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Advancements in Real-Time Control Systems and Sensing Technologies for Seismic Isolation in Future Gravitational-Wave Detectors

The pursuit of next-generation gravitational-wave detectors, such as the Einstein Telescope, with its ambitious goals for sensitivity, places extreme demands on the complex systems controlling the position of suspended mirrors. Operating in underground environments with exceptionally low seismic noise and targeting an extended bandwidth from low to high frequencies, these systems require major advancements in real-time control and sensing technologies. At INFN Pisa, we are investigating several solutions to address these challenges.

In terms of electronics hardware, we are pursuing two primary strategies. Firstly, we are improving consolidated DSP-based architectures, extending flexibility with FPGA modules and optimizing data converters. This will also support the upcoming upgrades to the current generation of detectors. Secondly, we are exploring the potential of GPU-accelerated architectures, including integration of machine learning techniques for controls and data processing tasks. The feasibility of this solution is under evaluation on a GPU-FPGA testbed, using direct memory access techniques to reduce latency, a critical parameter for reliable operation.

In parallel, we are progressing with the development and testing of position and inertial sensors, particularly focusing on the evaluation of optical readout mechanisms for a newly designed accelerometer. A tabletop test system based on a fiber-optic interferometric setup is used to assess performance, aiming for novel solutions to improve the sensitivity of current sensor technologies.

This contribution would like to present the status of these ongoing R&D efforts at INFN Pisa, along with preliminary results from experimental testbeds.

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