Optimal Sensor Fusion using $\mathcal{H}_\infty$ Methods - Synthesizing Complementary Filters for Active Seismic Noise Isolation Systems in KAGRA*

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Abstract

Like LIGO and Virgo, active isolation is used in KAGRA to suppress low frequency seismic disturbances acting on the interferometer main optics. Active isolation, such as feedback and feedforward control, can introduce control noise at higher frequencies, which would contaminate the sensitivity of the detector in the detection band, i.e. $10 - 1000\,\mathrm{Hz}$. One way to reduce the control noise is to minimize the noise of the sensors that are used for active isolation. This can be achieved by so-called sensor fusion technique. One of the sensor fusion techniques is to simply combine the readouts from many different sensors via complementary filters, which compose of filters that are summed to unity, to produce a virtual sensing readout that has overall better noise performance. Here, we propose to use $\mathcal{H}_\infty$ method to synthesize complementary filters that optimally blends two sensors with different noise characteristics. We define a generalized plant that has an $\mathcal{H}_\infty$ norm that is approximately the maximum log-difference between the complementary sensor readout noise and the lower bound of the sensor noises. The plant has a regulator equal to one of the complementary filters. Therefore, $\mathcal{H}_\infty$ synthesis gives an optimal complementary filter that suppress the sensor noise to very close to the lower bound of the sensor noises at all frequencies. We also show that many control problems, e.g. feedback control filters and sensor correction filters, in active isolation can be formulated as a complementary filter problem. And so, this method is not only applicable to sensor fusion, but is also related to many aspects in active vibration isolation in gravitational wave detectors.

*I need help on designing the title. I want a title that contains the words "optimal", "sensor fusion", "$\mathcal{H}_\infty$", "active seismic noise isolation", and "KAGRA".