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Data-driven dissipativity analysis with quadratic difference form supply-rate functions and its applications

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Bibliography

- [1] M. ApS. *The MOSEK optimization toolbox for MATLAB manual. Version 9.0.*, 2019.
- [2] K. J. Astrom and T. Hagglund. *PID controllers: Theory, design, and tuning. instrument. Society of America*, 1995.
- [3] K. J. Åström and B. Wittenmark. *Adaptive control*. Courier Corporation, 2013.
- [4] A. S. Bazanella, L. Campestri, and D. Eckhard. *Data-driven controller design: the H2 approach*. Springer Science & Business Media, 2011.
- [5] J. Berberich and F. Allgöwer. A trajectory-based framework for data-driven system analysis and control. In *2020 European Control Conference (ECC)*, pages 1365–1370. IEEE, 2020.
- [6] J. Bongard, J. Berberich, J. Köhler, and F. Allgöwer. Robust stability analysis of a simple data-driven model predictive control approach. *IEEE Transactions on Automatic Control*, 2022.
- [7] B. Brogliato, R. Lozano, B. Maschke, and O. Egeland. *Dissipative systems analysis and control: Theory and Applications*, volume 2. Springer, 2007.
- [8] L. P. Carvalho, J. M. Palma, T. E. Rosa, B. Jayawardhana, and O. Costa. Gain-scheduled controller for fault accommodation in linear parameter varying systems with imprecise measurements. *IFAC-PapersOnLine*, 54(8):57–63, 2021.
- [9] L. P. Carvalho, J. M. Palma, T. E. Rosa, B. Jayawardhana, and O. L. d. V. Costa. Gain-scheduled fault detection filter for discrete-time LPV systems. *IEEE Access*, 9:143349–143365, 2021.

- [10] L. P. Carvalho, T. E. Rosa, B. Jayawardhana, and O. Costa. Fault accommodation controller under markovian jump linear systems with asynchronous modes. *International Journal of Robust and Nonlinear Control*, 30(18):8503–8520, 2020.
- [11] L. P. Carvalho, T. E. Rosa, B. Jayawardhana, and O. L. d. V. Costa. Fault compensation controller for markovian jump linear systems. *IFAC-PapersOnLine*, 53(2):4103–4108, 2020.
- [12] C. Chan-Zheng, P. Borja, and J. M. Scherpen. Passivity-based control of mechanical systems with linear damping identification. *IFAC-PapersOnLine*, 54(19):255–260, 2021.
- [13] J. Chen and R. J. Patton. *Robust model-based fault diagnosis for dynamic systems*, volume 3. Springer Science & Business Media, 2012.
- [14] Y. Chu and F. You. Model-based integration of control and operations: Overview, challenges, advances, and opportunities. *Computers & Chemical Engineering*, 83:2–20, 2015.
- [15] G. M. da Silva and R. Pederiva. Fault diagnosis of active magnetic bearings. *Mechatronics*, 84:102801, 2022.
- [16] M. C. de Oliveira and R. E. Skelton. Stability tests for constrained linear systems. In *Perspectives in robust control*, pages 241–257. Springer, 2001.
- [17] C. De Persis and P. Tesi. Formulas for data-driven control: Stabilization, optimality, and robustness. *IEEE Transactions on Automatic Control*, 65(3):909–924, 2019.
- [18] T. Ding, M. Sznaier, and O. Camps. A rank minimization approach to fast dynamic event detection and track matching in video sequences. In *2007 46th IEEE Conference on Decision and Control*, pages 4122–4127. IEEE, 2007.
- [19] J. C. Doyle, K. Glover, P. P. Khargonekar, and B. A. Francis. State-space solutions to standard \mathcal{H}_2 and \mathcal{H}_∞ control problems. *IEEE Transactions on Automatic Control*, 34(8):831–847, 1989.
- [20] M. Dresscher. *Toward Controlled Ultra-High Vacuum Chemical Vapor Deposition Processes*. PhD thesis, University of Groningen, The Netherlands, 2019.
- [21] M. Dresscher, B. Jayawardhana, B. Kooi, and J. Scherpen. Toward observable UHVCD: Modeling of flow dynamics and AAS partial pressure measurement implementation. *Mechatronics*, 71:102427, 2020.

- [22] Y. Du, T. C. Droubay, A. V. Liyu, G. Li, and S. A. Chambers. Self-corrected sensors based on atomic absorption spectroscopy for atom flux measurements in molecular beam epitaxy. *Applied Physics Letters*, 104(16):163110, 2014.
- [23] L. Eckertová. *Physics of thin films*. Plenum Publish Corporation, 1977.
- [24] T. F. Edgar, S. W. Butler, W. J. Campbell, C. Pfeifer, C. Bode, S. B. Hwang, K. S. Balakrishnan, and J. Hahn. Automatic control in microelectronics manufacturing: Practices, challenges, and possibilities. *Automatica*, 36:1567–1603, 2000.
- [25] S. Formentin, A. Karimi, and S. M. Savaresi. Optimal input design for direct data-driven tuning of model-reference controllers. *Automatica*, 49(6):1874–1882, 2013.
- [26] H. Frey and H. R. Khan. *Handbook of thin film technology*. Springer, 2015.
- [27] D. J. Hill and P. J. Moylan. The stability of nonlinear dissipative systems. *IEEE Transactions on Automatic Control*, 21(5):708–711, 1976.
- [28] D. J. Hill and P. J. Moylan. Dissipative dynamical systems: Basic input-output and state properties. *Journal of the Franklin Institute*, 309(5):327–357, 1980.
- [29] J. Huisman. *Improving the Atomic Absorption Spectroscopy measurements of an UHV CVD system*. Master’s thesis, University of Groningen, The Netherlands, 2020.
- [30] R. Isermann. *Fault-diagnosis systems: an introduction from fault detection to fault tolerance*. Springer Science & Business Media, 2005.
- [31] K. Jiang, M. Kheradmandi, C. Hu, S. Pal, and F. Yan. Data-driven fault tolerant predictive control for temperature regulation in data center with rack-based cooling architecture. *Mechatronics*, 79:102633, 2021.
- [32] H. Jin, M. Stefanovic, and P. Tesi. Data-driven robust control: Special issue dedicated to the 70th birthday of Michael G. Safonov. *International Journal of Robust and Nonlinear Control*, 28(12):3665–3666, 2018.
- [33] O. Kaneko and T. Fujii. Discrete-time average positivity and spectral factorization in a behavioral framework. *Systems & Control Letters*, 39(1):31–44, 2000.
- [34] A. Koch, J. Berberich, and F. Allgower. Provably robust verification of dissipativity properties from data. *IEEE Transactions on Automatic Control*, 2021.

- [35] N. Kottenstette and P. J. Antsaklis. Relationships between positive real, passive dissipative, & positive systems. In *Proc. of the 2010 Amer. Control Conference*, pages 409–416. IEEE, 2010.
- [36] S. Kumar and D. K. Aswal. *Recent Advances in Thin Films*. Springer Nature, 2020.
- [37] A. Lanzon and I. R. Petersen. Stability robustness of a feedback interconnection of systems with negative imaginary frequency response. *IEEE Transactions on Automatic Control*, 53(4):1042–1046, 2008.
- [38] Q. Lei and J. Bao. Dissipativity based fault detection and diagnosis for linear systems. In *2015 IEEE Conference on Control Applications (CCA)*, pages 133–138. IEEE, 2015.
- [39] Q. Lei, M. T. Munir, J. Bao, and B. Young. A data-driven fault detection method based on dissipative trajectories. *IFAC-PapersOnLine*, 49(7):717–722, 2016.
- [40] W. Li, J. Bao, and G. Wei. A new fault detection method from data-based dissipativity theory. In *2021 40th Chinese Control Conference (CCC)*, pages 4579–4584. IEEE, 2021.
- [41] W. Li, Y. Yan, and J. Bao. Data-based fault diagnosis via dissipativity-shaping. *IEEE Control Systems Letters*, 7:484–489, 2022.
- [42] Z. Liu, A. Hansson, and L. Vandenberghe. Nuclear norm system identification with missing inputs and outputs. *Systems & Control Letters*, 62(8):605–612, 2013.
- [43] J. Löfberg. YALMIP: A toolbox for modeling and optimization in MATLAB. pages 284–289, Taipei, Taiwan, September 2004.
- [44] M. A. Mabrok, M. A. Alyami, and E. E. Mahmoud. On the dissipativity property of negative imaginary systems. *Alexandria Engineering Journal*, 60(1):1403–1410, 2021.
- [45] I. Markovsky. Exact system identification with missing data. In *52nd IEEE Conference on Decision and Control*, pages 151–155. IEEE, 2013.
- [46] I. Markovsky. A missing data approach to data-driven filtering and control. *IEEE Transactions on Automatic Control*, 62(4):1972–1978, 2016.
- [47] I. Markovsky and F. Dörfler. Behavioral systems theory in data-driven analysis, signal processing, and control. *Annual Reviews in Control*, 52:42–64, 2021.

- [48] I. Markovskiy and P. Rapisarda. Data-driven simulation and control. *International Journal of Control*, 81(12):1946–1959, 2008.
- [49] T. Maupong, J. C. Mayo-Maldonado, and P. Rapisarda. On Lyapunov functions and data-driven dissipativity. *IFAC-PapersOnLine*, 50(1):7783–7788, 2017.
- [50] W. Mencke. *Towards standardized calibration experiments for atomic absorption spectrometry in UHV/CVD environments*. Master’s thesis, University of Groningen, The Netherlands, 2020.
- [51] B. Mnassri, E. M. El Adel, B. Ananou, and M. Ouladsine. Fault detection and diagnosis based on PCA and a new contribution plot. *IFAC Proceedings Volumes*, 42(8):834–839, 2009. 7th IFAC Symposium on Fault Detection, Supervision and Safety of Technical Processes.
- [52] P. Moylan. *Dissipative systems and stability*, 2014.
- [53] A. N. Nesmeyanov. *Vapor pressure of the chemical elements*. Elsevier Publishing Company, 1963.
- [54] W. D. Nix. Mechanical properties of thin films. *Metallurgical transactions A*, 20(11):2217–2245, 1989.
- [55] S. Noh, M. D. Zoltowski, Y. Sung, and D. J. Love. Pilot beam pattern design for channel estimation in massive mimo systems. *IEEE Journal of Selected Topics in Signal Processing*, 8(5):787–801, 2014.
- [56] N. M. Nor, C. R. C. Hassan, and M. A. Hussain. A review of data-driven fault detection and diagnosis methods: Applications in chemical process systems. *Reviews in Chemical Engineering*, 36(4):513–553, 2020.
- [57] M. Ohring. *Materials science of thin films*. Academic Press, 2001.
- [58] R. Ortega, J. A. L. Perez, P. J. Nicklasson, and H. J. Sira-Ramirez. *Passivity-based control of Euler-Lagrange systems: mechanical, electrical and electromechanical applications*. Springer Science & Business Media, 2013.
- [59] R. Ouyang, V. Andrieu, and B. Jayawardhana. On the characterization of the Duhem hysteresis operator with clockwise input-output dynamics. *Systems & Control Letters*, 62(3):286–293, 2013.
- [60] R. Ouyang and B. Jayawardhana. Absolute stability analysis of linear systems with Duhem hysteresis operator. *Automatica*, 50(7):1860–1866, 2014.
- [61] R. J. Patton, P. M. Frank, and R. N. Clark. *Issues of fault diagnosis for dynamic systems*. Springer Science & Business Media, 2000.

- [62] Quanser. *2 DOF Serial Flexible Joint, Reference Manual. Doc. No. 800, Rev 1*, 2013.
- [63] A. Romer, J. Berberich, J. Köhler, and F. Allgöwer. One-shot verification of dissipativity properties from input–output data. *IEEE Control Systems Letters*, 3(3):709–714, 2019.
- [64] T. E. Rosa, L. P. Carvalho, G. A. Gleizer, and B. Jayawardhana. Fault detection for LTI systems using data-driven dissipativity analysis. Submitted.
- [65] T. E. Rosa and B. Jayawardhana. On the one-shot data-driven verification of dissipativity of LTI systems with general quadratic supply rate function. In *Proc. 19th European Control Conference*, pages 1291–1296, Rotterdam, 2021. IEEE.
- [66] T. E. Rosa and B. Jayawardhana. Data-driven dissipative verification of LTI systems: multiple shots of data, QDF supply-rate and application to a planar manipulator. In *16th European Workshop on Advanced Control and Diagnosis*. IFAC, 2022.
- [67] T. E. Rosa and B. Jayawardhana. Experiments and data-driven dissipativity analysis of dual AAS measurements of UHVCVD reactors. Submitted.
- [68] T. E. Rosa, C. F. Morais, and R. C. Oliveira. New robust LMI synthesis conditions for mixed gain-scheduled reduced-order DOF control of discrete-time LPV systems. *International Journal of Robust and Nonlinear Control*, 28(18):6122–6145, 2018.
- [69] M. Rotulo, C. De Persis, and P. Tesi. Online learning of data-driven controllers for unknown switched linear systems. *Automatica*, 145:110519, 2022.
- [70] M. G. Safonov. Robust control: Fooled by assumptions. *International Journal of Robust and Nonlinear Control*, 28(12):3667–3677, 2018.
- [71] K. Seshan. *Handbook of thin film deposition processes and techniques*. William Andrew, 2018.
- [72] J. G. Speight. *Natural water remediation: Chemistry and technology*. Butterworth-Heinemann, 2019.
- [73] D. Stanisavljevic and M. Spitzer. A review of related work on machine learning in semiconductor manufacturing and assembly lines. In *SAMI@ iKNOW*, 2016.
- [74] G. A. Susto, S. Pampuri, A. Schirru, G. De Nicolao, S. F. McLoone, and A. Beghi. Automatic control and machine learning for semiconductor manufacturing: Review and challenges. In *Proc. of the 10th European Workshop on Advanced Control and Diagnosis (ACD 2012)*, 2012.

- [75] R. S. Sutton and A. G. Barto. *Reinforcement learning: An introduction*. MIT press, 2018.
- [76] W. Tang and P. Daoutidis. Dissipativity learning control (DLC): A framework of input–output data-driven control. *Computers & Chemical Engineering*, 130:106576, 2019.
- [77] H. Trentelman and J. Willems. Every storage function is a state function. *Systems & Control Letters*, 32(5):249–259, 1997.
- [78] H. J. van Waarde, M. K. Camlibel, P. Rapisarda, and H. L. Trentelman. Data-driven dissipativity analysis: application of the matrix S-lemma. *IEEE Control Systems Magazine*, 42(3):140–149, 2022.
- [79] H. J. van Waarde, C. De Persis, M. K. Camlibel, and P. Tesi. Willems’ fundamental lemma for state-space systems and its extension to multiple datasets. *IEEE Control Systems Letters*, 4(3):602–607, 2020.
- [80] H. J. Van Waarde, J. Eising, H. L. Trentelman, and M. K. Camlibel. Data informativity: a new perspective on data-driven analysis and control. *IEEE Transactions on Automatic Control*, 65(11):4753–4768, 2020.
- [81] J. L. Vossen and W. Kern. *Thin Film Processes II*. Academic Press, Inc, 1991.
- [82] Q. Wei, R. Song, and P. Yan. Data-driven zero-sum neuro-optimal control for a class of continuous-time unknown nonlinear systems with disturbance using ADP. *IEEE Transactions on neural networks and learning systems*, 27(2):444–458, 2016.
- [83] J. C. Willems. Dissipative dynamical systems part I: General theory. *Archive for rational mechanics and analysis*, 45(5):321–351, 1972.
- [84] J. C. Willems, P. Rapisarda, I. Markovsky, and B. L. De Moor. A note on persistency of excitation. *Systems & Control Letters*, 54(4):325–329, 2005.
- [85] J. C. Willems and H. L. Trentelman. On quadratic differential forms. *SIAM Journal on Control and Optimization*, 36(5):1703–1749, 1998.
- [86] S. Yin, X. Li, H. Gao, and O. Kaynak. Data-based techniques focused on modern industry: An overview. *IEEE Transactions on Industrial Electronics*, 62(1):657–667, 2015.

