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FACULTY
OF MATHEMATICS, INFORMATICS
AND NATURAL SCIENCES

MACHINE LEARNING FOR MOTION PREDICTION OF SUSPENDED OPTICS AND SEISMIC NOISE CANCELLATION

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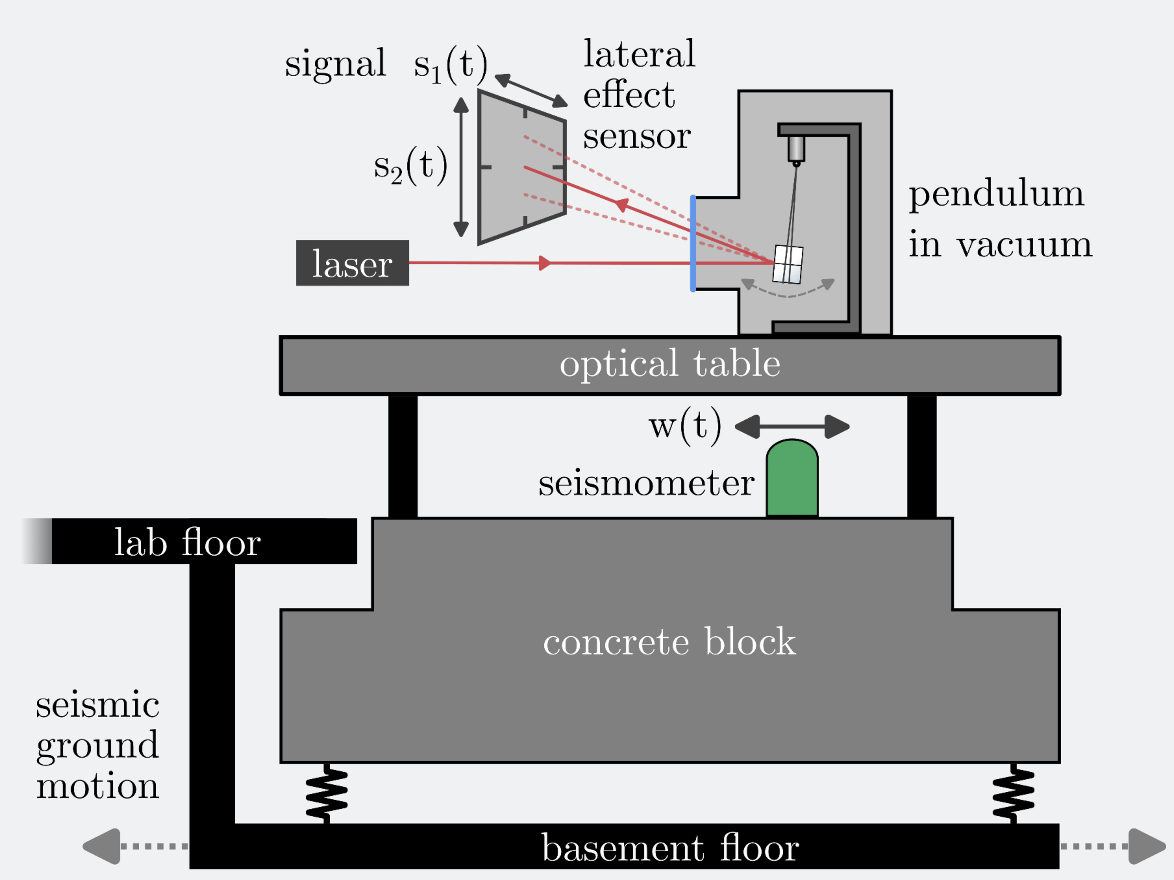
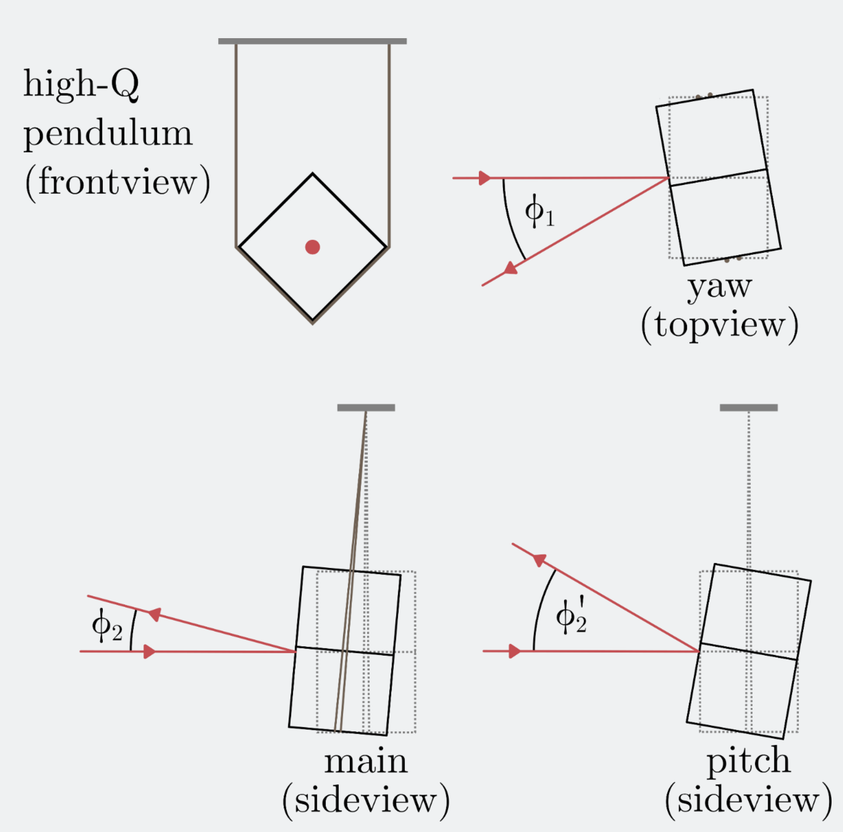
HIGH-Q PENDULUM EXPERIMENT

Our setup features a coated fused-silica test-mass suspended on tungsten fibers in a high vacuum environment. By tracking the horizontal and vertical beamspot motion of a reflected laser beam, we recorded the excitation of various pendulum modes over multiple days. Additionally, a seismometer recorded the seismic motion of the passive isolation platform supporting the suspension setup. This platform consists of a 30 metric ton concrete block suspended on helical springs directly coupled to the building's basement. The corresponding spring-mass system has resonances at 2 and 3 Hz, amplifying the natural seismic activity around these frequencies.

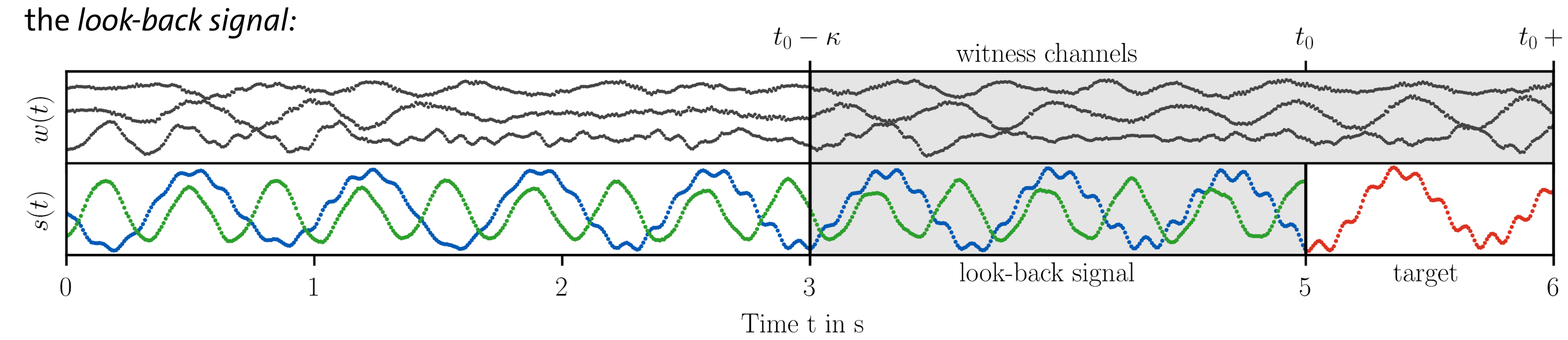


The test-mass with a weight of 100 g has a rectangular profile to provide sharp contact points to the suspension wires. Q-factors between 10^4 and 10^5 were observed for the suspension modes. The horizontal deflection of the beam ϕ_1 mainly corresponds to excitation of the yaw mode resonance around 3 Hz while the vertical deflection ϕ_2 is dominated by the main pendulum and pitch-mode at 1.4 and 10 Hz, respectively.

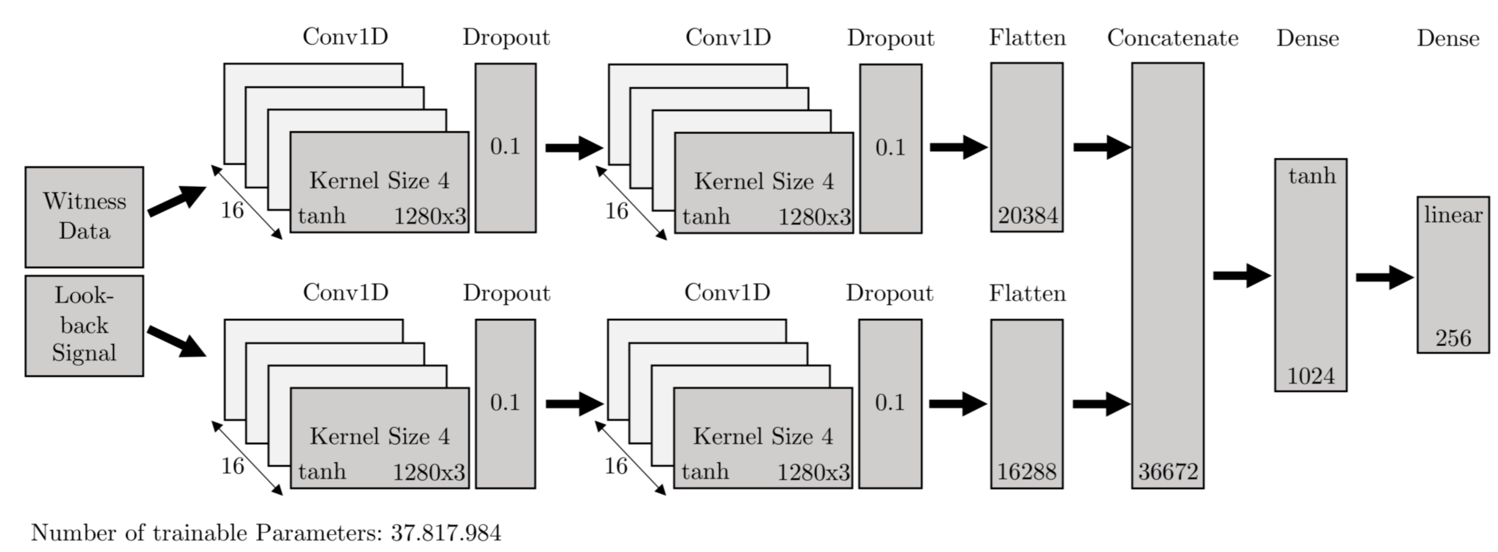


DATA PIPELINE

The goal is predicting the vertical beamspot motion in the *target* window utilizing the seismic *witness channels* and the *look-back signal:*



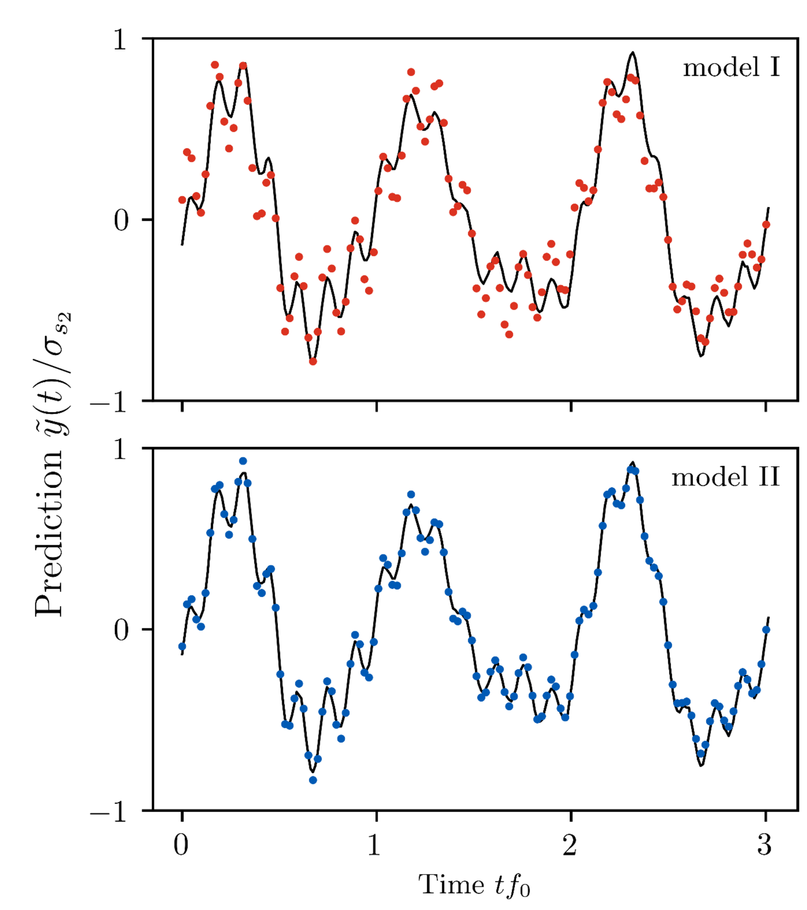
We used a convolutional neural network to predict the target with independent convolutional layers for witness and history data.

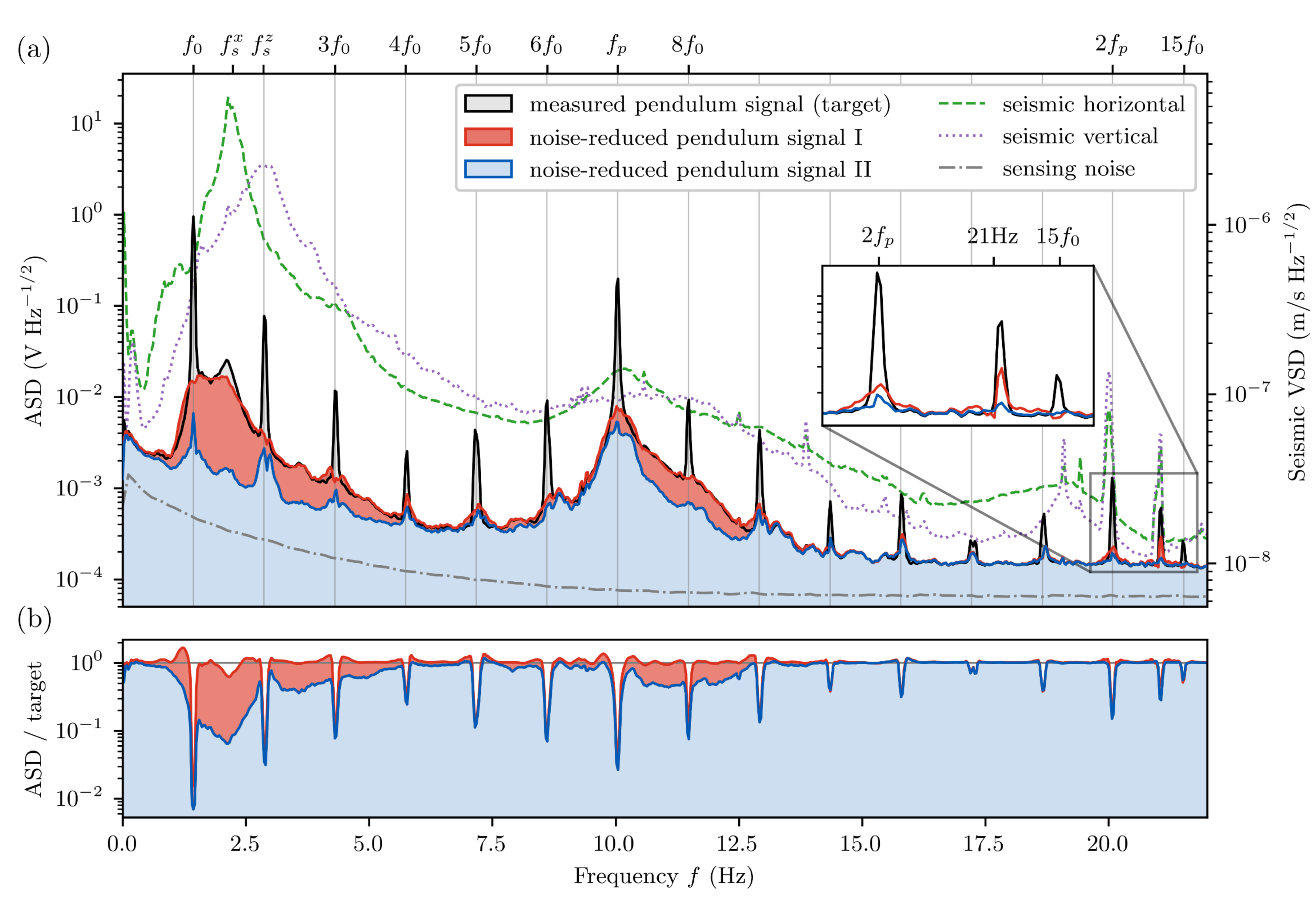


With this model-free, data-driven approach, the system dynamics are inferred in the training process, which eases scalability and adaptation to other systems. 80% of the record was used for training the models and the performance was validated on the remaining 20%.

PREDICTIVE CAPABILITIES

To evaluate the improvement of including the seismic witness data, we trained two models. Model I (red) bases the prediction solely on the look-back signal while model II (blue) utilizes the seismic witness data as well. The time series sample to the right shows how both models extrapolate the excitation of the suspension resonances while model II qualitatively improves the predictive precision compared to model I. Below, we show the averaged amplitude spectral density (ASD) of the original vertical pendulum signal (black) as well the ASDs of the signals obtained by subtracting the predictions of the models from the signal. The seismic background (dashed and dotted) is shown as well.





Suspension resonances as well as their higher harmonics caused by sensor nonlinearity were successfully extrapolated by model I, reducing the rms amplitude in the region of high seismic activity (0.5-5 Hz) by 71%. The prediction of broadband seismic noise by model II further reduced the amplitude by a factor of 4. We conclude that our approach is suitable for feed-forward noise mitigation even in the presence of excited resonant modes.

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