GWADW

Controls Sessions

we make it look easy, but …

Opening Comments

- Controls are fundamentally different from the other session topics
  - Difficult to discuss controls for a system/interferometer which has not been designed (barely conceptualized)
  - While control considerations are integral to system design trade-offs, these considerations are generally simple & fundamental (observability/controllability, sensor/actuator locations, bandwidth, …)
  - We assume (correctly, I think) that *“if you build it, they will control it”*
    - *control system design must be integral in the detailed design phase*
- Our control synthesis has been (generally) based on classical control theory
  - Can we benefit from “Modern” controls?
  - Can we benefit from the recent AI successes (e.g. deep learning)?

Controls Sessions

A	Tue	9:00-10:30	System identification and modern Control
B	Tue	11:00 – 12:30	Optimal feedback
C	Tue	4:00 – 6:00	Noise feedforward and subtraction
D	Wed	9:00 – 10:30	Lock acquisition problems and improvements
E	Wed	4:00 – 5:30	Interferometer stability (Keeping the IFO Lock)
F	Wed	6:00 – 7:00	Next Generation Control System Architecture

- *Hopefully not too much scope*
- *Other topics, and sub-topics, are possible, depending upon the interests of workshop participants (e.g. robust controls, fault-tolerant controls, ...). Participants can help us shape the direction of the workshop*

Session A: System Identification

- Data and models for the controller design
- Transfer functions for SISO controller
- Matrices of transfer function for MIMO calculations
- Matrices of transfer functions for Diagonalization
- State Space model for optimal control (fitting, phase loss, right half plan zeros, high order model…)

Problems

- Can be time consuming
- Tune parameters (Amplitude, frequency band, averages…)
- Usually not optimized (Schroeder…)
- SNR, Dynamic range, Saturations… multiple sensors
- Accuracy, coherence (fitting, model reduction, phase loss, right half plan zeros…)

Goals:

- Compare techniques
- Exchange tools and ideas
- Define goals (state of the art, explore new tools…)
- Could help upgrades, next generations (early stages of testing and commissioning)

A	Tues	9:00	10:30	1:30	System identification and modern Control	Coordinating/Leading discussion	Brett Shapiro
		9:00	9:15	0:15		Overview of System ID techniques & setting the session goals	Dennis
		9:15	9:35	0:20		System ID for Suspensions & Seismic Isolation Systems	Brett Shapiro
		9:35	9:55	0:20		System ID at VIRGO	Bas Swinkels
		9:55	10:15	0:20		Cross couplings in suspensions and seismic platforms	Anamaria Effler
		10:15	10:30	0:15		Sys ID for Modern Control	Brett, Jo, Giancarlo, Manuel

Session B: Optimal Control

- SISO filtering versus Optimal Control
  - We have a very good knowledge of our systems,
  - Designed to be diagonal
  - Extremely well instrumented, all dofs, states measured
  - SISO is easy to debug (phase margin, gain margin…)
  - Pole placement, high order controller
- (i) Optimal controllers (ii) Observers, SNR (iii) Modal control
- LQR: Cost function, weight…
- Kalman filter

Goals:

- Already investigated, good outcome, still not used, why
- Prospects, application
- Working groups, collaboration

Partial step done…

B	Tues	11:00	12:30	1:30	Optimal feedback	Coordinating/Leading discussion	Dennis/Fabrice
		11:00	11:20	0:20		Introduction talk (review of modern control tools, state space methods, their pros and cons)	Den Martynov
		11:20	11:40	0:20		Discussion and comparison of classical and modern control techniques	Christophe Collette
		11:40	11:55	0:15		Summary of the Caltech Workshop	Gabriele
		11:55	12:15	0:20		Kalman filtering for vibration isolation	Jo van den Brand
		12:15	12:30	0:15		Suspension Controls, including thoughts on applicability of modern controls	Brett Shapiro

Session C: Feedforward and noise subtraction

Already made the step…

- The standard way (rely on intuition, identify the sensor path, identify the correction path, implement)
- The optimal way (array of sensors, linear regression, least square minimization, Wiener…)
- Results already obtained

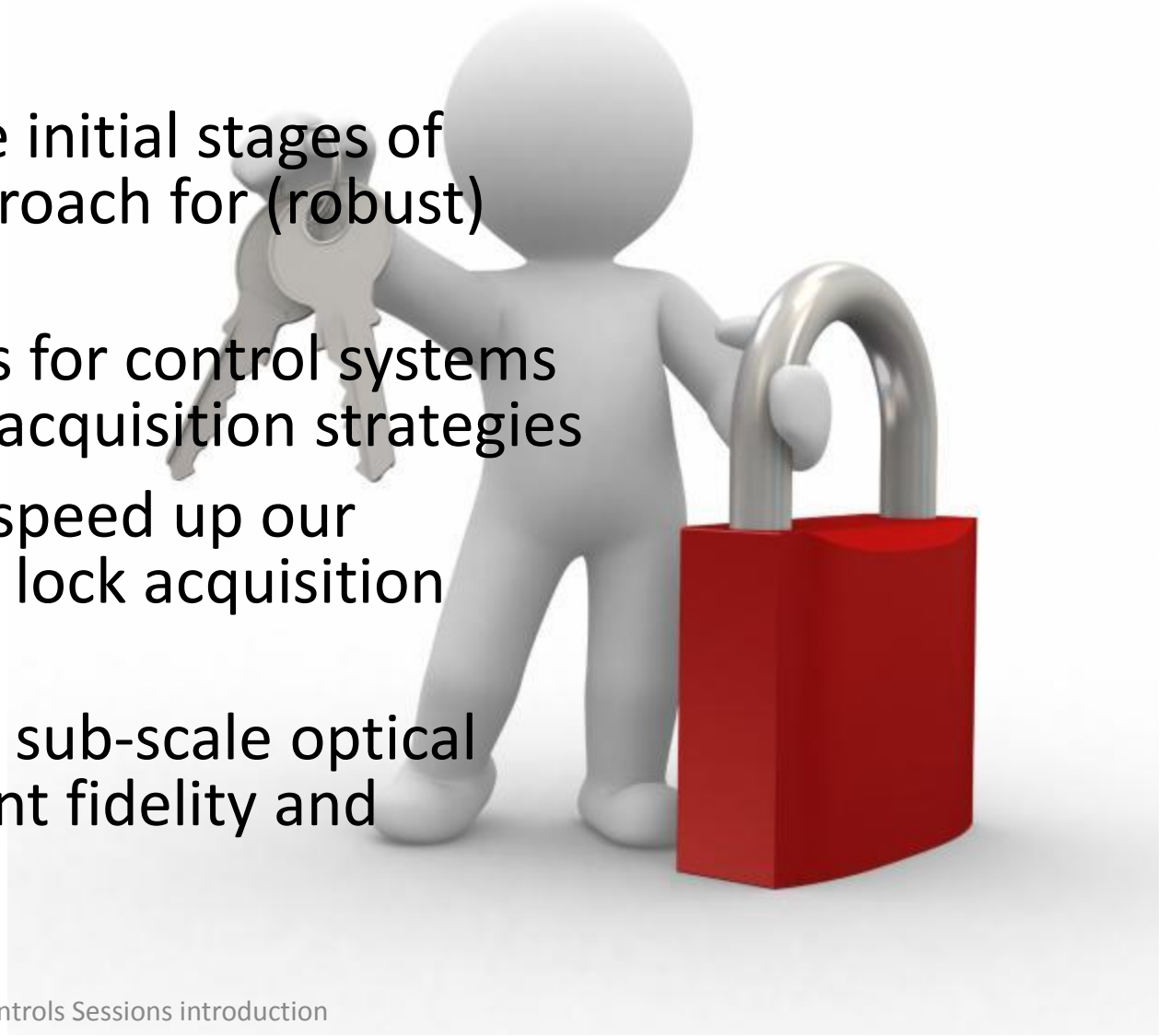
Goals:

- Where do we stand (Past results, current work)
- Prospects, applications
- Instrumentalist and DetChar
- Automating
- Adaptive

C	Tues	4:00	6:00	2:00	Noise feedforward and subtraction	Coordinating/Leading discussion	Gabriele Vajente
		4:00	4:10	0:10		Introduction and setting the stage	Gabriele Vajente
		4:55	5:15	0:20		Sensor correction in seismic and suspensions	Fabrice
		4:10	4:35	0:25		Feed forward of auxilairy degrees of freedom	Bas Swinkels
		5:15	5:30	0:15		Online subtraction pipeline, and bilinear noise coupling	Keita Kawabe
		4:35	4:55	0:20		Feedforward at LLO and 40m, adaptive feed forward	Denis Martynov
		5:30	6:00	0:30		Data mining tools: hot to find channels that can be used for subtraction; how to tackle non stationary noises and couplings?	Gabriele Vajente

D: Lock Acquisition Problems & Improvements: *description*

- Significant time is expended in the initial stages of commissioning to discover an approach for (robust) lock acquisition
- Perhaps one of the biggest payoffs for control systems is in improving the nonlinear lock acquisition strategies
- Can learning methods be used to speed up our discovery of faster or more robust lock acquisition strategies?
- Can simulation, or emulation with sub-scale optical plants, be used to provide sufficient fidelity and examples for learning strategies?



D: Lock Acquisition Problems & Improvements: *program* – *Wed 9:00a – 10:30a*

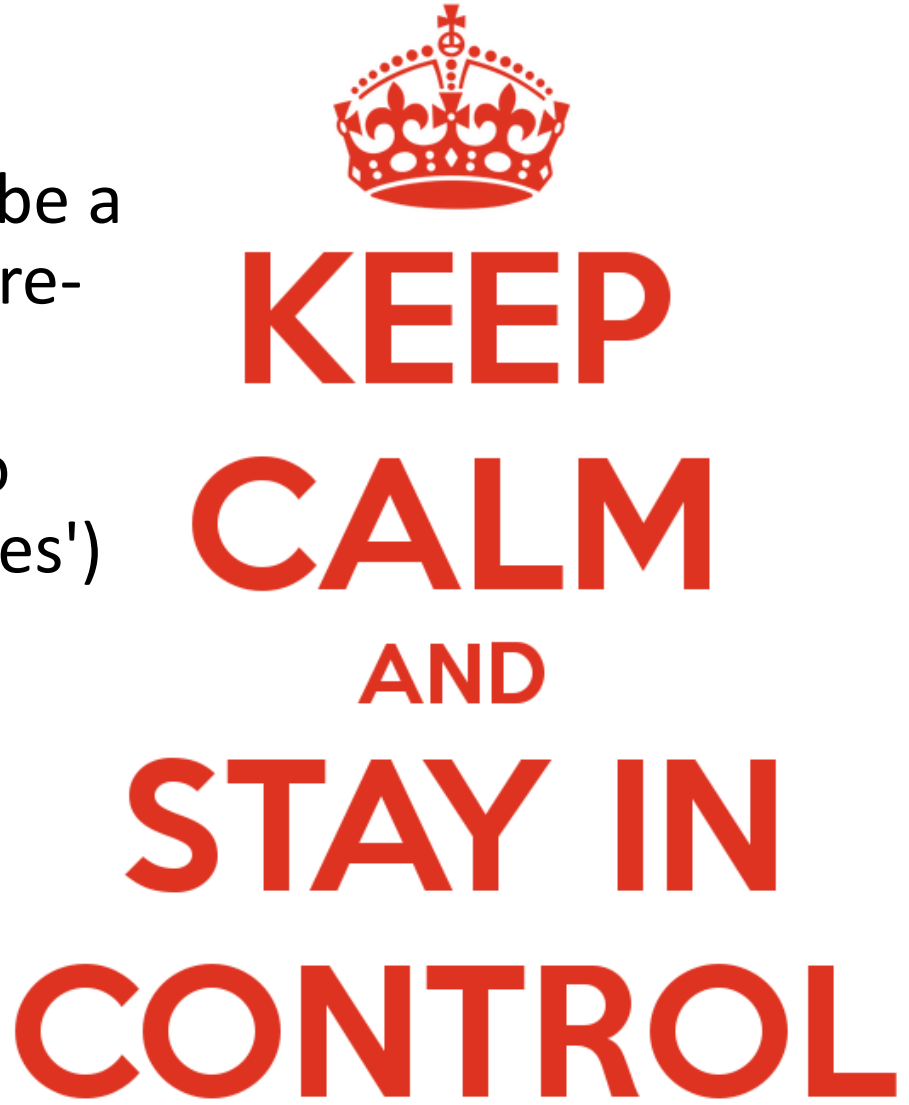
- Session to be led/coordinated by Keita Kawabe
- Acquisition overview/problems & discussions
  - LHO (*Sheila Dwyer*) LLO (TBD)
  - VIRGO (TBD) GEO (TBD)
  - KAGRA (TBD) 40m Lab (TBD)
  - Group discussion on common themes
- "Mode hoping in low finesse cavities" (*Paul Faulda*)
  - one potential lock acquisition problem
- "Bayesian approach to the locking problem for high finesse suspended optical cavities" (*Manuel Marchio and Giancarlo Cella*)
- "Noise modeling for interferometer control" (*Chris Wipf*)
  - focused on how noise budget modeling can be useful for locking and lock loss studies

D: Lock Acquisition Problems & Improvements: *goals/questions*

- From each interferometer, gather a compendium of
  - lock acquisition problems
  - Locking metrics & statistics
- Discuss approaches to address each lock acquisition problem and their relative merits and success to date
- Are the pre-lock auxiliary systems (OptLev, ALS, TCS, …) adequate, or are improvements necessary?
- Shouldn’t future interferometers be designed to observe and control all DOF (bounce, roll, violin modes)?
- Would we benefit from embedding independent sensing/actuation into the interferometers for routine diagnostic measurements & characterization?
- Which lock acquisition problems can & should be pursued on small scale research interferometers?

E: Interferometer stability (maintaining lock) *description*

- Much of an interferometer's down-time may be a result of cavity lock loss and subsequent lock re-acquisition
- Methods to prevent lock loss (whether due to environmental disturbance or machine 'glitches') could be very beneficial
- Potential causes: wind, earthquake, thermal stability, parametric instability, ...



E: Interferometer stability (maintaining lock) *program* – *Wed 4:00p – 5:30p*

- Session to be led/coordinated by Sheila Dwyer
- Overview of lock loss events/causes (Geo/Virgo/LHO/LLO)
  Bas Swinkles, Anamaria Effler, Keita Kawabe, Hartmut or Kate ?)
- Mitigation of disturbances caused by wind on the detectors
  (Krishna)
- TCS controls approaches to prevent lock loss, or mitigate the effects of lock loss (Alastair Heptonstall)
- LIGO/Virgo earthquake studies and controls configuration (Sebastien Biscans, in collaboration with Michael Coughlin and Paolo Ruggi)

E: Interferometer stability (maintaining lock) *goals/questions*

- Gather a compendium of lock loss event causes
  - Do we have detchar infrastructure for automatic detection, logging, and calculation of statistical metrics?
- Discuss approaches to address each lock loss cause and their relative merits and success to date
- Are the lock loss prevention auxiliary systems adequate, or are improvements necessary?
- Would we benefit from embedding independent sensing/actuation into the interferometers for environment sensing?
- Which lock loss problems can & should be pursued on small scale research interferometers?

F: Next Generation Control System *Architecture *description*

- Explore the requirements and features of a next-generation, control system architecture
  - supervisory controls,
  - slow controls
  - fast, real-time controls
- We need participation from real-time control system experts and commissioners

*by architecture we mean “everything”: hardware, software, interfaces, comm. protocols, DB mgmnt …

F: Next Generation Control System Architecture *program* – *Wed 6:00p – 7:00p*

- Session to be led/coordinated by Jamie Rollins
- Requirements and features of a next generation control system (Jamie Rollins)
  - With hoped-for participation by many control system users
- Pros & Cons of Current Gravitational Observatory Control Systems (Rolf Bork)
  - With hoped-for participation by many control system users

F: Next Generation Control System Architecture *goals/questions*

- Requirements and desired features of next generation control systems
- In what ways can we the GW community better collaborate/share and (possibly) migrate to a common platform, or at least common elements?
- What systems and technologies are emerging which show promise for future detectors?
- Develop a plan to explore the applicability of industrial control systems and the experience of other physics projects with modern and next-generation control systems

Final Comments

- How can we as a community share and sustain a growing expertise in the application of advanced/modern controls to GW interferometer systems?
  - We lost the momentum from the 2014 winter workshop on advanced controls at CIT
  - LVC working group on controls techniques?
  - Bi-yearly (virtual) meetings?