Online computing for ET





for the 'Data acquisition and real time control' work package

'Interferometer Division' of the 'ET Instrument Science Board'



EIB kick-off meeting 30/11/2021

Outline

- Overview of various types of online computing needed to control and operate a GW interferometer
- Explain Data Acquisition (DAQ) chain
- First attempt at defining what is in scope for DAQ/control WP and what for the EIB
- Disclaimer: I am not an expert on computing or data analysis, but have interacted with all software needed to run the Virgo interferometer





Instrument control



- Control system is an integral part of a GW interferometer: keep mirrors quiet and cavities on resonance
- Various levels of control:
 - 1) very fast analog/digital loops (~MHz)
 - 2) fast local control of suspensions (~10 kHz)
 - 3) fast global control of whole interferometer (~10 kHz)
 - 4) slow automation: lock acquisition (~1 Hz)
 - 5) 'human-in-the-loop' monitoring and operation (minutes)
- Hard real time, distributed, hierarchical control
- All signals from control system and environmental monitoring recorded by data-acquisition (DAQ) chain



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Control hardware





- Historic progression of control electronics: analog -> barely working custom digital -> comfortable custom digital -> offthe-shelf
- Current generation: hard real-time digital control consisting of ADCs, DACs, DAQ-boxes and controllers (real-time Linux PCs, DSPs). Typical sample frequency 10-20 kHz, control algorithm programmed by end-user in Simulink or similar
- Distributed system, sensors and actuators separated by kilometers: need real-time fiber communication
 LIGO uses 'Reflected Memory' by Dolphin, Virgo uses home built fiber system (TOLM), maybe >10 Gbit Ethernet in future?
- Fastest loops are mostly analog, but some recent examples of digital loops at \sim 1 MHz More flexible, might go completely digital in future



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DAQ chain



- *'frame builders'* which collect the data of the fast real-time processes in 1-sec chunks of data
- merging of various data streams
- additional signal processing (decimation, image processing, ...)
- automation nodes
- forward frames to storage machines and low-latency pipelines
- provide data viewers, GUIs for human interaction with the interferometer
- data flux relatively modest compared to e.g. CERN, but we care about latency





Automation

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- Automation processes are embedded in the DAQ chain, so they have access to all data (with a latency of a few frames). Responsible for sequencing lock acquisition, various slow loops, basic safety checks
- Currently Python-based hierarchical set of state machines: Guardian/Metatron, see arXiv:1604.01456
- Needs a SCADA-like framework/communication protocol to change parameters of the fast processes (change gains/offsets/change filters, switch on loops): EPICS, TANGO, Cm, ...
- Process monitoring: Virgo Process Monitoring (VPM)



Monitoring

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- GUIs, data viewers for live monitoring of instrument status
- Web-pages with predefined plots for monitoring on scales of hours to days
- Supervising process to check that thousands of parameters are at their expected values, send alarm messages via mails/SMS when something breaks at night: Detector Monitoring System (DMS)





In scope for DAQ/control WP

- Exact boundaries TBD, but roughly "all specialized computing hardware and software that directly interfaces with the experimental hardware": DAQ front ends, data collection, monitoring, data visualization
- Interface with hardware subsystems: monitor/provide analog and digital signals from sensors and actuators, provide computing for their control loops
- Interface with EIB: infrastructure (hardware, software, network), data storage
- Estimate total data flux from front ends to storage input
- Choose the hardware architecture for the real-time detector control and data acquisition:
 - general purpose front-ends with ADCs, DACs
 (as far as they are not built into the sensors/actuators)
 - fast ADCs for digital demodulation
 - low phase noise timing distribution
 - real-time communication network (TOLM, reflective memory, ...)
 - fast computing for controls (real-time PC, DSP, FPGA, ...)
- Provide the software tools/architecture for the detector slow control
- Provide the software tools/architecture for the data acquisition pipeline





In scope for EIB

- Provide general purpose computing hardware for running the DAQ chain and slow controls
- Integrate the hardware for the real-time control in the general computing environment
- Provide hardware for control room and other needs of the commissioners (user management ...)
- Provide network hardware (fibers, patch-panels, ...) and management (DHCP, HTTP, ...) used by all
 experimental devices
- Install and maintain operating systems for DAQ system machines
- Long term storage, distribution and backup of data
- Design the data flow and architecture for online alert generation system
- All off-line computing







- Shared between EIB/DAQ
 - chose frameworks for low-latency frame distribution (Fd like)
 - chose protocol for inter-process communication (Cm/TANGO/EPICS like)
 - define file format for data exchange (gwf, hdf5, ...)
 - common package management?
 - Done by other subsystems
 - provide space, power, cooling for underground control hardware (Infrastructure)
 - software for online data quality (Detector Characterization)
 - software for online/offline data analysis (Data analysis)
 - hardware/software for safety critical systems (laser interlocks, PLCs for vacuum system ...).
 Best if this is provided by the corresponding subsystem, but all status data should be provided read-only to the DAQ system





Scaling up from Virgo to ET

- No major technological breakthroughs needed to control ET, could be evolution of current hardware
 - data flux might increase by order of magnitude: 4 TB/day now, but we will have multiple interferometers that are more complex
 - would like ADCs, DACs with a bit less noise
 - slightly faster digital loops (replace some more analog loops)
 - slightly better timing: lower phase noise
 - upgrade software to state-of-the-art
- Go more from custom built hardware and software to off-the-shelve where possible





the end...



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