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Control in Gravitational Wave detectors

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1 Introduction

Gravitational Waves are distortions of *spacetime* which are induced by cosmic events such as the merger of black holes. Current generation detectors such as Virgo [1] and LIGO [2] have been able to measure these spatial distortions which are in the order of 1×10^{-18} m. Next generation detectors such as Einstein Telescope [3] aim to measure distortions in the order of 1×10^{-20} m, allowing to look even further into space.

2 Measurement principle

These distortions of space are measured using the concept of interferometry. In Fig. 1, a basic interferometer is shown, which is a simplified configuration of a typical Gravitational Wave detector. The laser on the left emits a beam of light through the Beam Splitter (BS), splitting the beam into two orthogonal directions: to the right and upwards. The individual beams are reflected back by the End Mirrors (EM) and subsequently interfere at the BS. The interference pattern, determined by the relative length difference between the BS and two EMs, is measured by a photodiode (PD). Gravitational Waves have the property that they stretch *spacetime* in a certain direction and simultaneously contract it in the orthogonal direction by the same amount, hence changing the measured interference pattern.

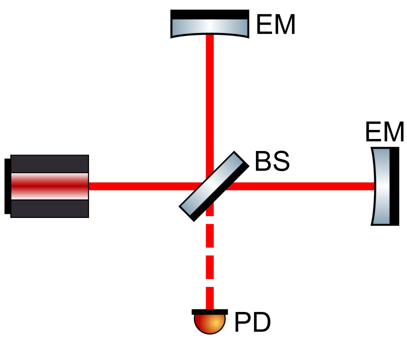

Figure 1: Simplified configuration of an interferometer used in Gravitational Wave detectors.

3 Control challenges

Control systems play a crucial role in the operation and performance of Gravitational Wave detectors. One of their main applications is to actively align the mirrors with respect to each other, both in the longitudinal direction of the beam as well as their angular orientations. The mirrors and other optical components must furthermore also be isolated from environmental disturbances, requiring the use of multi-stage vibration isolation systems. Passive isolation is typically not sufficient, necessitating active control of the isolation stages. Both types of control systems are often MIMO problems that deal with different types of disturbances, yielding a variety of challenges when designing the controllers for these systems.

The sensitivity of the detector is solely determined by a single degree of freedom (DoF), which is the difference in length between the two arms. Each disturbance couples through different subsystems to the differential arm length and many of these disturbances are attenuated on a subsystem level. A more global approach to the control design may yield further improvements in terms of optimizing the detector sensitivity.

4 Technological challenges

Current and next generation Gravitational Wave detectors face a wide variety of technological challenges. Advancements in the control systems can contribute to tackling many of these challenges and therefore lead to improved detection capabilities.

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