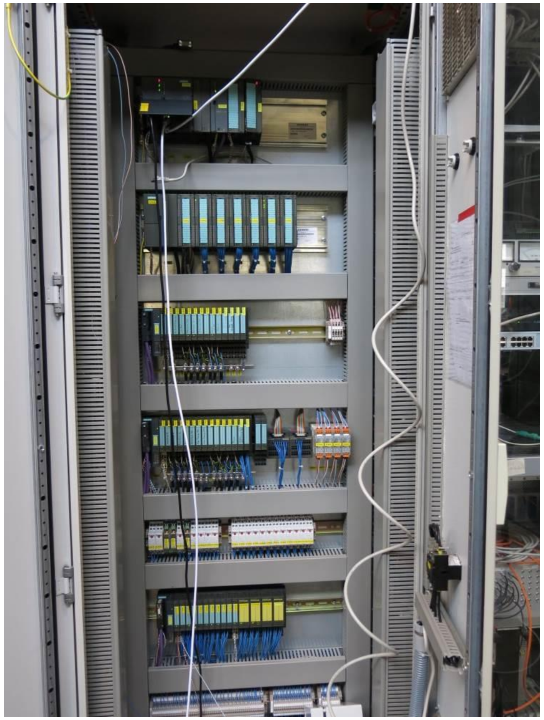
- Antares: Cold neutron tomography and radiography instrument of TUM at MLZ



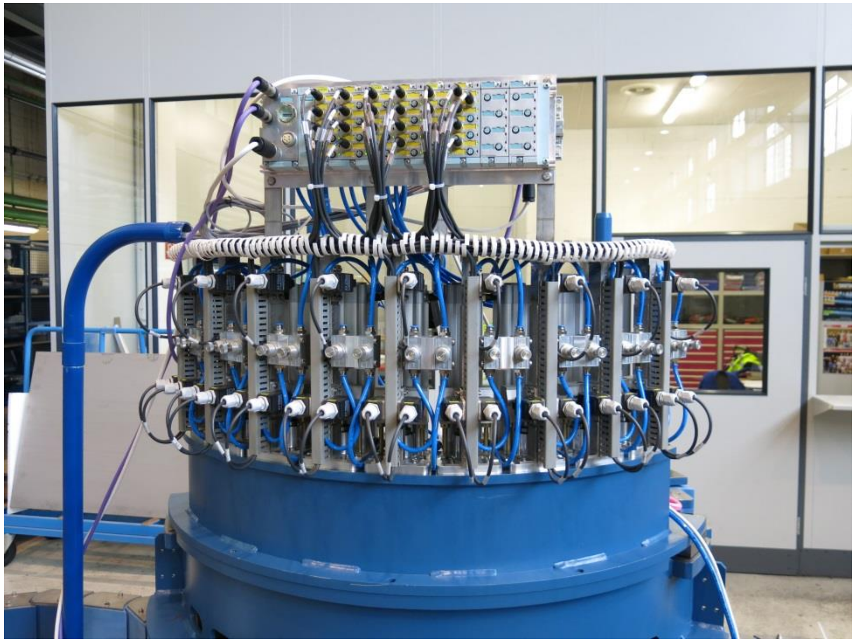
Example 3: TOF instrument DNS



DNS Implementation I



DNS Imlementation II



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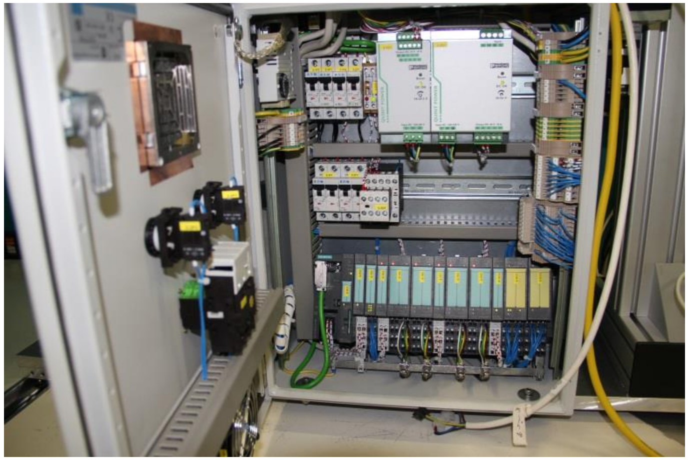
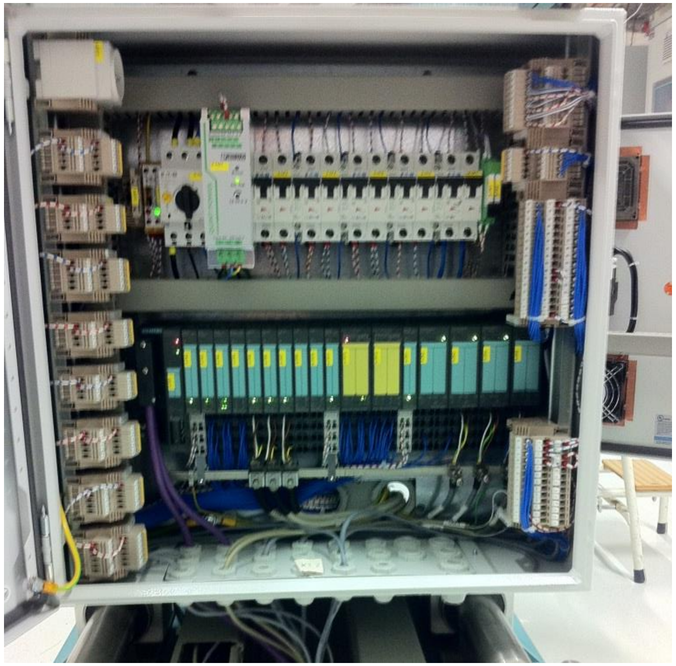
Examples of decentral cabinets





Example 4: S7-1500 at the Spin Echo Instrument

Conclusions

- Successful concept for more than 20 years
  - Standardized software and hardware
  - Gradual technological evolution (TACO => TANGO, NICOS, introduction of S7 1500 and ET200SP)
  - Arbitrary mixing of PROFIBUS, PROFINET, S7-300, S7-1500, ET200S/SP/M/MP possible
- Decision for the de-facto industry standard:
  - Easy interfacing of devices from other vendors
- ESS: S7-1500 for safety, vacuum, etc. but Beckhoff Ethercat modules for motion
  - Effort in working with new vendor required
  - Pilot project: Refurbishment of PANDA at FRM-II
  - First experiences show disadvantages regarding functionality, electro mechanical design, documentation, help system, diagnostics,…..