Tutorial Proposal

Title: Control of Mechatronic Systems Using the COMES Toolbox

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Abstract:

This tutorial concentrates on four different approaches that are widely used in controlling mechatronic systems. These control approaches are: classical control, preview control, disturbance observer control and repetitive control. The COntrol of MEchatronic Systems (COMES) toolbox developed as a Matlab based graphical user interface for designing classical, preview, disturbance observer and repetitive controllers will be introduced and used in the examples. The focus of the tutorial will be more on the disturbance observer and repetitive control methods. For these two approaches, the method of mapping frequency domain criteria like sensitivity minimization, phase/gain margin bounds to controller parameter space will be presented as an easy to use, interactive and practical method of designing low order controllers. This method allows the use of frequency domain specifications in a parameter space design setting. Three case studies will be used to illustrate the presented methods. The first case study is on yaw stability control of a road vehicle based on the disturbance observer. The second case study is on control of the piezo-tube in an atomic force microscope using a disturbance observer. The third case study is on repetitive control applied to an atomic force microscope.

Intended Audience: graduate students in control theory, practicing control engineers and researchers.

Description:

This tutorial covers four different approaches that are widely used in controlling mechatronic systems which are: classical control, preview control, disturbance observer control and repetitive control. The main focus will be on disturbance observer and on repetitive controller design in parameter space. Along with Hurwitz and D-stability maps, the method of mapping frequency domain constraints like those on mixed sensitivity, phase/gain margin and D-stability will also be presented [1-2]. The application of the parameter space design with frequency domain constraint mapping method will be presented in the tutorial.

COMES GUI: COMES is a MATLAB graphical user interface (GUI) developed by the tutorial organizers and their former students that covers four different control approaches: classical control (lead, lag, PID etc.), preview control, disturbance observer control and repetitive control [3]. COMES will be used in the examples treated in this tutorial. Mapping of frequency domain constraints to parameter space is the main tool in COMES. COMES hides the underlying numerical calculations from the user as much as possible. Thus, the user can focus on the design and analysis phases through the graphical displays rather than being burdened by the calculations that are involved.

Classical Control: Classical (also called conventional) control techniques work best for single-input-single-output (SISO), linear time-invariant (LTI) systems where the required performance specifications are given in the time and/or frequency-domain. In spite of the presence of a large number of advanced control techniques in the literature, classical control methods are widely used in the control of mechatronic systems because they can easily be implemented as real-time systems at relatively low cost. Specified error constant, gain crossover frequency and phase margin are used for tuning the parameters of classical controllers like lead, lag, lead-lag and PID controllers in COMES.

Preview Control: Preview control is a well established feedforward control method that provides a non-causal, approximate inverse filter of the closed loop controlled plant. Preview control is best designed and implemented in discrete time. The preview control methods currently implemented in COMES are the zero phase error, precision tracking and optimal precision tracking methods [4-5]. Preview control filters can also be used to obtain the approximate inverse filters that are used in disturbance observer and repetitive control.

Disturbance Observer Control: The disturbance observer is a particular method of designing a two degree-of-freedom control architecture in order to achieve insensitivity against modeling errors and excellent disturbance rejection. It has been successfully applied to many application areas including motion control, high speed direct drive positioning, friction compensation and vehicle steering control [6-7]. Disturbance rejection and model regulation are the two very important features of a disturbance observer. Disturbance observer design in the COMES toolbox based on mapping a mixed sensitivity frequency domain bound to disturbance observer parameter space will be presented. Two case studies will be presented: 1) disturbance observer control applied to road vehicle yaw stability improvement [8] and 2) use of a MIMO disturbance observer to decouple the coupled axes of a pizeo tube actuator used in an AFM [9].

Repetitive Control: Repetitive controllers are used to accurately track periodic reference signals or to reject periodic disturbances with known period by introducing a highly frequency selective gain through a positive feedback loop which contains a time delay element as it is a generator of periodic signals. The delay time is equal to the known period of the repetitive reference (or disturbance) signal. Significant improvement in the tracking accuracy or disturbance rejection characteristics of systems subject to periodic exogenous signals can be achieved using repetitive control. Repetitive controller design based on shaping the regeneration spectrum and based on placing bounds on sensitivity will be presented using the COMES toolbox as a design aid [10-12]. The third case study is on the application of repetitive control to controlling an AFM [9], [13-14].

Materials: The pdf copy of the course slides and the annotated bibliography will be made available to tutorial attendees.

Bio-sketches:

Professor Levent Güvenç received the B.S. degree in mechanical engineering from Boğaziçi University in İstanbul, in 1985, the M.S. degree in mechanical engineering from Clemson University in 1988 and the Ph.D. degree in mechanical engineering from the Ohio State University in 1992. During 1996-2011, he worked in the mechanical engineering department of İstanbul Technical University where he was the director of the European Union Framework Programme 6 funded Center of Excellence on Automotive Control and Mechatronics. He is currently the department chair of mechanical engineering at İstanbul Okan University and is the founder and director of Mekar Labs. He spent the year 2000 working as a guest researcher sponsored by the Alexander von Humboldt Foundation in the Institute of Robotics and Mechatronics of the German Aerospace Center in Oberpfaffenhofen. His current research interests concentrate on applied robust control, mechatronics, cooperative mobility of road vehicles, automotive control and control applications in AFM. Prof. Güvenç is an associate editor of the IEEE Transactions on Vehicular Technology and the International Journal of Manufacturing and Mechatronics. He is a member of the International Federation of Automatic Control (IFAC) Technical Committees on Automotive Control, Mechatronics and Intelligent Autonomous Vehicles and the IEEE Technical Committees on Automotive Control and Intelligent Vehicular Systems and Control.

Professor Bilin Aksun Güvenç received the B.S., M.S., and Ph.D. degrees in mechanical engineering from İstanbul Technical University, İstanbul, Turkey, in 1993, 1996, and 2001, respectively. She is currently a professor of mechanical engineering at İstanbul Okan University and is affiliated with Mekar Labs. During 1993-2011, she worked in the mechanical engineering department of İstanbul Technical University. She was the principal investigator of several automotive control projects funded by the automotive industry. Her research focuses on ITS, motion control, robust control, and automotive control systems. Professor Aksun Güvenç is a member of the International Federation of Automatic Control (IFAC) Technical Committee on Automotive Control.

Mümin Tolga Emirler received the B.S. degrees in mechanical engineering and in manufacturing engineering (double major) from İstanbul Technical University in 2007 and in 2008, respectively, and the M.S. degree in mechatronics engineering from İstanbul Technical University in 2010. He is currently a Ph.D. student in mechanical engineering at İstanbul Technical University. Since February 2008, he has been affiliated with Mekar Labs. He was awarded a scholarship by TUBITAK (The Scientific and Technological Research Council of Turkey) during his Ph.D. studies. His current research interest focuses on robust control systems theory and design with an emphasis on vehicle chassis control systems, vehicle yaw rate estimation, cooperative driving, and electric vehicle control. Mr. Emirler is a junior member of the International Federation of Automatic Control (IFAC) Technical Committee on Automotive Control.

References

[1] Ackermann, J., Blue, P., Bünte, T., Güvenç, L., Kaesbauer, D., Kordt, M., Muhler, M., Odenthal, D., 2002, Robust Control: the Parameter Space Approach, Springer Verlag, London, 978-1-85233-514-4.

[2] Güvenç, L., Ackermann, J., 2001, "Links Between the Parameter Space and Frequency Domain Methods of Robust Control," International Journal of Robust and Nonlinear Control, Special Issue on Robustness Analysis and Design for Systems with Real Parametric Uncertainties, Vol. 11, no. 15, pp. 1435-1453.

[3] Demirel, B., Güvenç, L., 2010 "Control of Mechatronic Systems – COMES Toolbox," ASME ESDA Engineering Systems Design and Analysis Conference, İstanbul, July 12-14.

[4] Aksun Güvenç, B., Güvenç, L., 2001, "Characterization and Compensation of Complex Nonminimum Phase Zeros for Preview Control," Proceedings of the 2001 Mediterranean Control Conference, June, Dubrovnik.

[5] Aksun Güvenç, B., Güvenç, L., 2001, "Performance Robustness Analysis of Preview Control Systems Using the Structured Singular Value," Proceedings of the 2001 Mediterranean Control Conference, June, Dubrovnik.

[6] Aksun Güvenç, B., Güvenç, L., 2002, "Robust Two Degree of Freedom Add-On Controller Design For Automatic Steering," IEEE Transactions on Control Systems Technology, Vol. 10, no. 1, pp.137-148.

[7] Aksun Güvenç, B., Güvenç, L., Karaman, S., 2010, "Robust MIMO Disturbance Observer Analysis and Design with Application to Active Car Steering," International Journal of Robust and Nonlinear Control, Vol. 20, pp. 873-891.

[8] Aksun Güvenç, B., Güvenç, L., Karaman, S., 2009, "Robust Yaw Stability Controller Design and Hardware in the Loop Testing for a Road Vehicle," IEEE Transactions on Vehicular Technology, Vol. 58, No. 2, pp. 555-571.

[9] Aksun Güvenç, B., Necipoğlu, S., Demirel, B., Güvenç, L., 2011, "Robust Control of Atomic Force Microscopy," Chapter 3 in Mechatronics, Editor: P. Davim, ISTE/Wiley, London, ISBN: 978-1-84821-308-1, pp. 103-132.

[10] Güvenç, L., 2003, "Repetitive Controller Design in Parameter Space," ASME Journal of Dynamic Systems, Measurement and Control, Vol. 125, No. 1, pp. 134-138.

[11] Aksun Güvenç, B., Güvenç, L., 2006, "Robust Repetitive Controller Design in Parameter Space," ASME Journal of Dynamic Systems, Measurement and Control, Vol. 128, No. 2, pp. 406-413.

[12] Demirel, B., Güvenç, L., 2010, "Parameter Space Design of Repetitive Controllers for Satisfying a Mixed Sensitivity Performance Requirement," IEEE Transactions on Automatic Control, Vol. 55, No. 8, pp. 1893-1899.

[13] Necipoğlu, S., Cebeci, S.A., Başdoğan, Ç., Has, Y.E., Güvenç, L., 2011, "Repetitive Control of an XYZ Piezo-stage for Faster Nano-scanning: Numerical Simulations and Experiment," Mechatronics, Vol. 21, No. 6, pp. 1098-1107.

[14] Necipoğlu, S., Cebeci, S.A., Has, Y.E., Güvenç, L., Başdoğan, Ç., 2011, "A Robust Repetitive Controller for Fast AFM Imaging," IEEE Transactions on Nanotechnology, Vol. 10, No. 5, pp. 1074-1082.