Telescope Control Systems and the Automation Industry

COTS products building a control system for telescopes

The Way In and Out again

Operating System

Live-Demo

Six Examples – Two Reasons

Fieldbus

I/O mapping and Multicore

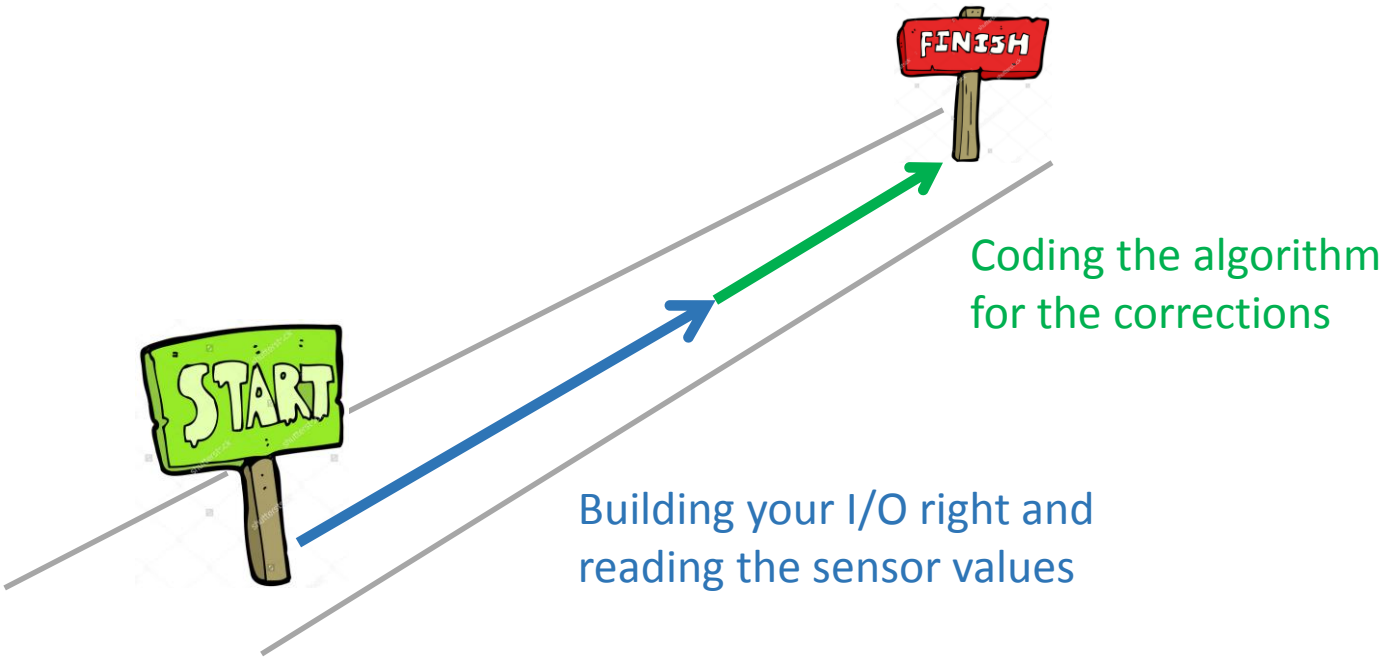
Flexibility and Software Reuse

Challenges and Examples

Experience about 13 years ago

the task: read in 3 analog values and calculate the corrections for AZ and EL

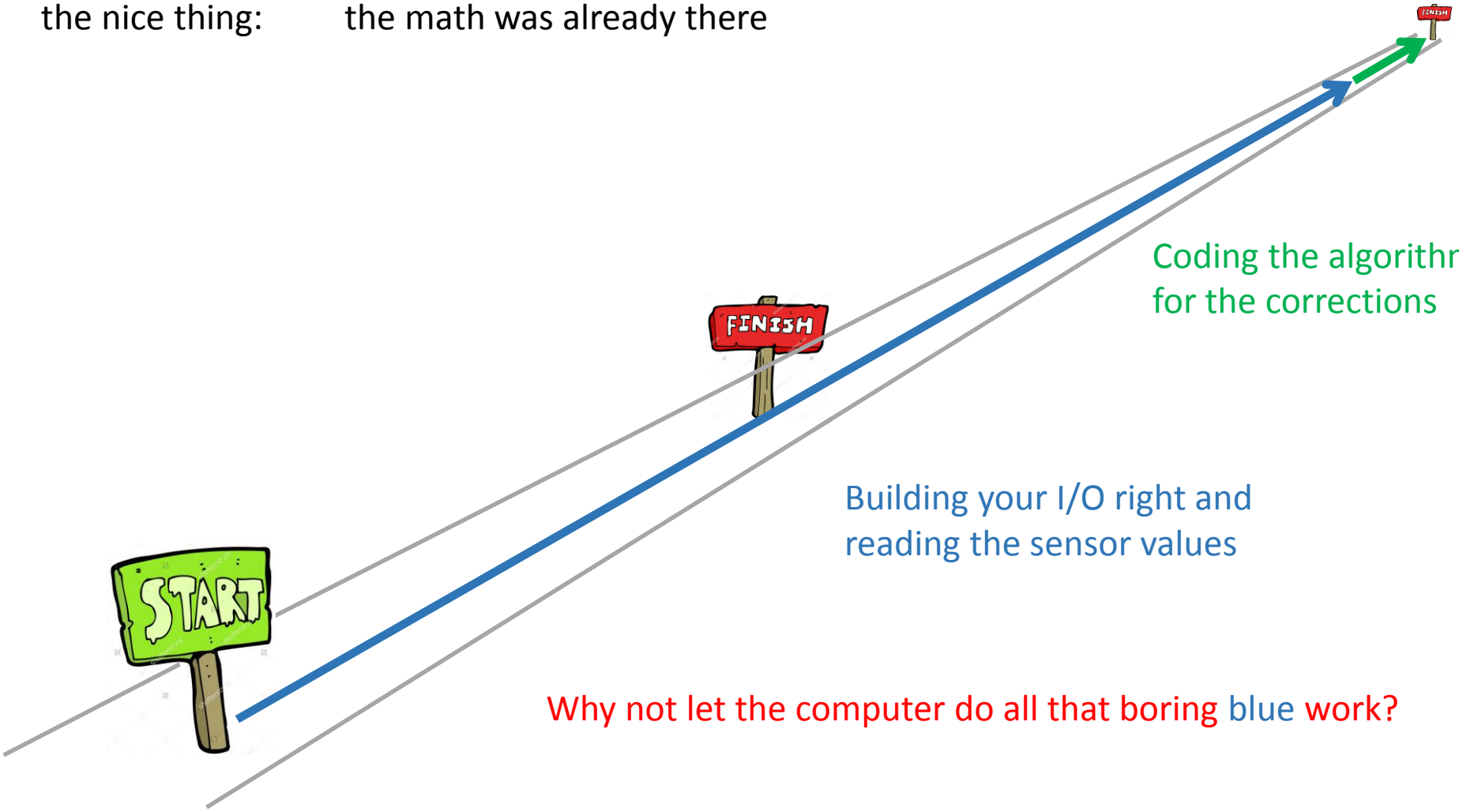
the nice thing: the math was already there



Experience about 13 years ago

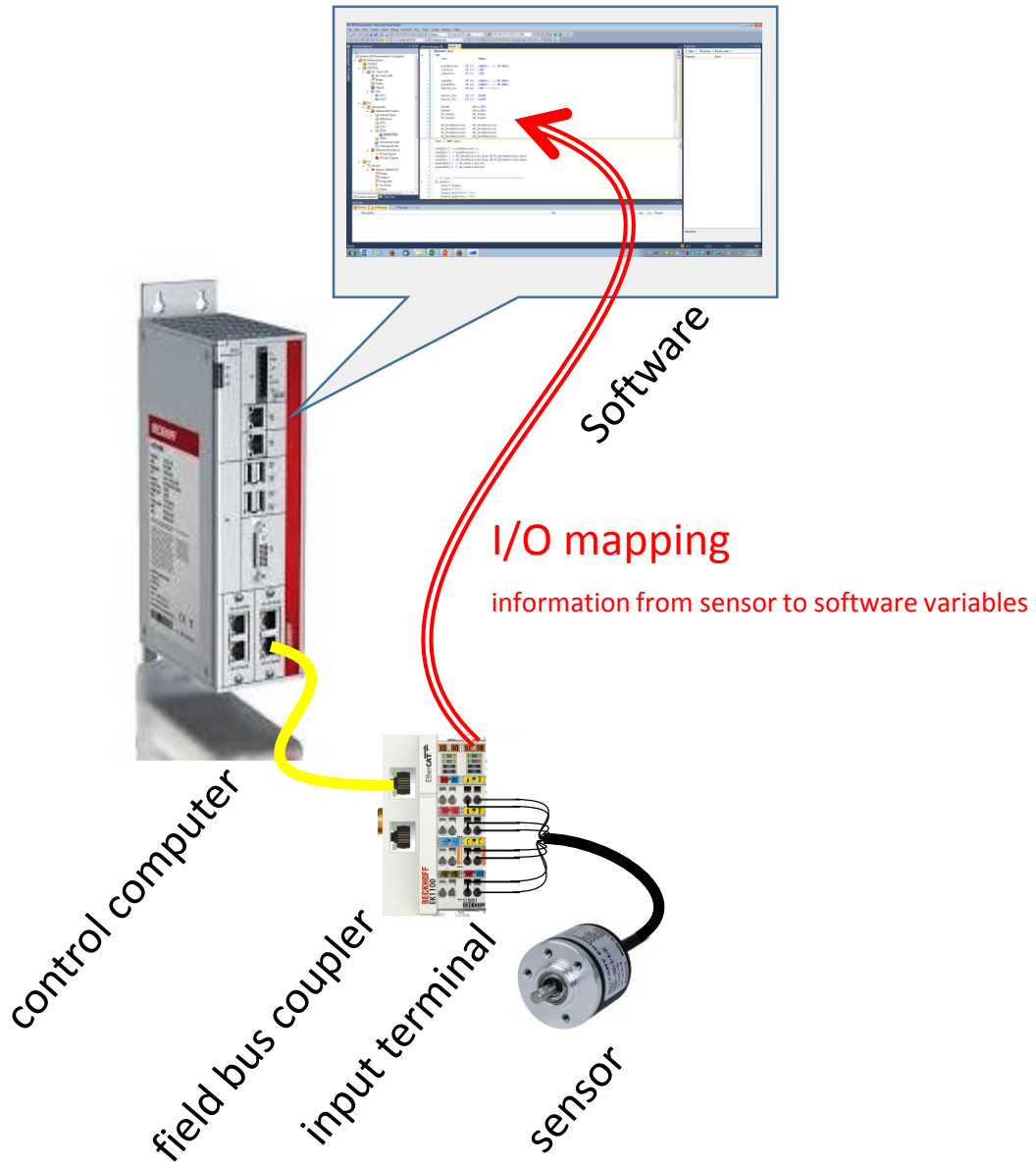
the task: read in 3 analog values and calculate the corrections for AZ and EL

the nice thing: the math was already there

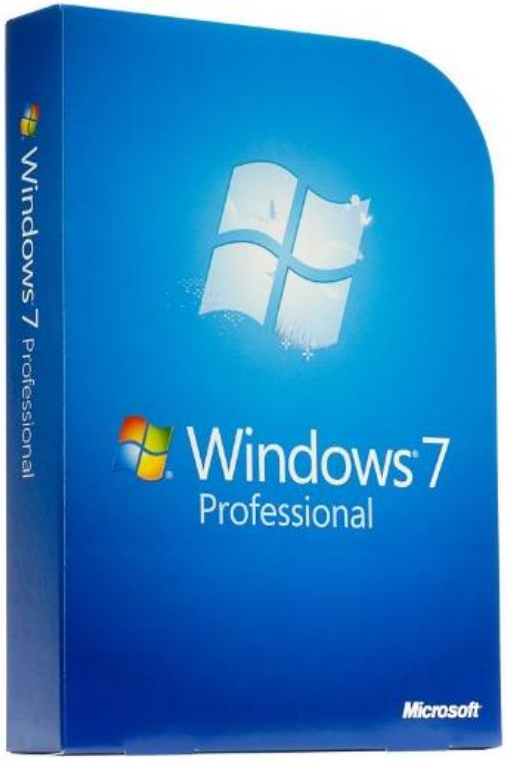


Main Components

- sensor / actuator
- I/O terminal / module
- control computer
- fieldbus
- software



Now, what is the software that runs all our algotithms and helps us such, that we do not really need to worry about mapping?

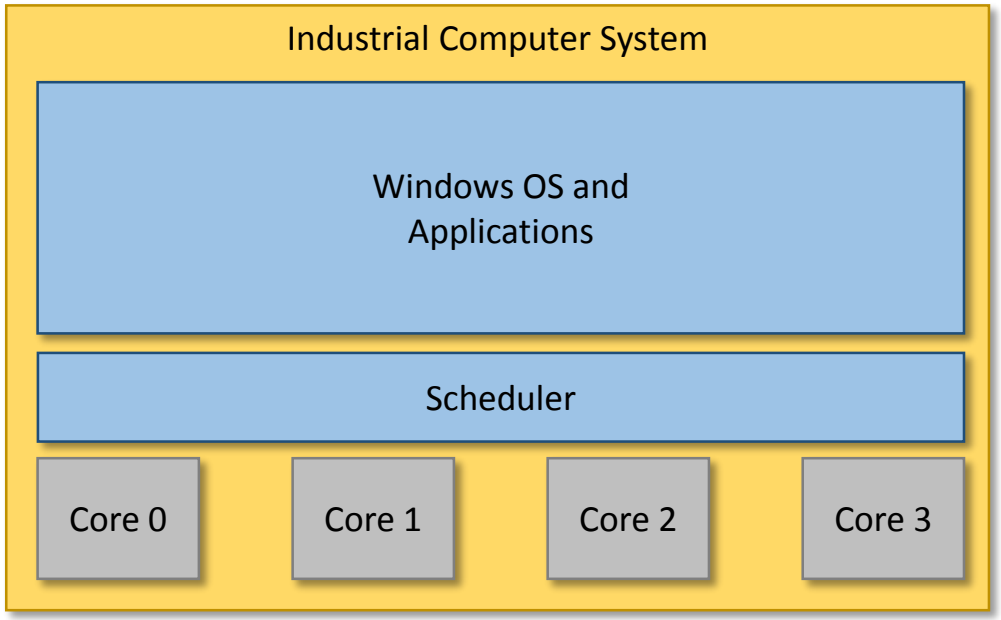


Windows as basis for our most important and beloved control systems?

=> Really?

=>

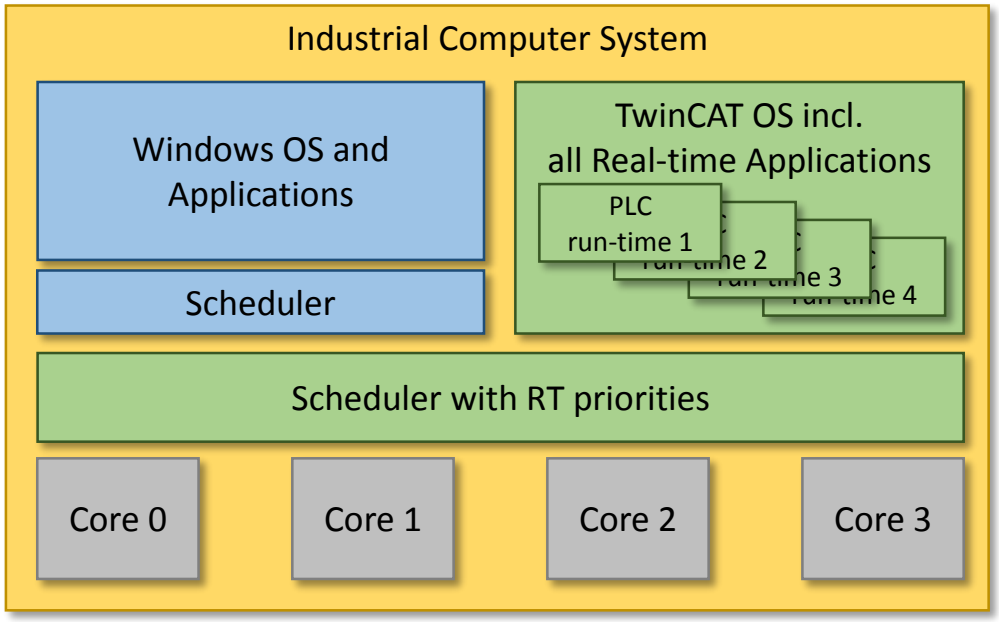
=> Not entirely, we need something in addition!

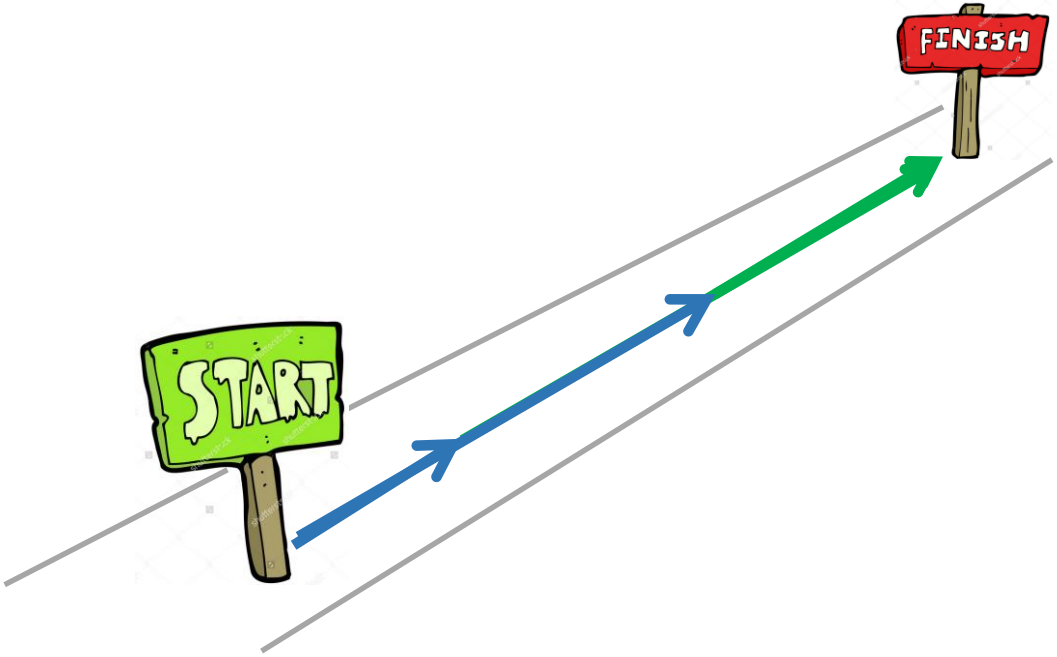


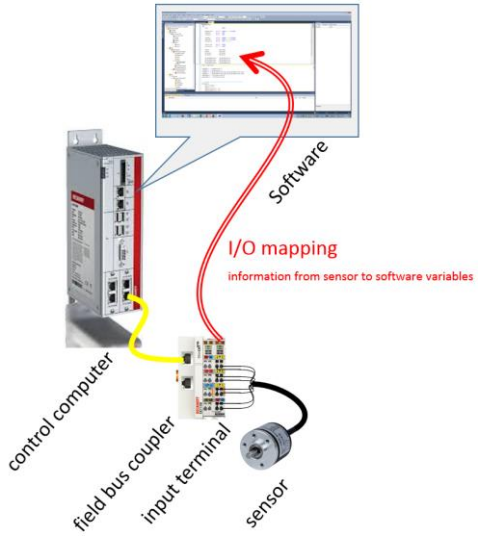
Standard Windows OS Computer System

Windows OS Computer System

incl. TwinCAT Real-time OS with guaranteed cycle times



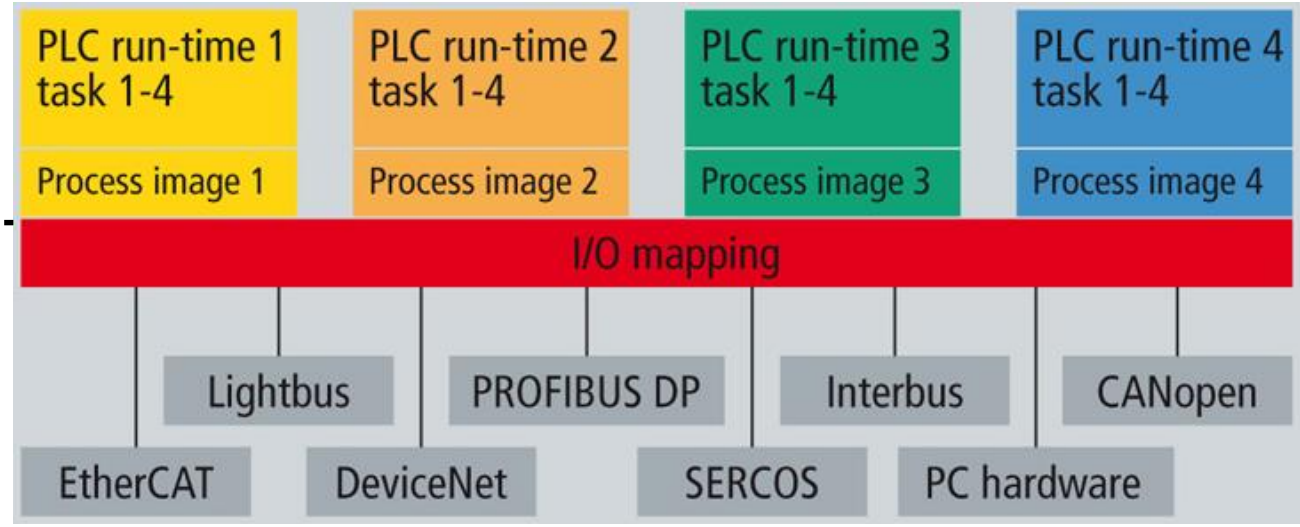




Coding the algorithm for the corrections

Building your I/O right and reading the sensor values

95% done by computer!



Live Demonstration

the way in and out again

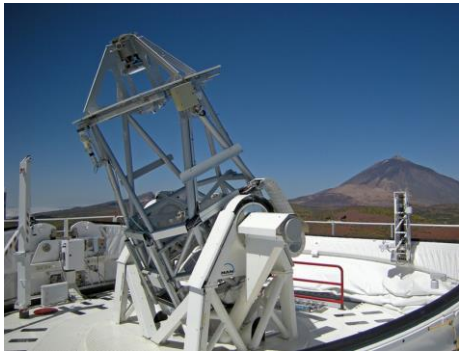
Let’s cross fingers!

40m IGN Radio Telescope

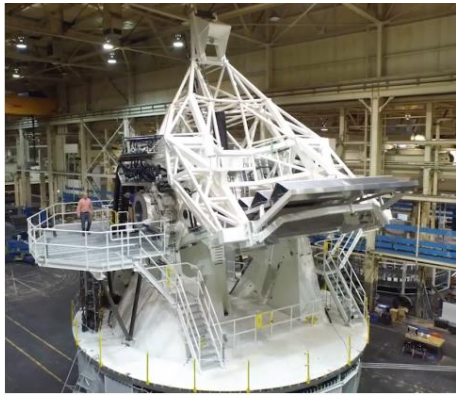
LMT Radio Telescope

Sardinia Radio Telescope

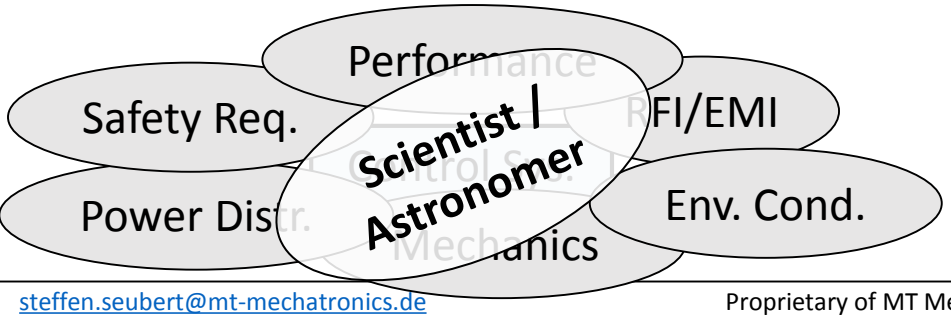
13m VLBI Radio Telescope



Gregor Solar Telescope



DKIST Solar Telescope



Flexibility and Reliability

Flexibility during the different project phases:

- Proposal and Design
- Construction, Commissioning & Acceptance
- Operations

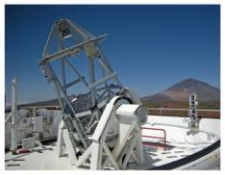

40m IGN Radio Telescope


LMT Radio Telescope


Sardinia Radio Telescope


13m VLBI Radio Telescope

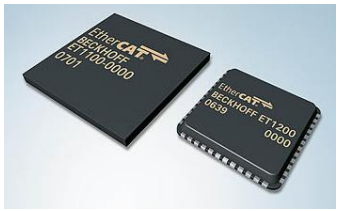

DKIST Solar Telescope


Gregor Solar Telescope

Reliability during all project phases:

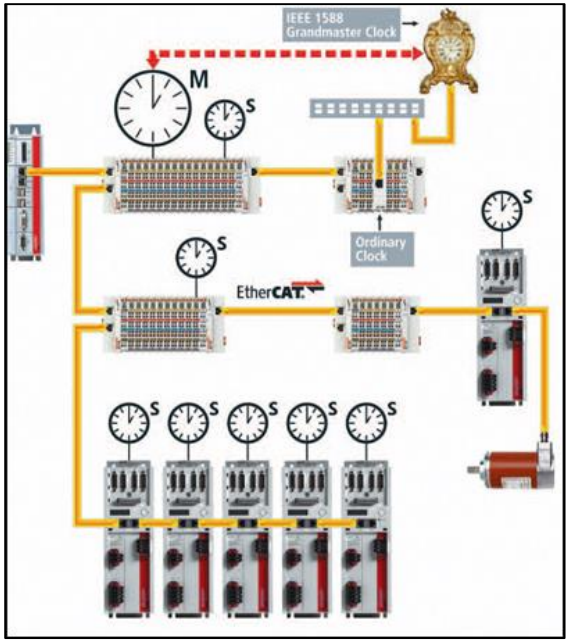
- defined product life cycles => discontinuation and **replacement strategies**
- well tested and documented products => design quality and quality assurance
- highly available spares and well trained support

Standardization, Modularization and Distribution

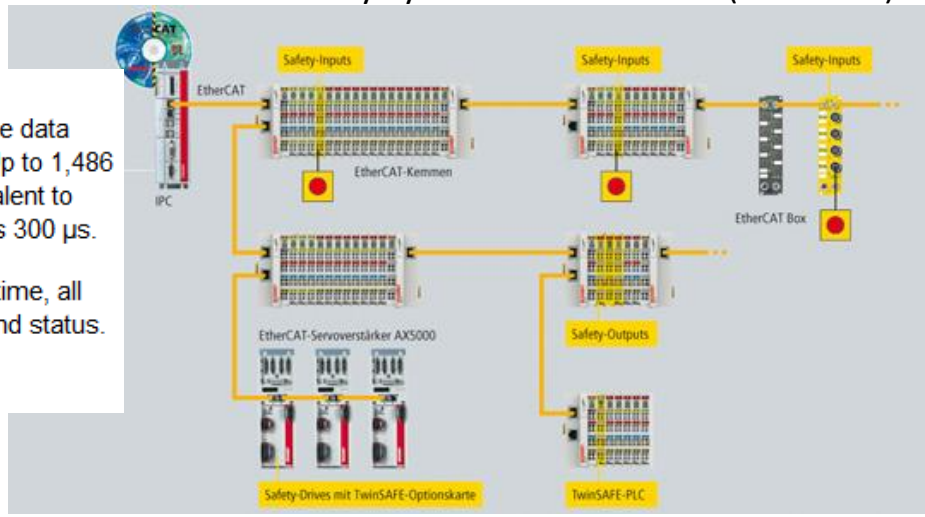


Each terminal is one EtherCAT slave on its own

Distributed clocks synchronize I/O to jitter << 1µs



Distributed Safety Systems over Fieldbus (TwinSAFE)



Performance

EtherCAT reaches new dimensions in network performance. The update time for the data from 1,000 distributed inputs/outputs is only 30 µs – including terminal cycle time. Up to 1,486 byte of process data can be exchanged with a single Ethernet frame – this is equivalent to almost 12,000 digital inputs and outputs. The transfer of this data quantity only takes 300 µs.

The communication with 100 servo axes takes place every 100 µs. With this cycle time, all axes are provided with set values and control data and report their actual position and status. The distributed clock technique enables the axes to be synchronised with a jitter of significantly less than 1 microsecond.

http://www.beckhoff.de

XFC performance data

Extreme short control cycle time
– 100 µs (min. 50 µs)
– new performance class for PLC application: control loops with 100 µs

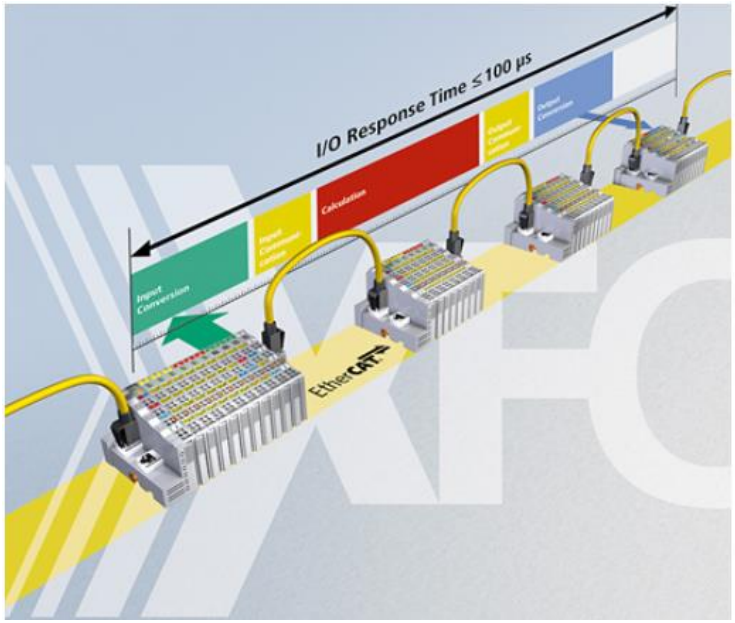
Extreme fast I/O response time
– from 85 µs
– Deterministic synchronised input and output signal conversion leads to low process timing jitter.
– Process timing jitter is independent of communication and CPU jitter.

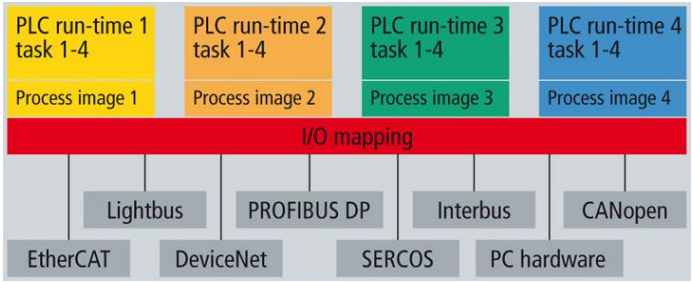
Signal oversampling
– multiple signal conversion in one control cycle
– hard time synchronisation through distributed clocks
– for digital input/output signals
– for analog input/output signals

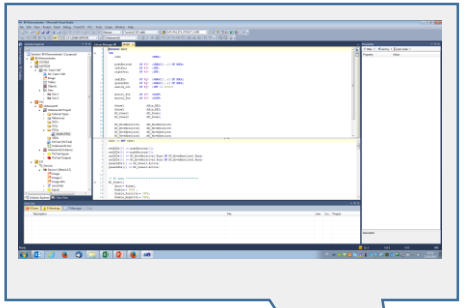
– support of analog I/O EtherCAT Terminals
  – up to 100 kHz signal conversion
  – down to 10 µs time resolution

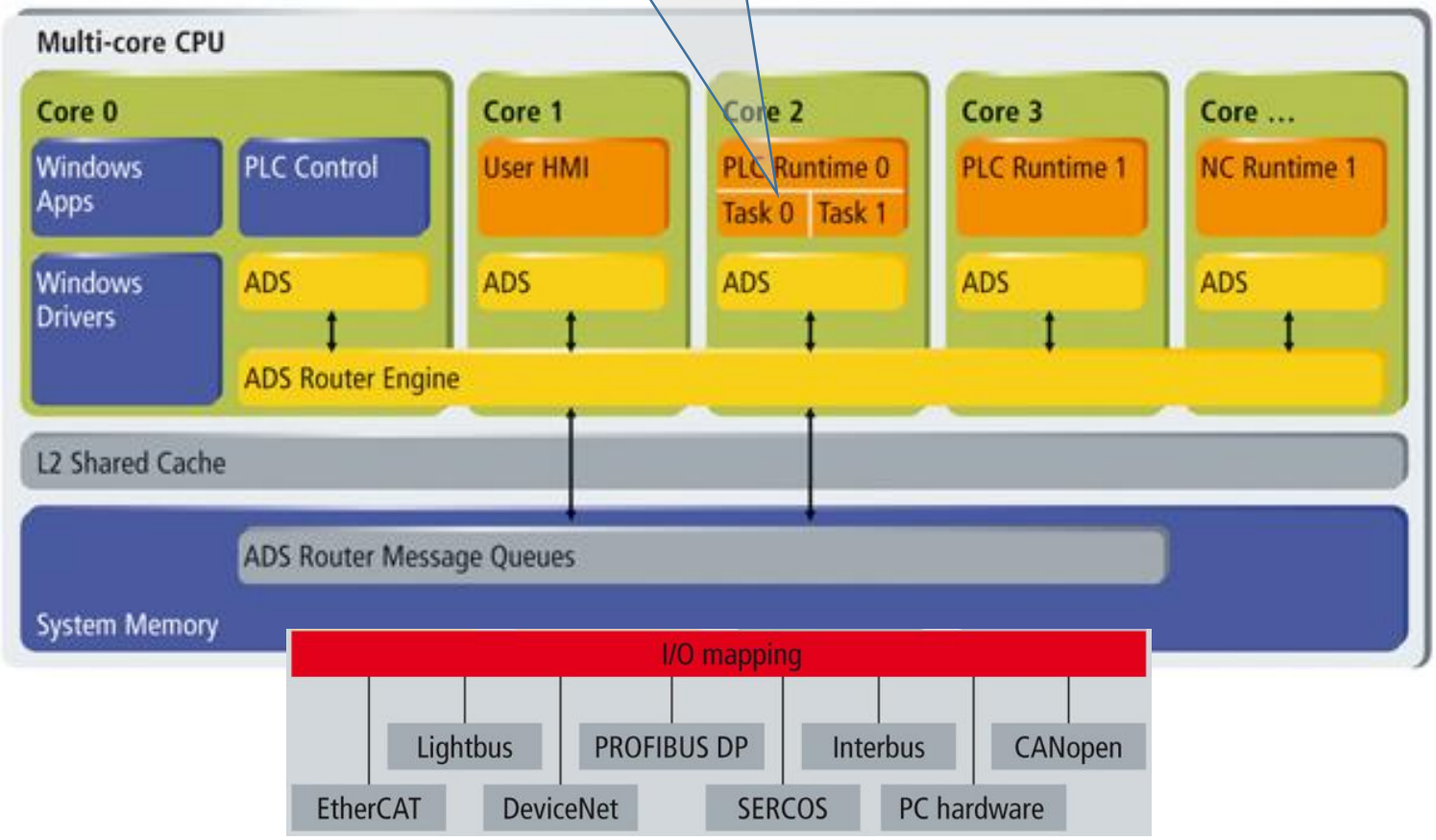
– support of digital I/O EtherCAT Terminals
  – up to 1 MHz
  – up to 1 µs time resolution

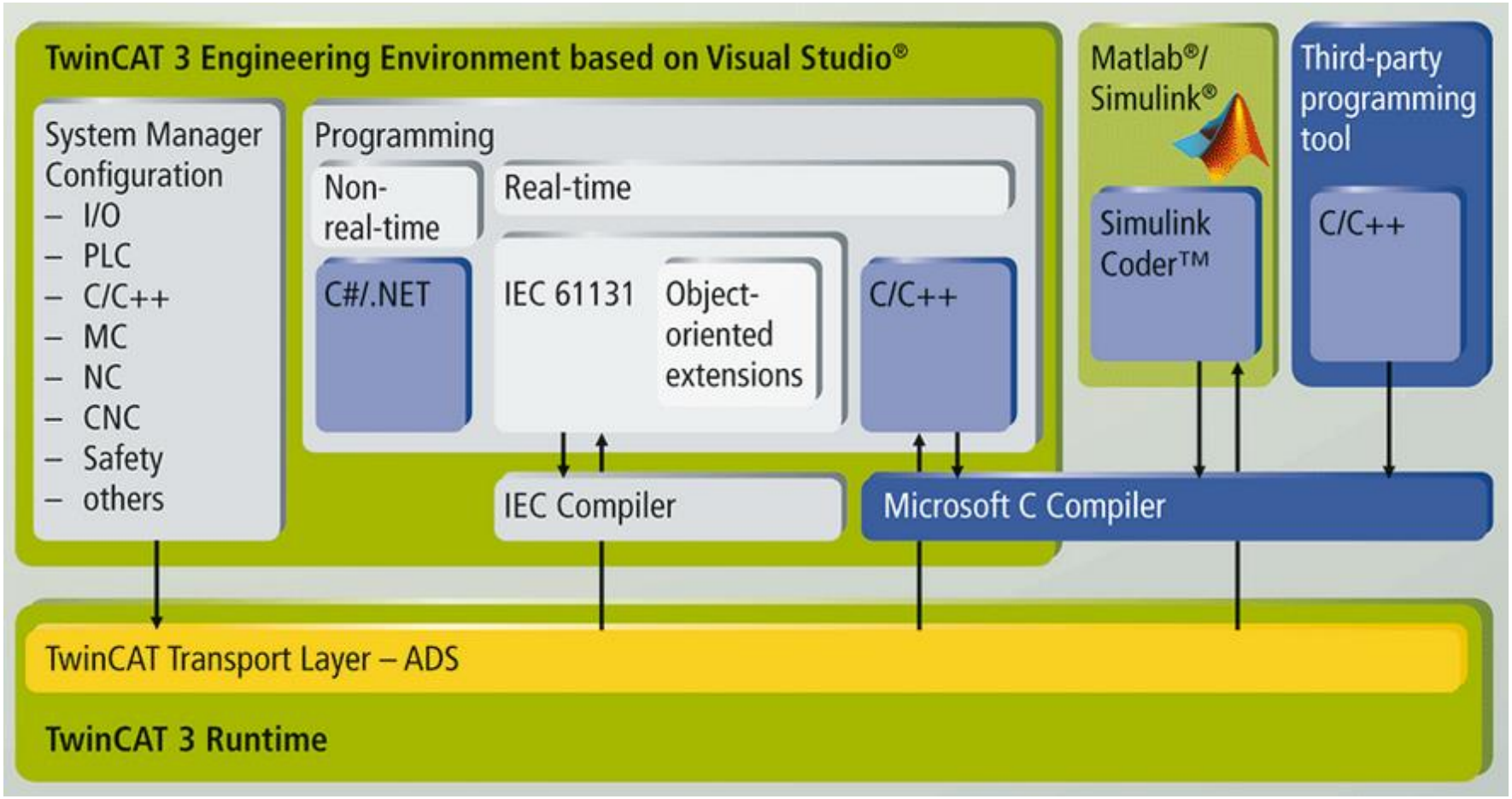
http://www.beckhoff.de

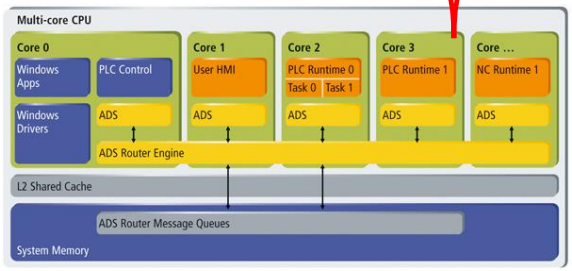


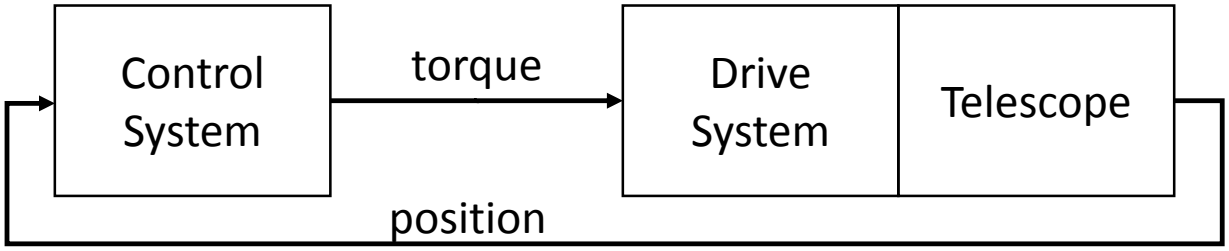

PLC run-time 1 task 1-4
PLC run-time 2 task 1-4
PLC run-time 3 task 1-4
PLC run-time 4 task 1-4
Process image 1
Process image 2
Process image 3
Process image 4
I/O mapping
Lightbus
PROFIBUS DP
Interbus
CANopen
EtherCAT
DeviceNet
SERCOS
PC hardware

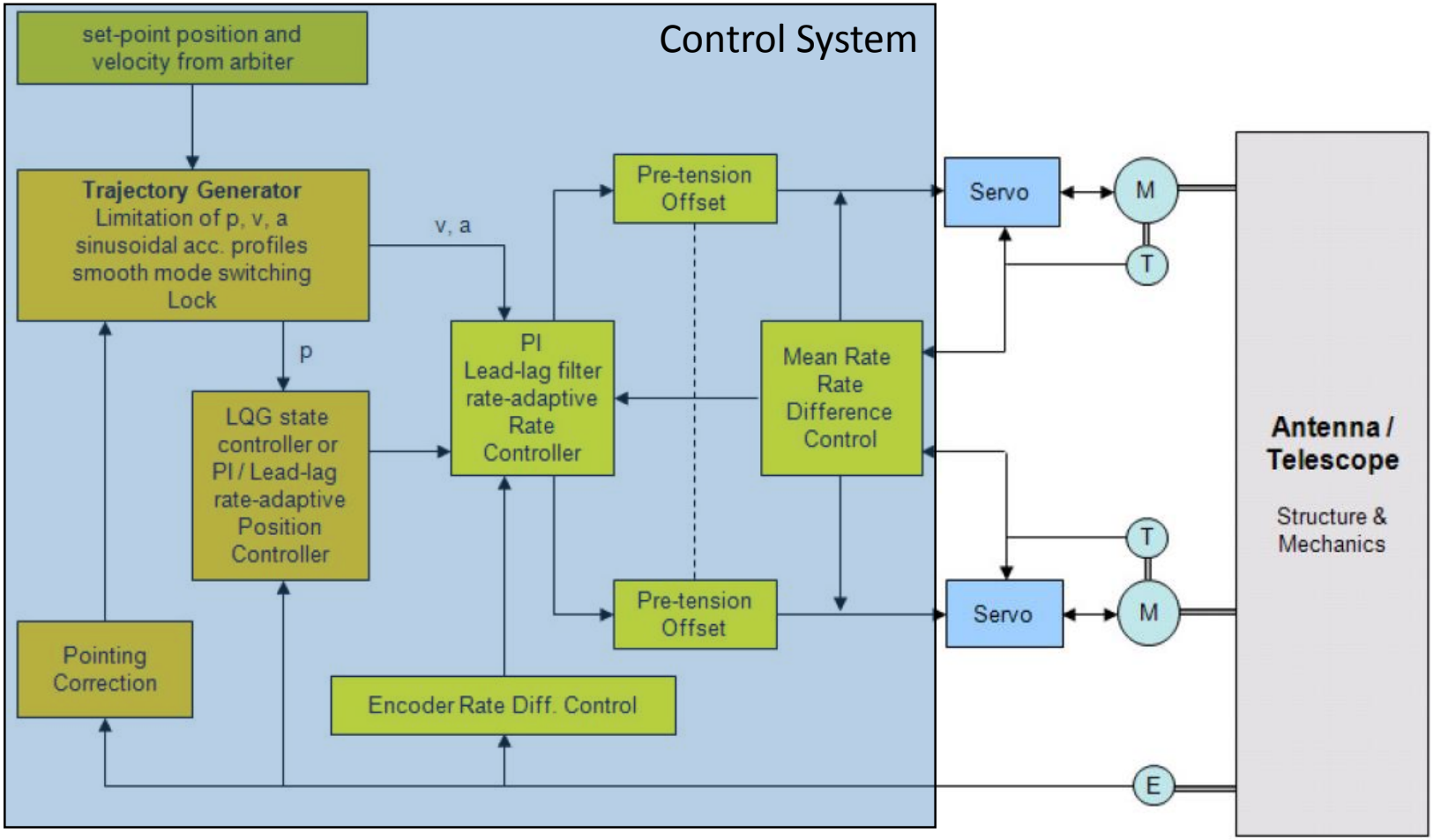


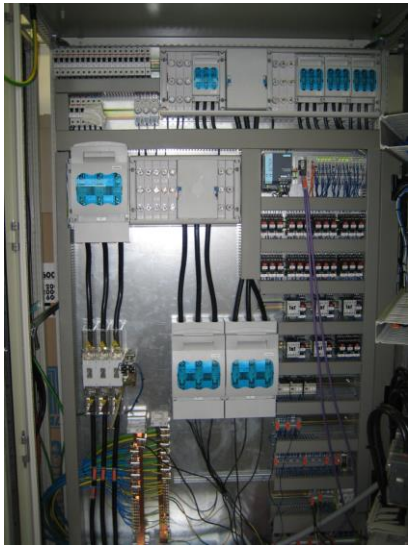

Multi-core CPU
Core 0
Windows Apps
PLC Control
Windows Drivers
ADS
Core 1
User HMI
ADS
Core 2
PLC Runtime 0
Task 0
Task 1
ADS
Core 3
PLC Runtime 1
ADS
Core ...
NC Runtime 1
ADS
ADS Router Engine
L2 Shared Cache
ADS Router Message Queues
System Memory
I/O mapping
Lightbus
PROFIBUS DP
Interbus
CANopen
EtherCAT
DeviceNet
SERCOS
PC hardware


TwinCAT 3 Engineering Environment based on Visual Studio®
System Manager Configuration
– I/O
– PLC
– C/C++
– MC
– NC
– CNC
– Safety
– others
Programming
Non-real-time
Real-time
C#/.NET
IEC 61131
Object-oriented extensions
C/C++
IEC Compiler
Microsoft C Compiler
Matlab®/ Simulink®
Simulink Coder™
Third-party programming tool
C/C++
TwinCAT Transport Layer – ADS
TwinCAT 3 Runtime


Multi-core CPU
Core 0
Windows Apps
PLC Control
Windows Drivers
ADS
Core 1
User HMI
ADS
Core 2
PLC Runtime 0
Task 0
Task 1
ADS
Core 3
PLC Runtime 1
ADS
Core ...
NC Runtime 1
ADS
ADS Router Engine
L2 Shared Cache
ADS Router Message Queues
System Memory


Control System
torque
Drive System
Telescope
position


Control System
set-point position and velocity from arbiter
Trajectory Generator
Limitation of p, v, a
sinusoidal acc. profiles
smooth mode switching
Lock
v, a
p
LQG state controller or PI / Lead-lag rate-adaptive Position Controller
PI Lead-lag filter rate-adaptive Rate Controller
Pre-tension Offset
Mean Rate Rate Difference Control
Pre-tension Offset
Pointing Correction
Encoder Rate Diff. Control
Servo
Servo
M
M
T
T
E
Antenna / Telescope
Structure & Mechanics



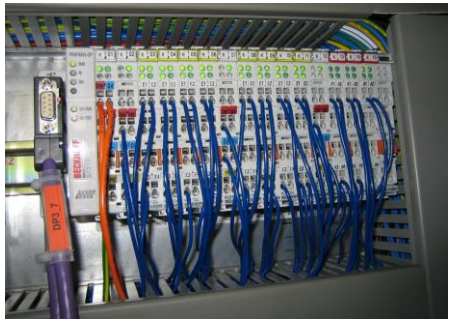
16 azimuth drives + 1 precision encoder

4 elevation drives + 1 precision encoder

2 Stow pin actuators + sensors

1 Local control Panel + 1 hhp + Profibus Remote-IF

6 individual profibus braches (two with m&c protocol)



40m IGN ARIES XXI, Spain

4 azimuth drives + 1 precision encoder

4 elevation drives + 2 precision encoder + 2 tiltmeters

1 primary secondary focus drive

6 M2 hexapod drives

2 M3 elevation drives + precision encoder

1 M3 redirection drive

8 Vertex shutter actuators + sensors

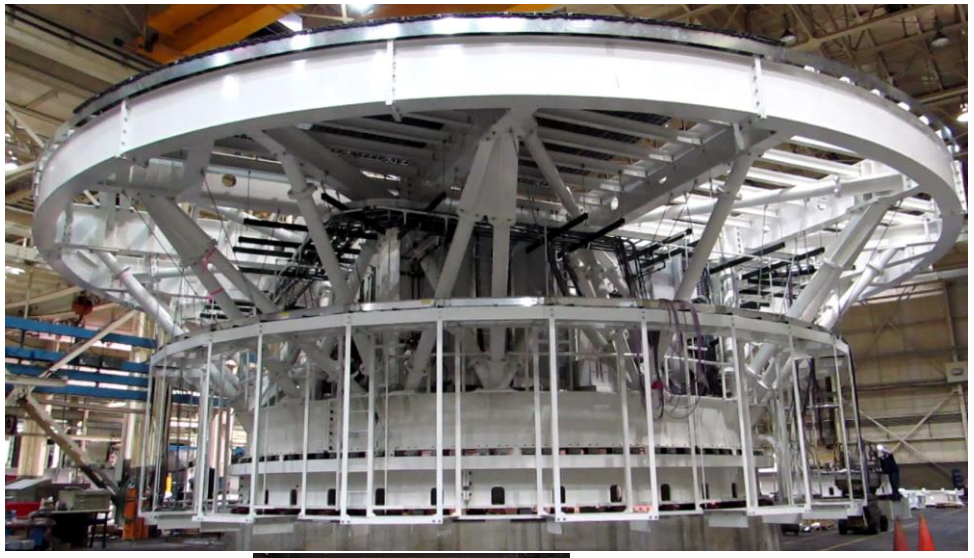
3 Stow pin actuators + sensors

3 local operating panels + 1 hhd + TCP/IP Remote-IF

n+1 distributed safety interlocks (limits, e-stops, doors & hatches,...)

4 individual profibus branches (two with mc-protocol)

4m DKIST Solar Telescope, Hawaii



4 mount azimuth torque drives + 30m precision tape encoder

2 mount altitude direct drives + 2x 4m precision tape encoders

2 high precision, high dynamics tiltmeters

4 coudé azimuth torque drives + 30m precision tape encoder

1 M1 mirror cover ups backup 4,5m x 4,5m closing in ~15sec

2 self driven & synchronized cable wraps

n+10 distributed safety interlocks (limits, e-stops, doors & hatches,...)

2 Individual Control Systems (Mount / Coudé)

1 Control System MCS, based on Linux and CSF

EtherCAT fieldbus with time sync. via IEEE1588 to a grand master clock

13m VLBI Telescopes

4 azimuth drives + 1 precision tape encoder

4 elevation drives + 1 precision tape encoder + 2 tiltmeters

Asynchronious motors for main axes

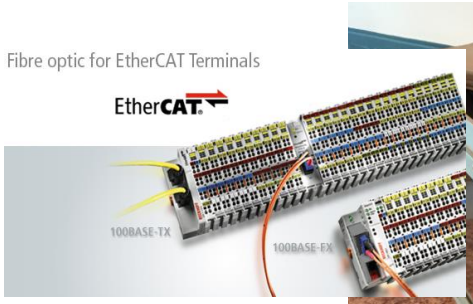
6 M2 hexapod drives

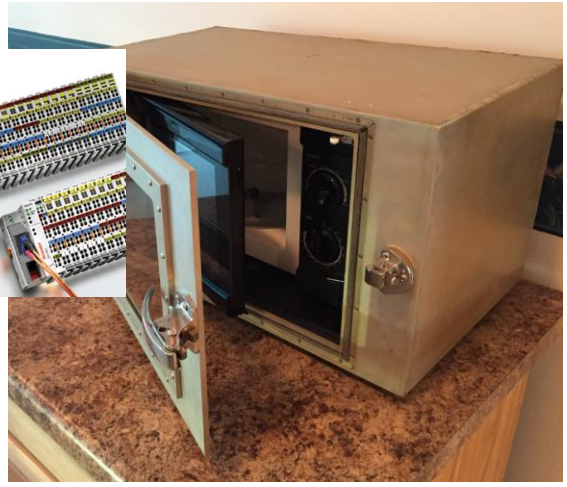
3 Stow pin actuators + sensors

2 local operating panels + 1 hhd + TCP/IP Remote-IF

~12 distributed safety interlocks (e-stops, doors & hatches,...)

1 EtherCAT fieldbus using distributed clocks





Distributed safety system inkl. motion supervision via safe encoder system => position, velocity, acceleration and stop ramp can be monitored

Thank you.