CODE	COURSE NAME	CATEGORY	L	T	P	CREDIT
EET448	ROBUST AND ADAPTIVE CONTROL	PEC	2	1	0	3

Preamble: This course provides a mathematical introduction to the field of robust and adaptive control. The concepts in this course are considered advanced in the field of modern control theory.

Prerequisite: EET304 Linear Control System, EET401Advanced Control System

Course Outcomes: After the completion of the course the student will be able to

CO 1	Compute the norms of transfer functions and transfer function matrices.
CO 2	Interpret the robustness of the control system using Robust Stability and Robust Performance measures.
CO 3	Explain the synthesis of stabilising controllers in H_2 and H_∞ .
CO 4	Design sliding mode controllers for a system.
CO 5	Design adaptive controllers for a system .

Mapping of course outcomes with program outcomes

	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12
CO 1	3	3										3
CO 2	3	3	3									3
CO 3	3	3										3
CO 4	3	3	3									3
CO 5	3	3	3									3

Assessment Pattern

Bloom's Category	Continuous Assessment Tests		End Semester Examination
	1	2	
Remember	10	10	10
Understand	20	20	20
Apply	20	20	70
Analyse			
Evaluate			
Create			

Mark distribution

Total Marks	CIE	ESE	ESE Duration
150	50	100	3 hours

Continuous Internal Evaluation Pattern:

Attendance : 10 marks

Continuous Assessment Test (2 numbers) : 25 marks

Assignment/Quiz/Course project : 15 marks

End Semester Examination Pattern: There will be two parts; Part A and Part B. Part A contain 10 questions with 2 questions from each module, having 3 marks for each question. Students should answer all questions. Part B contains 2 questions from each module of which student should answer any one. Each question can have maximum 2 sub-divisions and carry 14 marks.

Course Level Assessment Questions

Course Outcome 1 (CO1):

1. Define the various norms of a system.(K1,PO1)

2. Compute the various norms of a system.(K2,PO2)

3. Identify the properness, stabilizability and detectability of the given system.(K2,PO2)

Course Outcome 2 (CO2)

1. Define Robust Stability and Performance of a system. (K1,PO1)

2. Apply Robust Stability and Performance measures for a system.(K3,PO3)

3. Use additive and multiplicative uncertainty to model an uncertain system.(K3,PO2,PO3)

Course Outcome 3(CO3):

1. Explain the formulation of H_2 control. (K2,PO2)

2. Explain the formulation of $H\infty$ control. (K2,PO2)

3. Explain the formulation of controller using mu synthesis. (K2,PO2)

Course Outcome 4 (CO4):

1. Differentiate between variable structure control and SMC.(K2,PO2)

2. Explain the formulation of sliding mode control.(K2,PO3)

3. Explain the method of sliding surface design using pole placement method.(K3,PO3)

Course Outcome 5 (CO5):

1. Illustrate the block diagram of any one adaptive scheme.(K2,PO2)

2. Design a MRAC using MIT rule.(K3,PO3)

3. Distinguish adaptive versus conventional feedback system.(K2,PO2)

Model Question Paper

QP CODE:

PAGES:2

Reg.No:______________

Name:______________

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY

EIGHTH SEMESTER B.TECH DEGREE EXAMINATION,

MONTH & YEAR

Course Code: EET 448

Course Name: ROBUST AND ADAPTIVE CONTROL

Max. Marks: 100 **Duration:3 Hours**

PART A (3 x 10 = 30 Marks)

Answer all Questions. Each question carries 3 marks

1. Calculate the 2-norm and ∞-norm of the given vector $x = [1 \quad -2 \quad -3 \quad 4]^T$.
$x = [1 \quad -2 \quad -3 \quad 4]^T$
2. Define H_2 and H_∞ norm.
3. Define Small gain theorem.
4. Explain the importance of Sensitivity function in robust control.
5. Formulate the standard LQR problem.
6. Explain the lack of Robustness of LQG control.
7. Differentiate between variable structure control and SMC.
8. What is chattering phenomenon in Sliding mode control? How does it affect the system?
9. Justify the statement "Process variations affect the performance of a system" with example.
10. List three applications of Adaptive control.

PART B (14 x 5 = 70 Marks)

Answer any one full question from each module. Each question carries 14 marks

Module 1

11. a) What is observability and controllability grammian. **(8)**

b) What is meant by Singular values of a transfer function matrix? What is their significance. **(6)**

12. a). How is H_∞ norm computed for a SISO system? How is H_∞ norm computation done for a MIMO system? **(8)**

b) The system given by

$$\dot{x} = Ax + Bu\,, y = Cx, where\ A = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 3 & 0 \\ 0 & 0 & -2 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, C = [1 \quad 1 \quad 0]$$

$$\dot{x} = Ax + Bu\,, y = Cx, where\ A = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 3 & 0 \\ 0 & 0 & -2 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}, C = [1 \quad 1 \quad 0]$$

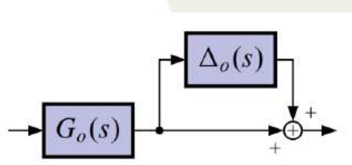
.

Check the stabilizability and detectability of the system. **(6)**

Module 2

13.a) Explain the terms nominal stability, robust stability, nominal performance and robust performance. What are the conditions to be satisfied by a feedback control system for each of the above? **(10)**

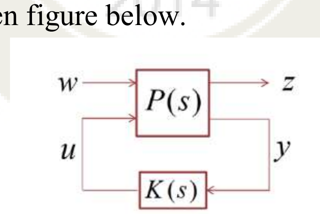
b) Identify the type of uncertainty in the given figure below. Write the mathematical model of the same.



(4)

14. a)Explain the concept of loop shaping in achieving robustness. **(7)**

b) Derive the LFT of the given figure below.



(7)

Module 3

15. a) Determine a LQR controller for the system defined by $\dot{x} = Ax + Bu, where\ A = \begin{bmatrix} 0 & 1 \\ 0 & -1 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$ $\dot{x} = Ax + Bu, where\ A = \begin{bmatrix} 0 & 1 \\ 0 & -1 \end{bmatrix}, B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$ such that the performance index $J = \int_0^\infty (x^T x + u^2) dt$ $J = \int_0^\infty (x^T x + u^2) dt$ is minimised. **(8)**

b) Explain the formulation of LQG control. **(6)**

16. a) Explain the formulation of H∞ control. **(6)**

b) What is a structured singular value. Mention the steps in designing a stabilizing controller by mu synthesis. **(8)**

Module 4

17.a) Write down the steps to be followed for designing a sliding mode controller. Also list the main features of sliding mode controllers. **(4)**

b) Design a stabilising variable structure control for a double integrator system **(10)**

18.a) Write two different reaching laws associated with sliding mode control design. Show how they assist the design to satisfy the reachability condition. **(8)**

b) In a sliding mode there exists a finite reaching time $t = t_f$ at which switching function s(t) becomes 0. Derive an expression for t_f in terms of s(0). **(6)**

Module 5

19. a) Explain the design of Self Tuning Regulator by pole placement design. **(8)**

b) Explain the least square estimation for parameter estimation. **(6)**

20. a) Design a MRAC for a first order system using MIT rule. **(8)**

b) Explain with illustration the basic blocks of a MRAS. **(6)**

Syllabus

Module 1: Introduction and mathematical preliminaries(8 hours)

Introduction to robust control

Vector space, linear subspaces, Norm and inner product of real vectors and matrix, Hilbert Spaces , H_2 and H_{inf} Spaces - Computing of H_2 and H_{inf} norms(transfer function and transfer matrices) , Computing of L_2 and L_{inf} Norms, singular value decomposition.

Proper systems, Controllability and Observability Grammians, Concept of Minimal Realisation, Stabilizability and Detectability, Packed form notation- various configurations.

Module 2: Feedback systems and Uncertainty modelling(9 hours)

Single degree and two degree of freedom Robust Control Systems - System Sensitivity, Relation between Sensitivity and disturbance inputs in a feedback system, Sensitivity and Complementary Sensitivity function. Sensitivity and Complementary Sensitivity peak selection- its relation to gain and phase margin - Weighted Sensitivity and weighted complementary sensitivity.

Well-Posedness of Feedback Loop, Internal Stability.

Model Uncertainty - Classification of uncertainties -parametric, structured and unstructured-m-delta configuration- linear fractional transformation-examples.

Nominal Performance, Nominal Stability, Robust Performance and Robust Stability-Small Gain Theorem, Concept of loop shaping.

Module 3: Robust controller design(7 hours)

Introduction to Regulator problem, Standard LQR and LQG problem, control-Lack of Robustness , Introduction to H2 control, Hinf control, mu Synthesis.

Module 4:Design of Sliding mode controllers (7 hours)

Introduction to Variable Structure Systems (VSS) - examples , Introduction to sliding mode control- -sliding surface- examples of dynamical systems with sliding modes, reaching laws-reachability condition, Invariance conditions- chattering-equivalent control, Design of sliding mode controllers using pole placement, LQR method.

Module 5: Introduction to Adaptive Control(7 hours)

Adaptive Control, effects of process variation - Adaptive Schemes - Adaptive Control problem - Applications - RealTime Parameter Estimation: Introduction - Regression Models - Recursive Least Squares, Self Tuning Regulators introduction, pole placement design, Model Reference Adaptive systems (MRAS) - the need for MRAS , MIT rule, MRAS for first order system.

Text Books

1. Sigurd Skogestad and Ian Postewaite, "Muti-variable Feedback Design" (Second Edition), John Wiley, 2005.

2. Kemin Zhou and Doyle J.C, "Essentials of Robust Control", Prentice-Hall, 1998.

3. C Edwards and Sarah Spurgeon, " Sliding Mode Control: Theory And Applications", Taylor and Francis,1998

4. K. J. Astrom and B. Wittenmark, "Adaptive Control", 2nd Edition, Addison-Wesley, 1995

Reference Books

1. P C Chandrasekharan, "Robust Control of Linear Dynamical Systems", Academic Press, 1996

2. Richard C. Dorf, Robert H. Bishop, "Modern Control Systems", Pearson Education, 2008.

3. S. Sastry and M. Bodson, "Adaptive Control", Prentice-Hall, 1989

3. John C. Doyle, Bruce A. Francis, Allen R. Tannenbaum, "Feedback Control Theory" , Macmillan Pub. Co, 1992

Course Contents and Lecture Schedule

No	Topic	No. of Lectures
1	**Introduction and mathematical preliminaries(8 hours)**	
1.1	Introduction to robust control, Vector space, linear subspaces, Norm and inner product of real vectors and matrix,	2
1.2	Hilbert Spaces, H_2 and H_{inf} Spaces - Computing of H_2 and H_{inf} norms(transfer function and transfer matrices) , Computing of L_2 and L_{inf} Norms, singular value decomposition.	3
1.3	Proper systems- various types, Review of Minimal Realisation, Stabilizability and Detectability, Packed form notation- various configuration,	3
2	**Feedback systems and Uncertainty modelling(9 hours)**	
2.1	Single degree and two degree of freedom Robust Control Systems - System Sensitivity, Relation between Sensitivity and disturbance	2

	inputs in a feedback system, Sensitivity and Complementary Sensitivity function.	
2.2	Sensitivity and Complementary Sensitivity peak selection- its relation to gain and phase margin - Weighted Sensitivity and weighted complementary sensitivity. Well-Posedness of Feedback Loop, Internal Stability.	2
2.3	Model Uncertainty - Classification of uncertainties -parametric, structured and unstructured-m-delta configuration- linear fractional transformation-examples.	3
2.4	Nominal Performance, Nominal Stability, Robust Performance and Robust Stability-Small Gain Theorem, Concept of loop shaping.	2
3	**Robust controller design(7 hours)**	
3.1	Introduction to Regulator problem, Standard LQR and LQG problem, control-Lack of Robustness ,	3
3.2	Introduction to H2 control, Hinf control, mu Synthesis.	4
4	**Design of Sliding mode controllers (7 hours)**	
4.1	Introduction to Variable Structure Systems (VSS)- examples , Introduction to sliding mode control- -sliding surface- examples of dynamical systems with sliding modes , reachability condition, Invariance conditions- chattering-equivalent control	5
4.2	Design of sliding mode controllers using pole placement, LQR method.	2
5	**Introduction to Adaptive Control(7 hours)**	
5.1	Adaptive Control, effects of process variation - Adaptive Schemes - Adaptive Control problem - Applications	1
5.2	RealTime Parameter Estimation: Introduction - Regression Models - Recursive Least Squares,	2

5.3	Self Tuning Regulators introduction, pole placement design,	2
5.4	Model Reference Adaptive systems (MRAS) - the need for MRAS , MIT rule, MRAS for first order system.	2