Controls and Machine Learning Workshop Summary

Gabriele Vajente - Caltech
Bas Swinkels – NIKHEF

GWADW 2021

Short but rich session

15:00 → 16:00 **Controls and machine learning workshop: Hour 2**

Conveners: Bas Swinkels (Nikhef) , Gabriele Vajente (Caltech)

15:00 **Lightsaber: A simulator of the angular sensing and control system in LIGO** 20m

The fundamental requirement for the angular sensing and control (ASC) scheme is to suppress the angular mirror motion at low frequencies, to overcome radiation pressure induced angular instabilities, without reintroducing noise in the GW signal. In the process of controlling test masses' angular motion at low frequencies, high-frequency noise is introduced in the observation band originating mainly from the readout noise of sensors. During the 03 run, controls noise dominated the noise budget approximately between 10 Hz and 25 Hz, and it was a significant noise source up to 55 Hz and there is no straightforward solution. We need better tools to analyze the system and for the development of solutions. We present Lightsaber, a new time-domain simulator of the ASC in LIGO. The simulation is a full, nonlinear simulation of the optomechanical system consisting of the high-power cavity laser beam and the last two stages of suspension in LIGO with the control system, focusing on pitch dynamics. Main noise inputs are power fluctuations, read-out noise of sensors, seismic noise from the ISI, and suspension damping noise. There is the conversion between the local and global basis of the angular motion in the linear feedback control, exactly as in the real system. Some of the studies that can be done with this simulation are understanding the role of DC miscentering and laser power fluctuations for angular dynamics and nonlinear angular mirror pitch motion to strain noise coupling.

Speaker: Tomislav Andrić (Istituto Nazionale di Fisica Nucleare)

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15:20 **Modal decomposition of phase camera images using convolutional neural networks** 20m

The alignment control systems of gravitational wave interferometers extensively rely on heterodyne imaging techniques to sense various length & misalignment degrees of freedom. This is achieved via demodulating the beat of various radio-frequency sidebands measured on single and quadrant element photo-diodes. Such a technique offers very high bandwidth sensing but is limited to resolutions of only a few pixels. Future gravitational wave detectors that utilize both higher circulating powers and higher levels of squeezing will require alignment systems which can sense and correct for higher order defects. There are currently various high resolution heterodyne imaging techniques, known collectively as phase cameras, which can provide higher resolution images of the sideband fields and allow the sensing of higher order defects. The utilization of phase cameras requires the development of techniques for processing and analyzing the images they produce.

In this presentation we report on recent work in training a convolutional neural network to perform modal decomposition using simulated phase camera images. This is to our knowledge the first machine learning decomposition scheme to utilize complex phase information to perform modal decomposition. The results of this work shows promise for future machine learning integrated alignment control schemes.

Speaker: Mitchell Schiworski (OzGrav, University of Adelaide)

Schiworski_Mode...

15:40 **Wavefront Sensors for 3rd Generation Gravitational Wave Detectors** 20m

Wavefront sensors are essential devices in gravitational wave detectors since they are an indispensable tool for the control of the interferometer and a valuable help for the optimisation of the detector.
Next-generation gravitational wave detectors will introduce some fundamental changes that will influence the performance of these sensors (e.g. the use of laser with different wavelength) and requires the development of novel, optimised, sensors. At Nikhef we are developing and characterising new InGaAs/InP photodiodes. We are currently focusing on low-noise large-area quadrant photodiodes for LISA. However, this work will also help us to gain experience in designing new sensors and in characterising photodetectors for future earth-based gravitational wave detectors, like for example ET. We will discuss shortly a strategy towards new sensors for longer wavelengths (1.5 and 2 micron): extended InGaAs, quantum dots, etc.
In parallel we are optimising the Nikhef Phase Cameras, wavefront sensors currently in use at Virgo to read phase and mode content of the beam. They can be used to implement feedback to correct the thermal effects that create aberrations in the mirrors. However, we are not yet using Phase Cameras to their full potential. So far only the intensity profile is studied to determine the the Higher-Order-Mode content, and we like to discuss how to utilise the phase information.

Speaker: Daniela Pascucci

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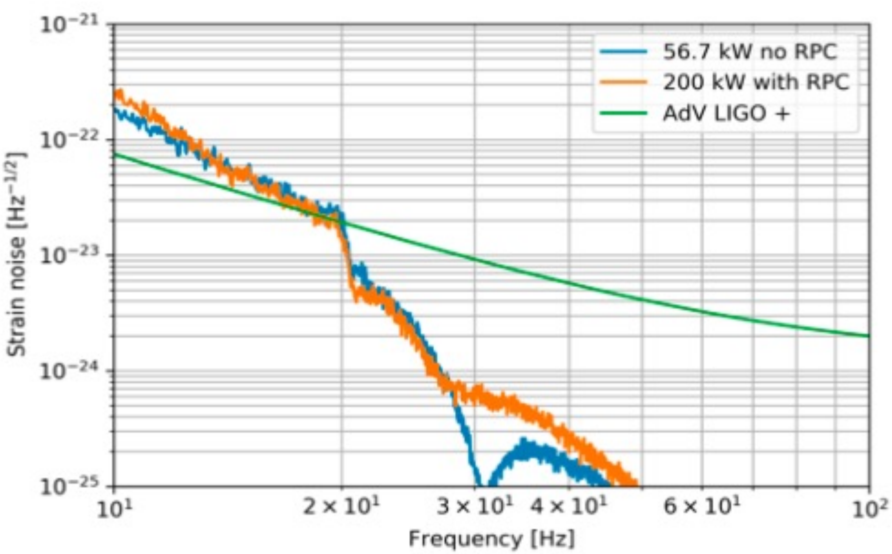
Time domain modeling of angular control

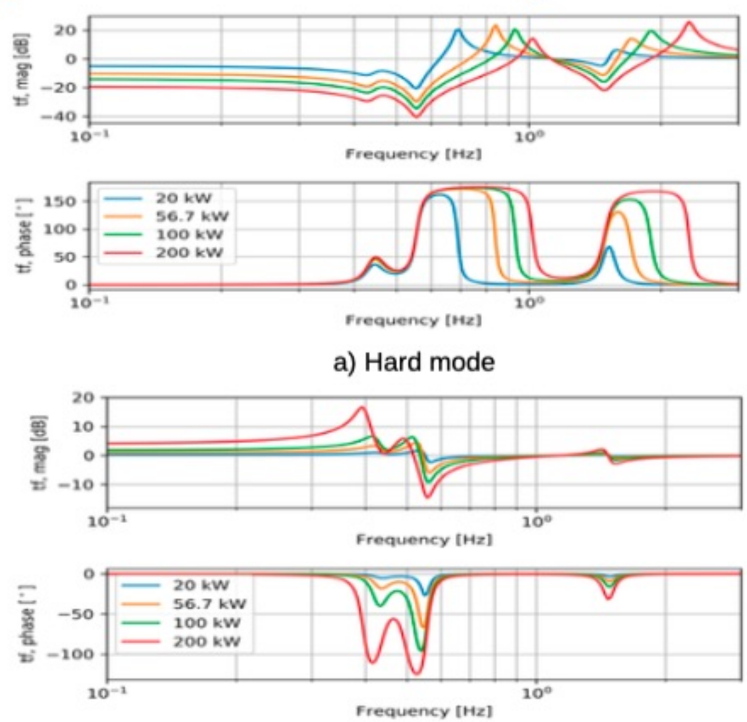
- Development of a time domain model of angular dynamics and couplings
- Allow to model controls, noise couplings
- Starting point for application of Reinforcement Learning, in collaboration with DeepMind

Lightsaber: A simulator of the angular sensing and control system in LIGO

Tomislav Andrić
Jan Harms
Hang Yu
Rana X. Adhikari



Optomechanical system



a) Hard mode

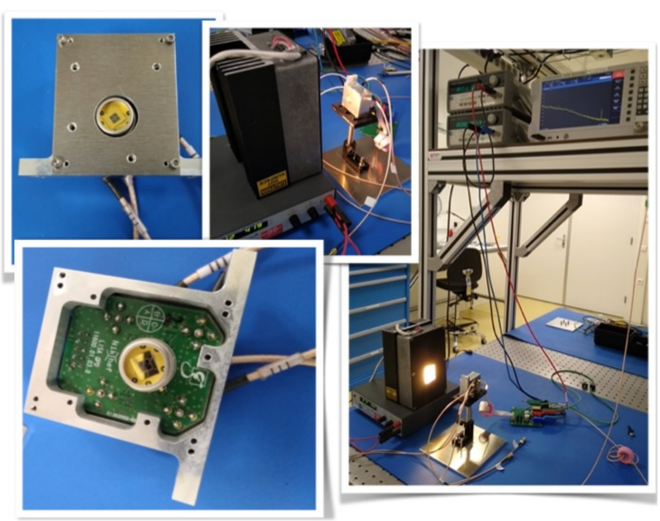
b) Soft mode

Wavefront Sensors for 3rd generation

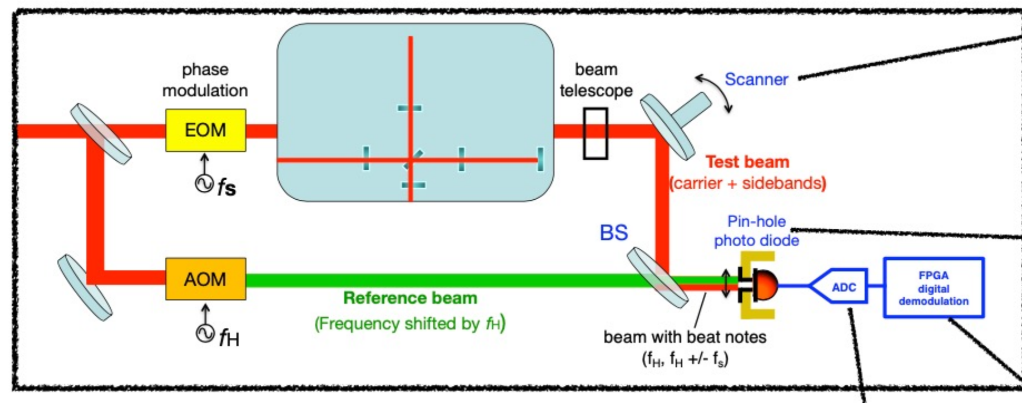
Development of quadrant detectors for LISA

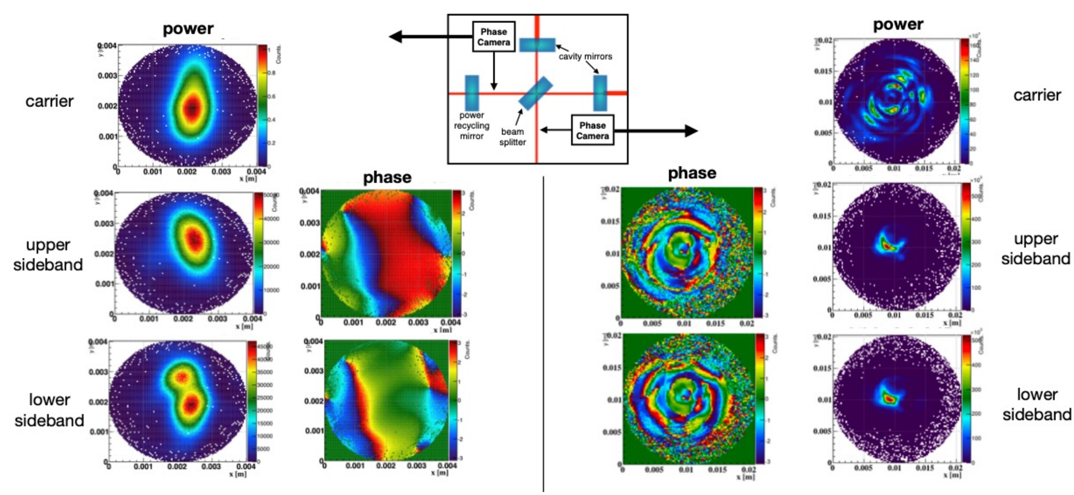
Requirements

- **Diameter: 2.0 mm (goal)**
  - Large is better to simplify alignment, but it would imply large capacitance
- **Gaps: 10 – 20 μm**
  - Large gap will waste light and increase TTL coupling noise
- **Current noise: < 2 pA/$\sqrt{Hz}$**
  - It requires low capacitance
- **Bandwidth: 2 … 25 (30) MHz**
  - It will depend from the Doppler shifts from the relative motion of the spacecraft
- **Responsivity: > 0.7 A/W (@1064 nm)**
  - To avoid wasting photons which would reduce SN ratio ➡ InGaAs



Development of phase cameras for Virgo





Machine Learning for Phase Camera Image processing

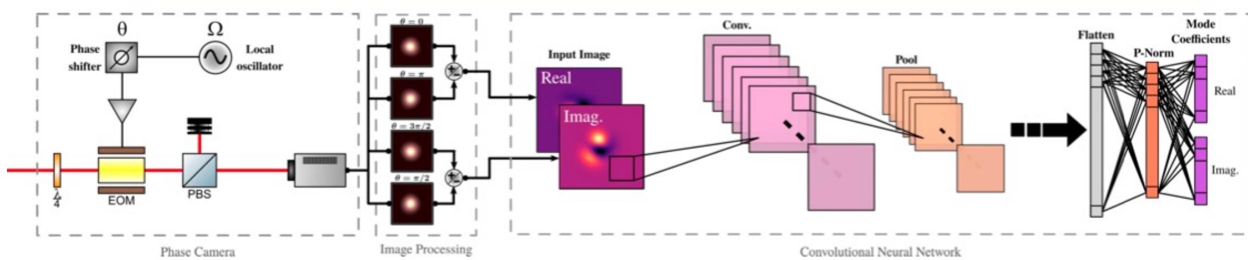
- Help with numerical interpretation of phase camera images, by decomposing into Hermite Gauss modes
- Using Machine Learning to improve accuracy and speed
- Network less susceptible to beam centering

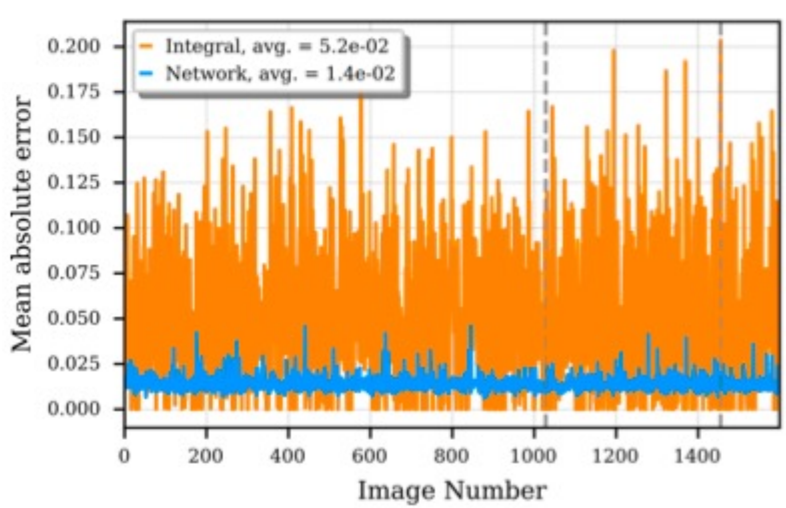
Mode decomposition of phase camera images with convolutional neural networks

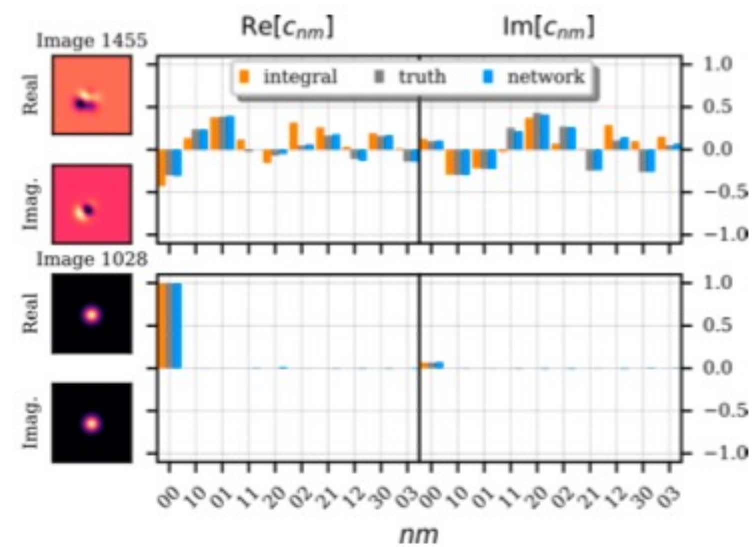
Mitchell G. Schiworski, Daniel D. Brown, and David J. Ottaway

OzGrav, Australian Research Council Centre of Excellence for Gravitational Wave Discovery
Department of Physics and The Institue of Photonics and Advanced Sensing (IPAS), University of Adelaide, SA, 5005, Australia

CNN decomposition







Summary

- Sessions showed interest in new (for us) techniques like Machine Learning, Neural Networks and Reinforcement Learning
- Lot of overlap with other sessions: especially Low Frequency