Experimental Validation of Optimal Clipped Linear Strategies for Controllable Damping

Qian Fang¹, Patrick T. Brewick¹, ², Erik A. Johnson¹
Steven F. Wojtkiewicz³, Samuel E. Rosato³, Michael Harris⁴

¹ USC Sonny Astani Dept. of Civil & Environmental Engineering
² U.S. Naval Research Laboratory
³ Clarkson University, Dept. of Civil & Environmental Engineering
⁴ University of Connecticut, Civil & Environmental Engineering Dept.

11NCEE LA 2018
Westin Bonaventure Hotel
26 June 2018
Motivation and Background

- Controllable dampers: adjust internal parameters or properties → performance superior to fixed dampers
- Clipped-optimal control: a typical strategy for commanding controllable dampers:
  - Primary controller: determine a desired control force (e.g., LQR);
  - Secondary clipping controller: command a device to exert force close to the desired force.
- Problem: clipped-optimal control is designed ignoring the dissipative constraint of the device, causing frequent clipping and deactivating the device.
- Solution: an alternate clipped linear strategy: **Optimal Clipped Linear Control (OCLC)**

![Diagram showing control force and dissipativity constraint]

Control force

- Non-dissipative
- Dissipative

Dissipativity constraint

- Non-dissipative
- Dissipative

Velocity
Motivation and background

- SDOF: \( m = 100 \, \text{Mg}, \quad \omega = 2\pi \, \text{rad/s}, \quad \zeta = 0.05; \) Gaussian white noise base excitation

- Similar or better results with historical earthquake excitations (e.g., El Centro, Kobe)
Experimental setup

$L$: 30 ft; Natural frequency is 1.66Hz, damping 0.1%; 20Hz-bandlimited white noise excitation.

- Full-order simulation model built with 40-term Rayleigh-Ritz method using the exact cantilevered-beam shape functions
- Balanced truncation to reduce to SDOF model
- Devices’ locations:
  - Sensor and damper $L$: natural frequency and damping ratio of reduced-order match dominant mode of original
  - Exciter $0.9L$: avoid strong acceleration response
OCLC for the beam

- State-space equation for the reduced-order system:

\[
\dot{x}_r(t) = A_r x_r(t) + B_r w(t), \quad y(t) = C_r x_r(t) + D_r w(t)
\]

output \(y\) is tip displacement, velocity or acceleration

- Objective is to **minimize**:

\[
J = \mathbb{E}[y^2 + \rho u^2] = \lim_{t_f \to \infty} \frac{1}{t_f} \int_0^{t_f} [y^2 + \rho u^2]dt
\]

Chosen \(\rho\) for different systems with different measurements

<table>
<thead>
<tr>
<th>Measurement</th>
<th>disp.</th>
<th>vel.</th>
<th>accel.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chosen (\rho)</td>
<td>(1 \times 10^{-16})</td>
<td>(1 \times 10^{-8})</td>
<td>(1 \times 10^{-8})</td>
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</tbody>
</table>

- Reparameterize clipped linear control relative to LQR:

\[
u^d = -K_{r1}^{LQR}(1 - \alpha)x_{r1} - K_{r2}^{LQR}(1 - \beta)x_{r2}
\]

For the semiactive system: \(u(t) = u^d H[u^d v_d]\)

\(H[\cdot]\) = Heaviside unit step fcn. \(v_d\): Damper velocity
OCLC for the beam

Displacement

Acceleration

Velocity
### Results summary:

- When measurement is displacement and velocity, OCLC provides significant performance reduction (36% and 48%, respectively);
- When measurement is acceleration, OCLC performs better and control force level is 17% lower than that of CLQR;
- When measurement is velocity, OCLC has dramatic performance reduction with almost identical control force level.

### On-going research:

The validation experiment will be conducted to evaluate OCLC and compare it to both CLQR and hybrid MPC to verify the theoretical results.
Acknowledgments

- Viterbi Doctoral Fellowship support of the first author
- NSF CMMI Grants 14-36018 and 14-36058
- Prof. Richard Christenson’s group for experimental beam data, Civil and Environmental Engineering Department, University of Connecticut

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the U.S. National Science Foundation nor of the University of Southern California.
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Today Poster Session:
- Time: 5:15 - 7:00 pm
- Room: Pasadena Hall (Exhibit Hall)
- Poster location: Number 136
THANK YOU