



Nonlinear Systems



School of ECE, University of Tehran

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Course Outline

Session #	Presentation Date	Section	Detailed Topics	General Topics	Sources
1	1399/08/17	1.1	System Description	Nonlinear Systems: An Introduction	[1,2,3,6]
			Types of Systems		
			Equilibrium Points		
		1.2	Stability of First-Order Systems		
2	1399/08/17	2.1	Autonomous (Time Invariant) Systems	Nonlinear State Models	[1,2,3,6]
			Unforced Systems		
			Affine Systems		
		2.2	Essentially Nonlinear Phenomena		
			Common Types of Nonlinearities		
3	1399/08/17	3.1	Vector and Matrix Norms	Some Linear Algebraic Concepts	[1,3]
			Norm Inequalities		
			Hölder's Inequality		
		3.2	Sufficient Conditions for being Locally Lipschitz	Continuity and Lipschitz Conditions	
			Necessary and Sufficient Conditions for being Globally Lipschitz		
		3.3	Local Existence and Uniqueness	Existence and Uniqueness Theorems	
			Global Existence and Uniqueness		
		3.4	Sensitivity Equations	Differentiability of Solutions	
4	1399/08/24	4.1	Gronwall-Bellman Inequality	Compute Bounds on Solutions	[1,3]
			Comparison Principle		
		4.2	Sum of Vectors	Second-Order Systems	[1,2,3]
			Qualitative Behavior of Linear Systems		
			Qualitative Behavior Near Equilibrium Points		
			Lyapunov's Indirect Method		
5	1399/08/24	5.1	The Method of Isocline	Constructing Phase Portraits	[1,2,3]
			Numerical Construction of Phase Portraits		
		5.2	Types of Limit Cycles	Limit Cycles	
6	1399/08/24	6.1	Bendixon Criterion		
			Poincaré-Bendixon Criterion		
		6.2	Types of Stability		

7	1399/09/01	7.1	Lyapunov Function	Lyapunov Stability	[1,2,3,4]
			Lyapunov's Theorem		
			Lyapunov Surface (Level Sets)		
			Energy and Dissipation Functions		
		7.2	A Lyapunov Global Asymptotic Stability Theorem		
7.3	A Lyapunov Exponential Stability Theorem				
8	1399/09/01	8.1	Quadratic Forms of Lyapunov Functions		
			Lyapunov Equation		
			Variable Gradient Method		
		8.2	A Lyapunov Global Exponential Stability Theorem		
9	1399/09/01	9.1	Instability Theorems		
		9.2	The Invariance Principle		
			Positive Limit Point/Set		
			(Positively) Invariant Sets		
			LaSalle's Theorem		
10	1399/09/08	10.1	Exponential Stability		
		10.2	Region of Attraction		
			Estimate of Region of Attraction		
11	1399/09/08	11.1	Time-Varying Systems		
			Comparison Functions		
			Uniform Stability		
			Lyapunov Theorems for Time-Varying Systems		
		11.2	Converse Theorems		
12	1399/09/08	12.1	Class K functions		
		12.2	Linearization Principle		
			Invariance Like Theorems		
		12.3	Barbalat's Lemma		
13	1399/09/15	13.1	Saddle-Node Bifurcation	Bifurcation	[1,4,6,8,9]
		13.2	Transcritical Bifurcation		
		13.3	Pitchfork Bifurcation		
		13.4	Hopf Bifurcation		
14	1399/09/15	14.1	Homoclinic Bifurcation		
		14.2	Hamiltonian Systems		
		14.3	Implicit Function Theorem		
15	1399/09/15	15.1	Invariant Manifolds	The Center Manifold Theorem	[1,5]
		15.2	Reduction Theorem		
16	1399/09/22	16.1	Definition	(Ultimate) Boundedness	[1]
			Lyapunov Analysis		

17	1399/09/22	17.1	Vanishing Perturbations	Stability of Perturbed Systems	[1]
18	1399/09/22	18.1	Non-vanishing Perturbations		
		18.2	Stability Analysis of Interconnected Systems	Interconnected Systems	
19	1399/10/06	19.1	Parameterized Families of Systems	Slowly Varying Systems	
		19.2	Uniform Stability in Parameter		
		19.3	Linear Parameterized Systems		
20	1399/10/06	20.1	Standard Form	Singular Perturbations	[1,7]
			Time-Scale Properties of the Standard Model		
		20.2	Boundary-Layer Systems		
			Exponential Stability of Boundary-Layer System		
		20.3	Tikhonov Theorem		
21	1399/10/06	21.1	Slow and Fast Manifolds		[1,7,10]
		21.2	Stability Analysis		
22	1399/10/13	22.1	Passivity Formalism	Passivity	
		22.2	Memoryless Functions		
		22.3	Sector Nonlinearity		
			State Models		
23	1399/10/13	23.1	Positive Real Transfer Functions		[1,2,11]
			Strictly Positive Real Functions		
		23.2	Positive Real Lemma		
		23.3	Kalman-Yakubovich-Popov Lemma		
24	1399/10/13	24.1	Connection with Lyapunov Stability	Absolute Stability	
		24.2	Absolute Stability		
		24.3	Circle Criterion		
25	1399/10/13	25.1	Popov Criterion		
26	1399/10/20	26.1	Input-to-State Stability of Systems	Input-to-State Stability	[1]
		26.2	Stability of Cascade Systems		
27	1399/10/20	27.1	P-norms	Input-Output Stability	[1,3,11]
		27.2	L^p Space		
		27.3	Causality		
		27.4	L – Stability		
			Small-Signal L – Stability		
			Finite-Gain L – Stability		

28	1399/10/20	28.1	L^2 Gain	Input-Output Stability	[1,11]
		28.2	L^2 Stability		
29	1399/10/20	29.1	Passivity of Feedback Connection	Passivity	
		29.2	Asymptotic Stability of Feedback Connections in terms of Passivity		
		29.3	Loop Transformation		
		29.4	L^2 Stability of Feedback Connections in terms of Passivity		
30	1399/10/20	30.1	Small-Gain Theorem	Input-Output Stability	
		30.2	Finite Gain L Stability of Feedback Connection		

Text Book

- [1] Nonlinear Systems, by: H. K. Khalil; Prentice Hall, 3rd Edition, 2001
- [2] Applied Nonlinear Control, by: J. J. Slotine and W. Li; Prentice Hall; 1st Edition, 1990
- [3] Nonlinear Systems Analysis, by: M. Vidyasagar; Prentice Hall, 2nd Edition, 1992

Additional References

- [4] Nonlinear Systems: Analysis, Stability and Control, by: S. Sastry, Springer, 1999
- [5] Differential Equations and Dynamical Systems, by: L. Perko, Springer, 3rd Edition, 2006
- [6] Nonlinear Dynamics and Chaos: With Applications To Physics, Biology, Chemistry, And Engineering, by: S. H. Strogatz, CRC Press, 1st Edition, 2000
- [7] Singular Perturbation Methods in Control: Analysis and Design, by: P.V. Kokotovic, H. K. Khalil, and J. O'reilly, Academic Press, 1986
- [8] An Introduction to Dynamical Systems and Chaos, by G. C. Layek, Springer-India, 2015
- [9] Introduction to Applied Nonlinear Dynamical Systems and Chaos, by: S. Wiggins, Springer, 2nd Edition, 2003
- [10] Slow Integral Manifolds in Control and Graduate Education in Samara, by: M. Osintsev and V. Sobolev, IFAC Proceedings Volumes, Volume 45, Issue 11, Page 45-50, 2012
- [11] Nonlinear Control, by: Hassan Khalil, Pearson, 1st Edition, 2015