# SEMESTER I

Discipline : ELECTRICAL & ELECTRONICS
Stream: EE6 (GUIDANCE & NAVIGATION CONTROL)

| Course No. | Course Name | L-T-P-Credits | Year of Introduction |
|---|---|---|---|
| **221TEE100** | LINEAR ALGEBRA AND LINEAR SYSTEMS | **3 - 0 - 0** | **2022** |

**Preamble:** Nil

**Course Prerequisites**

Basic knowledge of engineering mathematics at UG level.

**Course Objectives**

To equip the student with mathematical techniques necessary for computing applications in engineering systems

**Course Outcomes:**

After the completion of the course the student will be able to

| | |
|---|---|
| **CO 1** | Explain the concepts of vector spaces. |
| **CO 2** | Apply linear transformations in linear systems |
| **CO 3** | Solve systems of linear equations and interpret their results |
| **CO 4** | Solve LTI and LTV Systems |
| **CO 5** | Analyse linear systems. |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | | | 3 | 2 | 2 | 2 | |
| **CO 2** | | | 3 | 3 | 3 | 2 | |
| **CO 3** | | | 3 | 3 | 3 | 2 | |
| **CO 4** | | | 3 | 3 | 3 | 2 | |
| **CO 5** | | | 3 | 3 | 3 | 2 | |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 30 |
| Analyse | 20 |
| Evaluate | 20 |
| Create | |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern:**

Micro project/Course based project : 20 marks
Course based task/Seminar/Quiz : 10 marks
Test paper, 1 no. : 10 marks

The project shall be done individually. Group projects not permitted. Test paper shall include minimum 80% of the syllabus.

**End Semester Examination Pattern:**

The end semester examination will be conducted by the University. There will be two parts; Part A and Part B. Part A contain 5 numerical questions (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students), with 1 question from each module, having 5 marks for each question. Students shall answer all questions. Part B contains 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving M Tech Regulations, Curriculum 2022 and quantitative evaluation), with minimum one question from each module of which student shall answer any five. Each question can carry 7 marks. Total duration of the examination will be 150 minutes

**Model Question Paper**

**Pages** **SLOT**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**
**FIRST SEMESTER B.TECH DEGREE EXAMINATION, MONTH & YEAR**

**221TEE100: LINEAR ALGEBRA AND LINEAR SYSTEMS**

**Max. Marks: 60** **Time: 2.5 hrs**

| | **Part A (Answer all questions)** | **Marks** |
|---|---|---|
| 1 | How orthogonality is defined between vectors? Check whether the vectors $v_1 = [1, 2, 1], v_2 = [1, -1, 1]$ are orthogonal or not? If $S = \{v_1, v_2, ...., v_n\}$ is the set of $n$ mutually orthogonal vectors what is the dimension of the space spanned by the set S? Justify your answer? | (5) |
| 2 | Show that null space is the orthogonal complement of row space of a linear transformation matrix | (5) |
| 3 | Show that similarity transformation doses not change the Eigen values of a linear transformation matrix | (5) |
| 4 | What are Eigen vectors of a linear transformation? Find a non-singular matrix $P$ such that $P^T AP$ is diagonal $A = \begin{bmatrix} 1 & 1 & 2 \\ 0 & 3 & 2 \\ 1 & 3 & 9 \end{bmatrix}$ | (5) |
| 5 | Derive the expression for the controllability Grammian matrix of a linear system | (5) |
| | **Part B (Answer any five questions)** | |
| 6 | With the help of a suitable example analyze the stability of a system by pole zero cancellation. | (7) |
| 7 | Define inner product space? Consider the following polynomial $P(t)$ with inner product given by $< f, g >= \int_0^1 f(t)g(t)dt$ find i) $< f, g >$ and (ii) $\| f \|, \| g \|$ if $f(t) = t + 2, \quad g(t) = 3t - 2$ | (7) |

| | | |
|---|---|---|
| 8 | Find the Jordan canonical form of the matrix $A = \begin{bmatrix} 2 & 0 & 1 & -3 \\ 0 & 2 & 10 & 4 \\ 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 3 \end{bmatrix}$ | (7) |
| 9 | Explain in detail the separation principle in the design of control systems. | (7) |
| 10 | What is the significance of a observability Grammian matrix. Derive the expression for the observability Grammian matrix of a linear system. | (7) |
| 11 | What is minimum polynomial of a linear transformation? Find all the Eigen values of $B = \begin{bmatrix} 3 & -1 & 1 \\ 7 & -5 & 1 \\ 6 & -6 & 2 \end{bmatrix}$ what is meant by geometric multiplicity of an Eigen value? Find geometric multiplicity of Eigen values of B?. | (7) |
| 12 | Derive the Ackermanns formula to obtain the state feedback gain matrix. | (7) |

**Text book:**

1. Erwin Kreyszig, Advanced Engineering Mathematics 9th Edition, Wiley International Edition Press, Numerical Recipes for scientific computing,
2. Thomas Kailath, Linear Systems

**References:**


1. Bhaskar Dasgupta, Applied Mathematical Methods, Pearson,
2. Arfken, Weber and Harris, Mathematical Methods for Physicists, A comprehensive guide, 7th Edition, Elsevier, 2013

## Syllabus

### Module I

Vector Spaces - Spaces and Subspaces, Four Fundamental Subspaces, Spanning sets, Linear Independence, Basis and Dimension

### Module II

Linear Transformations – Space of Linear Transformations, Matrix representation of linear transformations, Change of Basis and Similarity

### Module III

Solutions to Linear System of Equations, Rectangular Systems and Echelon Forms, Homogeneous and Non homogeneous systems, Eigenvalues, Eigenvectors, Eigenspaces, Diagonalizability.

### Module IV

Linear Systems - Solutions to LTI and LTV Systems, Analysis of stabilization by pole zero cancellation - Initial conditions for Analog- Computer Simulation, Controllability, Controllabilty Grammians , Stabilizability, Controllable Subspaces, controllable and uncontrollable modes.

### Module V

Reachability and Constructability, Reachable Subspaces, Observability, Observability Grammians, Observable Decomposition, Kalman Decomposition, State feedback Controller Design, Observer Design, separation principle - combined observer controller configuration.

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | Vector Spaces | |
| 1.1 | Spaces and Subspaces. | 1 |
| 1.2 | Four Fundamental Subspaces | 2 |
| 1.3 | Spanning sets | 1 |

| | | |
|---|---|---|
| 1.4 | Linear Independence | 2 |
| 1.5 | Basis and Dimension | 2 |
| 2 | Linear Transformations | |
| 2.1 | Space of Linear Transformations | 2 |
| 2.2 | Matrix representation of linear transformations | 3 |
| 2.3 | Change of Basis and Similarity | 3 |
| 3 | Solutions to Linear System of Equations | |
| 3.1 | Rectangular Systems and Echelon Forms | 2 |
| 3.2 | Homogeneous and Non homogeneous systems | 2 |
| 3.3 | Eigenvalues, Eigenvectors, Eigenspaces | 2 |
| 3.4 | Diagonalizability | 2 |
| 4 | Linear Systems | |
| 4.1 | Solutions to LTI and LTV Systems | 2 |
| 4.2 | Analysis of stabilization by pole zero cancellation - Initial conditions for Analog- Computer Simulation | 2 |
| 4.3 | Controllability, Controllability Grammians , Stabilizability | 2 |
| 4.4 | Controllable Subspaces, controllable and uncontrollable modes | 2 |
| 5 | | |

| | | |
|---|---|---|
| 5.1 | Reachability and Constructability, Reachable Subspaces | 1 |
| 5.2 | Observability, Observability Grammians | 1 |
| 5.3 | Observable Decomposition, Kalman Decomposition | 2 |
| 5.4 | State feedback Controller Design | 2 |
| 5.5 | Observer Design, separation principle - combined observer controller configuration | 2 |

| CODE 221TEE009 | Principles of Aerospace Navigation | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | Program Core 1 | 3 | 0 | 0 | 3 |

**Preamble:** To understand the concepts of navigation of aerospace vehicles with the basics of navigation, various navigation schemes and inertial sensors to find the position of aerospace vehicle using Dead reckoning computations and/or multi sensor navigation systems

**Prerequisites:** Nil

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

| | |
|---|---|
| **CO 1** | Choose a specific reference frame and perform respective transformations to meet the specific objectives of aerospace problems |
| **CO 2** | Identify the performance parameters for inertial sensors and explain its significance in sensor operation. |
| **CO 3** | Select an inertial navigation mechanization to integrate inertial platforms with inertial navigation sensors |
| **CO 4** | Calculate position of an aerospace vehicle using Dead reckoning computations and/or multi sensor navigation systems |
| **CO5** | Illustrate the significance of aided navigation to obtain accurate position and velocity estimation |

**Mapping of course outcomes with program outcomes**

| | **PO 1** | **PO 2** | **PO 3** | **PO 4** | **PO 5** | **PO 6** | **PO 7** |
|---|---|---|---|---|---|---|---|
| **CO 1** | 2 | | 3 | 3 | 1 | 2 | 1 |
| **CO 2** | 2 | | 2 | 2 | 3 | 3 | 1 |
| **CO 3** | 3 | | 3 | 3 | 2 | 3 | 2 |
| **CO 4** | 1 | | 2 | 2 | 3 | 2 | 3 |
| **CO 5** | 2 | | 2 | 2 | 3 | 3 | 2 |

**Assessment Pattern**

| **Bloom's Category** | **End Semester Examination** |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 20 |
| Create | |

**Mark distribution**

| **Total Marks** | **CIE** | **ESE** | **ESE Duration** |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern: 40 marks**
**Core Course**
Micro/Course based Project: 20 Marks
Course based task/Seminar/Quiz: 10 Marks
Test paper 1 No.: 10 Marks

**End Semester Examination Pattern: 60 Marks**
There will be two parts; Part A and Part B. Part A contain 5 numerical questions /short answer questions (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students), with 1 question from each module, having 5 marks for each question. Students shall answer all

questions. Part B contains 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student shall answer any five. Each question can carry 7 marks. Total duration of the examination will be 150 minutes.

**Model Question paper**

**No. of Pages:3** **B**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

FIRST SEMESTER M. TECH DEGREE EXAMINATION

MONTH & YEAR

*Branch:* **Electrical & Electronics Engineering**

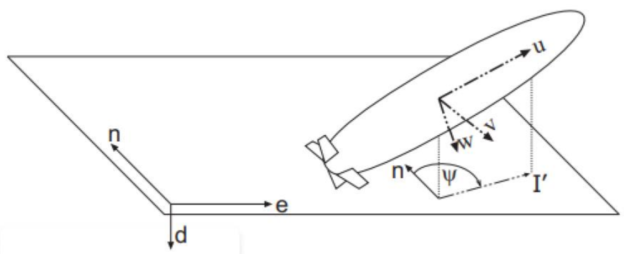
**221TEE009 PRINCIPLES OF AEROSPACE NAVIGATION**

Max. Marks: 60 Duration: 2.5 hours

**PART A**

*(Answer **All** Questions)* (5X5 = 25 Marks)

1. The velocity of an aircraft in geodetic frame $v^g = [-7.07, 0, 7.07]^T$ m/s.The attitude of the aircraft is (Φ, Θ, ψ) = (45, 0, 90) deg. What is the instantaneous rate of change of the aircraft position in the body frame? The frame transformation is as shown in figure.




2. An accelerometer mounted on the table of a centrifuge with its input axis horizontal and radially outward. What is its steady-state output in terms of the radial dimension and the angular velocity of the centrifuge about the vertical?
3. Differentiate local tangent frame and geographic frame. What is the difference between frame origins of local tangent and geographic frame for a stationary and moving aircraft?
4. An aircraft flies 3 hrs east then 2 hrs north at 300 knots at an altitude of 3 nmi, starting at 40 degree north latitude. Find its position using flat Earth Dead reckoning equations.
5. Consider a radar with pulse repetition frequency 1000 Hz. (i) Find the time duration between two pulses. (ii) Suppose an echo from a distant object is received 20 sec after a pulse is transmitted, what is the distance of the object from the radar? (iii) Is there a second-time-around echo from this object?

**PART B**

*(Answer **Any Five** Questions)* (7X 5 = 35 Marks)

6. a) Differentiate local tangent frame and geographic frame. What is the difference of frame origins of local tangent and geographic frame for a stationary and moving aircraft?

b) ECEF frames-of-reference is not an inertial reference frame. Justify it by comparing both the frames-of-references.

7. a) Compare closed-loop and open-loop accelerometers. Among these, which one is best suited for an aircraft with missiles carried at its wing tip, for hundreds of hours, and to make

supersonic dashes and with severe missile vibrations? Justify your answer.

b) List out major sources of error which arise in mechanical accelerometers.

8. Illustrate the law of gyroscopes and give the significance of sagnac effect.

9. A pendulum tuned to the "Schuler Frequency" will always indicate the vertical on a moving vehicle provided it has been initially aligned to it. Justify this with necessary formulation for Schuler time period.

10. Develop the mechanization of INS which is to navigate a vehicle with respect to the Earth, i.e., the ground speed in inertial axes. Use navigation equations to develop block schematic representation.

11. How is the precision landing of aircraft achieved by the satellite based navigation system GAGAN in the Indian region?

12. a) Compare the three Categories of Instrument Landing Systems.

b) Give the significance of Marker Beacons in ILS



**Syllabus**

**Module I**

Definition of navigation, guidance and control - General principles of conventional navigation systems - Geometric Concepts of navigation – Types of navigation. Reference frames- Euler angles, Direction cosines and quaternions - Coordinate transformations – numerical problems - Comparison of transformation methods.

**Module II**

Inertial Sensors: Accelerometers - Principle of operation – accelerometer error model - Transfer Function-Accelerometer performance parameters – Types of accelerometers.

**Module III**

Gyroscopes- Principle of Operation-Precession- Nutation- Gimbal Lock-Gimbal flip-Sagnac effect - Gyro transfer Function-Rate Gyro-Integrating Gyro-Gyro performance parameters.
Inertial navigation - Block diagram representation -Inertial platforms: Stable platforms - Gimballed INS and Strap-down - INS and their mechanization-IMU.

**Module IV**

Navigation Equations-Schuler principle and Mechanization-Error analysis – Platform levelling - Gyro compassing – transfer alignment – attitude and heading reference systems(AHRS) – numerical problems. Dead reckoning computations – Positioning – Terrain matching navigation – Course computation – Navigation errors – Numerical problems.

**Module V**

Radio navigation Systems-Short range navigation Systems-Basics of TACAN, DME-Long range navigation - Overview. Instrument Landing System. Introduction to radars-Block schematic diagram and Principle of operation-Radar equation-Range and frequencies- Application of radars-Types of radar– Numerical Problems. Global Navigation of Satellite Systems (GNSS)-GNSS integrity and availability – GPS overview- Combined GPS/GLONASS - GAGAN - Multi-sensor Navigation Systems

Design and Simulation of systems

1. Attitude Heading Reference System (AHRS)
2. Aided Inertial Navigation and analyse error state observability
3. A navigation system designed for a small autonomous underwater vehicle (AUV). The navigation sensors available on the AUV included an inertial measurement unit (IMU), a Doppler velocity log (DVL), an attitude and heading sensor, a pressure sensor, and a

long baseline (LBL) transceiver.

4. 11 state GPS INS linear error model
5. Design and Simulate Navigation System with total state approach

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | **Module I** | |
| 1.1 | Definition of navigation, guidance and control - General principles of conventional navigation systems - Geometric Concepts of navigation – Types of navigation | 3 |
| 1.2 | Reference frames- Euler angles , Direction cosines and quaternions - Coordinate transformations – numerical problems - Comparison of transformation methods. | 4 |
| 2 | **Module II** | |
| 2.1 | Inertial Sensors: Accelerometers - Principle of operation – accelerometer error model | 3 |
| 2.2 | Transfer function-Accelerometer performance parameters – Types of accelerometers | 3 |
| 3 | **Module III** | |
| 3.1 | Gyroscopes- Principle of operation-Precession- Nutation- Gimbal lock-Gimbal flip- Sagnac effect - Gyro transfer function-Rate gyro-Integrating gyro-Gyro performance parameters. | 5 |
| 3.2 | Inertial navigation - Block diagram representation -Inertial platforms: Stable platforms - Gimballed INS and Strap-down - INS and their mechanization-IMU. | 4 |
| 4 | **Module IV** | |
| 4.1 | Navigation equations-Schuler principle and mechanization-Error analysis – Platform levelling - Gyro compassing – transfer alignment – attitude and heading reference systems(AHRS) – numerical problems | 5 |
| 4.2 | Dead reckoning computations – Positioning – Terrain matching navigation – Course computation – Navigation errors – Numerical problems | 4 |
| 5 | **Module V** | |
| 5.1 | Radio navigation Systems-Short range navigation Systems-Basics of TACAN, DME-Long range navigation - Overview. Instrument Landing System. | 3 |
| 5.2 | Introduction to radars-Block schematic diagram and Principle of operation-Radar equation-Range and frequencies- Application of radars-Types of radar– Numerical Problems | 4 |
| 5.3 | Global Navigation of Satellite Systems (GNSS)- GNSS integrity and availability – GPS overview- Combined GPS/GLONASS - GAGAN | 2 |
| 5.4 | Multi-sensor Navigation Systems | 1 |
| | Design and Simulation of systems<br>1. Attitude Heading Reference System (AHRS)<br>2. Aided Inertial Navigation and analyse error state observability<br>3. A navigation system designed for a small autonomous underwater vehicle (AUV). The navigation sensors available on the AUV included an inertial measurement unit (IMU), a Doppler velocity log (DVL), an attitude and heading sensor, a pressure sensor, and a long baseline (LBL) transceiver.<br>4. 11 state GPS INS linear error model<br>5. Design and Simulate Navigation System with total state approach | |

**Reference Books**


1. Anthony Lawrence, 'Modern Inertial Technology', Second Edition. SpringerVerlag, New York, Inc., 2001.
2. David Titterton and John Weston, 'Strapdown Inertial Navigation Technology' Second Edition IEE Radar, Sonar, Navigation and Avionics Series, 2005.
3. Jay A. Farrell, "Aided Navigation GPS with High Rate Sensors", The McGraw-Hill, 2008.
4. M. I. Skolnik: Introduction to Radar Systems, Tata McGraw-Hill, 2007.
5. Ching-Fang Lin, 'Modern Navigation, Guidance and Control Processing', Prentice-Hall Inc., Engle Wood Cliffs, New Jersey, 1991
6. Myron Kayton and Walter R Fried, 'Avionics Navigation Systems', John Wiley & Sons Inc., Second Edition, 1997.
7. S. Grewal. Angus P. Andrews, C. G. Bartone, "Global Navigation Satellite Systems, Inertial Navigation, and Integration", Wiley – Interscience; 3rd edition, 2013.
8. Robert M. Rogers, "Applied Mathematics and Integrated Navigation Systems", AIAA Education Series, 3rd Edition, 2007.
9. D. J. Biezad, "Integrated Navigation and Guidance Systems", AIAA Education Series, 3rd Edition, 2007
10. Manuel Fernadez and George R. Macomber, 'Inertial Guidance Engineering', Prentice-Hall, Inc., Engle Wood Cliffs, New Jersey, 1962 6.

| CODE 221TEE010 | Introduction to Flight | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | PROGRAM CORE 2 | 3 | 0 | 0 | 3 |

**Preamble:** To give basic concepts of aerodynamics, principles, performance of airfoils, standard atmosphere and performance of flight to analyze the characteristics of the aircraft.

**Prerequisites**: Nil

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

| | |
|---|---|
| **CO 1** | Analyze aerodynamic performance of NACA series of airfoils as per NACA standards |
| **CO 2** | Develop aerodynamic characteristics of an airfoil at specified Mach number. |
| **CO 3** | Apply the concepts of standard atmosphere for analysing the characteristics of aircraft |
| **CO 4** | Assess standard atmosphere and the variation of pressure, temperature and density with height. |
| **CO 5** | Compare the different flow regimes based on Mach number and compare the performance of different airfoil shapes. |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | 1 | | 1 | 3 | 1 | 1 | |
| **CO 2** | 3 | | 2 | 3 | 2 | 1 | |
| **CO 3** | 2 | | 1 | 2 | 1 | 2 | |
| **CO 4** | 1 | | 1 | 2 | 2 | 2 | |
| **CO 5** | 2 | | 2 | 3 | 1 | 2 | |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 20 |
| Create | |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern: 40 marks**
**Core Course**
Micro/Course based Project: 20 Marks
Course based task/Seminar/Quiz: 10 Marks
Test paper 1 No.: 10 Marks

**End Semester Examination Pattern: 60 Marks**

There will be two parts; Part A and Part B. Part A contain 5 numerical questions (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students), with 1 question from each module, having 5 marks for each question. Students shall answer all questions. Part B contains 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student shall answer any five. Each question can carry 7 marks. Total duration of the examination will be 150 minutes.

**Model Question paper**

**No. of Pages:** **C**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

FIRST SEMESTER M.TECH DEGREE EXAMINATION

MONTH & YEAR

*Branch:* **Electrical & Electronics Engineering**

**221TEE010 INTRODUCTION TO FLIGHT**

Max. Marks: 60 Duration: 2.5 hours

**PART A**

*(Answer **All** Questions)* (5X5 = 25 Marks)

1. The pressure and temperature at a certain unknown altitude are measured to be 71800 $N/m^2$ and -10° C. Investigate the stability of the atmosphere between mean sea level and the unknown altitude. Compute unknown altitude. Assume a linear variation of temperature with altitude.
2. An airplane is flying at a standard altitude of 5 km with a velocity of 270 m/s. At a point on the wing on the airplane, the velocity is 330 m/s. Calculate pressure at this point. Assume incompressible flow.
3. An aircraft flying at a density altitude of 3km with a speed of 100m/s. If the free stream density at the above altitude is 0.909 $kg/m^3$, find induced drag on the airplane. The aircraft is with a weight of $7.5 \times 10^5$ N, wing area of 206 $m^2$ and aspect ratio of 10.
4. A NACA 4412 airfoil is tested in a wind tunnel at standard sea-level conditions and a test section velocity of 240 ft/sec and an angle of attack of 8deg. The airfoil is with 2 ft chord and 5 ft span. Find the airfoil's maximum thickness, maximum camber, location of maximum camber, and zero-lift angle of attack? Also, calculate the lift, drag, and pitching moment about the aerodynamic center. Use airfoil data of NACA 4412.
5. Consider a Boeing 747 airliner cruising at a velocity of 550 mi/h at a standard altitude of 38,000 ft, where the freestream pressure and temperature are 432.6 lb/ft2 and 390°R, respectively. A one-fiftieth scale model of the 747 is tested in a wind tunnel where the temperature is 430°R. Calculate the required velocity and pressure of the test airstream in the wind tunnel such that the lift and drag coefficients measured for the wind-tunnel model are the same as for free flight. Assume that both $\mu$ and $a$ are proportional to $T$ 1/2.

**PART B**

*(Answer **Any Five** Questions)* (7X5 = 35 Marks)

6. Derive the expression for the variation of pressure and density in the gradient layer. Also, deduce the stability conditions of the atmosphere.
7. Give the significance of velocity gradient in the boundary layer of an airfoil and deduce the relation between velocity gradient and shear stress at the airfoil wall.
8. Differentiate between aerodynamic center and center of pressure. Also give its significance with the variation of angle of attack.
9. a) Justify the influence of swept wing to delay the drag divergence in subsonic aircrafts. (4)
   b) How does a supercritical airfoil delay the drag divergence to a higher Mach number? (3)
10. a) Deduce the PI terms for force coefficient and Reynolds number using Buckingham PI theorem. (3)
    b) Give the significance of Mach number and compressibility in the variation of coefficient

of pressure in an airfoil (4)

11. Compare the shock waves of thin and thick airfoils with neat sketches. Also deduce the relation between Mach wave and Mach angle.
12. Differentiate between primary and secondary control surfaces. Explain the functions of each control surface.

**Syllabus**

**Module I**

Standard atmosphere-definition of altitudes-density, pressure and temperature altitudes - Layers of atmosphere- isothermal and gradient layers- calculation of pressure, temperature and density in stratosphere and troposphere - Lapse rate –stability of atmosphere.

**Module II**

Aerodynamic flows - inviscid and viscous flows-incompressible and compressible flows- Mach number-subsonic, transonic, supersonic and hypersonic flow regimes- Boundary layer-laminar and turbulent flows- Reynolds number. compressibility-isentropic flow-speed of sound.

**Module III**

Airfoil: Airfoil nomenclature-symmetric and cambered airfoils, aspect ratio-chord line –angle of attack- Wings-wing geometry-downwash and induced drag- wash-in and wash-out- swept wings - Control surfaces-elevator-aileron-rudder-canard-tail plane-loads on tailplane- dihedral angle-dihedral effect-flaps and slots-spoilers

**Module IV**

Aerodynamic forces and moments- Pressure and shear stress distribution- pressure distribution over airfoil-generation of lift- Aerodynamic coefficients-lift, drag and moment coefficients-variation with angle of attack-aerodynamic centre and centre of pressure-dynamic pressure-pressure coefficient- characteristics of ideal airfoil-stalling of airfoil-lift curve, drag curve and lift/drag ratio curve- NACA airfoils-modern low speed airfoils-supercritical airfoils-

**Module V**

Vorticity and circulation- dimensional analysis-Buckingham Pi theorem- aerodynamic heating-Critical Mach number-drag divergence Mach number-Mach angle-Mach number independence-flow similarity-drag polar. Wind tunnels-open, close and variable density wind tunnels -Classification of aerospace vehicles-aircrafts helicopters-launch vehicles-missiles-unmanned aerial vehicles and spacecraft. Basic concepts of high speed aerodynamics and aeroelasticity.

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | Standard atmosphere | |
| 1.1 | Standard atmosphere -definition of altitudes- density, pressure and temperature altitudes - | 2 |
| 1.2 | Layers of atmosphere- isothermal and gradient layers-calculation of pressure, temperature and density in stratosphere and troposphere | 4 |
| 1.3 | Lapse rate –stability of atmosphere. | 2 |
| 2 | Aerodynamic flows | |
| 2.1 | Aerodynamic flows - -inviscid and viscous flows-incompressible and compressible flows- | 3 |
| 2.2 | Mach number-subsonic, transonic, supersonic and hypersonic flow regimes- | 2 |
| 2.3 | Boundary layer-laminar and turbulent flows- Reynolds number. compressibility-isentropic flow-speed of sound. | 3 |
| 3 | Airfoil | |
| 3.1 | Airfoil nomenclature-symmetric and cambered airfoils, aspect ratio-chord line –angle of attack | 3 |
| 3.2 | Wings-wing geometry-downwash and induced drag- wash-in and wash-out- swept wings. | 2 |
| 3.3 | Control surfaces-elevator-aileron-rudder-canard-tail plane-loads on tail plane- dihedral angle-dihedral effect-flaps and slots-spoilers | 3 |
| 4 | | |
| 4.1 | Aerodynamic forces and moments- Pressure and shear stress distribution- pressure distribution over airfoil-generation of lift- | 3 |
| 4.2 | Aerodynamic coefficients-lift, drag and moment coefficients-variation with angle of attack-aerodynamic centre and centre of pressure- dynamic pressure-pressure coefficient- | 3 |
| 4.3 | characteristics of ideal airfoil-stalling of airfoil-lift curve, drag curve and lift/drag ratio curve- NACA airfoils-modern low speed airfoils-supercritical airfoils- | 2 |
| 5 | | |
| 5.1 | Vorticity and circulation- dimensional analysis-Buckingham Pi theorem- aerodynamic heating- | 4 |
| 5.2 | Critical Mach number-drag divergence Mach number-Mach angle-Mach number independence-flow similarity-drag polar. | 2 |
| 5.3 | Wind tunnels-open, close and variable density wind tunnels -Classification of aerospace vehicles-aircrafts helicopters-launch vehicles-missiles-unmanned aerial vehicles and spacecraft. Basic concepts of high-speed aerodynamics and aeroelasticity. | 2 |

**Reference Books**

1. John D Anderson Jr, 'Introduction to flight' McGraw Hill International, 5/e, 2005
2. John D Anderson Jr, 'Fundamentals of Aerodynamics' McGraw Hill International, 4/e, 2007
3. Richard S Shevell, 'Fundamentals of Flight' Pearson Education Inc. 2/e, 2004
4. A. C. Kermode, ''Mechanics of Flight', Pearson Education, 10/e, 2005.
5. Bernard Etkin, 'Dynamics of flight Stability and Control', John Wiley and Sons Inc. 3/e, 1996.
6. E. L. Houghton and N.B. Carruthers 'Aerodynamics for Engineering Students', Arnold Publishers, 3/e, 1986.
7. Thomas R. Yechout, 'Introduction to Aircraft Flight Mechanics', A1AA Education Series, 2003
8. Louis V. Schmidt 'Introduction to Aircraft Flight Dynamics', AIAA Education Series, 1997

| 221EEE048 | OPTIMAL CONTROL OF AEROSPACE SYSTEMS | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | Program Elective 1 | 3 | 0 | 0 | 3 |

**Preamble:** This course aims to provide a foundation to formulate and solve optimal control problems using techniques such as calculus of variations, dynamic programming etc.

**Prerequisites**: Nil

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

| | |
|---|---|
| **CO 1** | To choose a suitable performance measure to meet the specific requirements for a system and to formulate optimal control problems. |
| **CO 2** | To solve optimal control problems using calculus of variations |
| **CO 3** | To solve optimal control problems with control and state constraints |
| **CO 4** | To solve optimal control problems using dynamic programming |
| **CO 5** | To solve optimal control problems using Hamilton-Jacobi-Bellman equations |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

Evaluation shall only be based on application, analysis or design-based questions (for both internal and end semester examinations).

**Continuous Internal Evaluation Pattern: 40 Marks**

Preparing a review article based on peer reviewed original publications (minimum 10 Publications shall be referred): 15 marks

Course based task/Seminar/Data Collection and interpretation: 15 marks

Test paper, 1 no.: 10 marks

Test paper shall include minimum 80% of the syllabus.

**End Semester Examination Pattern:**

The end semester examination will be conducted by the respective College. There will be two parts; Part A and Part B. Part A will contain 5 numerical/short answer questions with 1 question from each module, having 5 marks for each question (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students). Students should answer all questions. Part B will contain 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student should answer any five. Each question can carry 7 marks.

Note: The marks obtained for the ESE for an elective course shall not exceed 20% over the average ESE mark % for the core courses. ESE marks awarded to a student for each elective course shall be normalized accordingly. For example if the average end semester mark % for a core course is 40, then the maximum eligible mark % for an elective course is 40+20 = 60 %.

**Model Question Paper**

**No. of Pages:** **D**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

FIRST SEMESTER M.TECH DEGREE EXAMINATION

MONTH & YEAR

*Branch:* **Electrical & Electronics Engineering**

**221EEE048 OPTIMAL CONTROL OF AEROSPACE SYSTEMS**

Max. Marks: 60 Duration: 2.5 hours

| | **Part A (Answer all questions)** | **Marks** |
|---|---|---|
| 1 | Check whether the functional is linear $J=\int_{t0}^{tf}(2x^2(t)+3x(t)+4)dt.$ Also find the first variation | (5) |
| 2 | Write the necessary conditions to be satisfied by an extremal Hamiltonian for a system with a standard performance measure and whose control is unconstrained. | (5) |
| 3 | Explain bang-bang control. | (5) |
| 4 | Explain the principle of imbedding. | (5) |
| 5 | Why are the LQR problems called so? Also write the performance measure for a standard LQR problem | (5) |
| | **Part B (Answer any five questions)** | |
| 6 | State and prove the fundamental theorem of calculus of variation | (7) |
| 7 | Determine $\dot{x}_1(t)=x_2(t)+u_1(t)$ $\dot{x}_2(t)=u_2(t)$ Find an optimal control that will extremize the performance measure $J=\int_0^1(u_1^2(t)+u_2^2(t))dt$ such that $[x_1(0)\ x_2(0)]^T=[1\ 1]^T$ and $x_1(1)=0$ after defining the Hamiltonian. | (7) |
| 8 | Prove that for the time optimal control in a LTI system, the necessary condition for the existence of singularity in control is that loss of controllability. | (7) |

| | | |
|---|---|---|
| 9 | A first order discrete-time system is described by $x(k+1) = -0.5x(k) + u(k)$ where the performance measure to be minimized is $J = \sum_{k=0}^{2} \lvert x(k) \rvert$ and the admissible states are constrained by $-0.2 \le x(k) \le 0.2$, $k = 0,1,2$ and control are constrained by $-0.1 \le u(k) \le 0.1$, $k = 0,1$. Find the optimal control sequence from all choices of $x(0)$ values, using dynamic programming after quantizing both states and control in steps of 0.1. Use linear interpolation if necessary. | (7) |
| 10 | For the system described by $\dot{x}(t) = x(t) + u(t)$, find the control law that minimize the performance measure $$J = \frac{1}{4}(x^2(T)) + \frac{1}{4}\int_{t=0}^{T} (u^2(t))\, dt$$ when T= 2 and also find the control law when T tends to infinity using HJB equation. | (7) |
| 11 | Prove that a straight line represents a minimum distance between two fixed points $x_o$ and $x_f$ in the $t - x$ plane where $x_o = x(t_o)$ and $x_f = x(t_f)$, $t_o$ is known and final $t$ which is $t_f$ is fixed | (7) |
| 12 | Derive the recurrence relation in dynamic programming. | (7) |

## Syllabus

### Module 1

Optimization problems vs optimal control problems, Optimal control problem formulation- -selection of performance measures, constraints- classification- problem formulation – examples, Calculus of Variations: basic concepts - variation of a functional - extremals – fundamental theorem of calculus of variation - Euler Equation-Cases with various conditions on final state and time-fixed end point and free end point problems.

Review of numerical methods for the solution of nonlinear equations—static and dynamic optimization -Motivational example for optimal control problem (Optimal launch of a satellite) – Optimal control problem formulation using calculus of variations

### Module 2

Piecewise smooth extremals, constrained minimization of functionals – Point constraints, differential equation constraints, isoperimetric constraints, Hamiltonian -necessary conditions for optimal control, problems with different boundary conditions

Solution of optimal control problem with calculus of variations approach using MATLAB (demo/assignment only)

Constrained extremals-problems of Lagrange, Mayer and Bolza-Euler-Lagrange Equation-Necessary conditions for optimal control, Pontryagin's minimum principle and state inequality constraints, classical numerical methods to solve optimal control problems.

### Module 3

Pontryagin's Minimum Principle, State variable inequality constraints, the set of reachable states, Minimum time problems-bang bang control, Minimum Fuel problems-bang off bang control- Minimum energy problems, Singular intervals- Numerical Examples.

Solution of optimal control problem with control and state constraints using MATLAB (demo/assignment only)

Formulation and solution of these classes of optimal control problems with emphasis on aerospace systems. Linear quadratic regulator problems, Riccati Equation.

### Module 4

Dynamic Programming - Optimal control law-principle of optimality - Application to decision making problems-routing problem-application to typical optimal control problem, Interpolation, recurrence relation in dynamic programming.

### Module 5

Hamilton Jacobi Bellman equation- Standard Regulator Problem: Continuous linear regulator Problems – Discrete Linear Regulator Problems –Finite time Vs Infinite time regulator Problems – Stability of linear regulator problems.

Solution of LQR problem, solution of matrix Riccati equation- using MATLAB (demo/assignment only)

Application of optimal control in aerospace systems -Linear optimal missile guidance using LQR-multiphase lunar landing trajectory with minimal fuel consumption; -Optimal control based on impact time and impact angle control; -UAV trajectory tracking with optimal control

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | | |
| 1.1 | Optimal control problems | 1 |
| 1.2 | Mathematical models-selection of performance measures, constraints- classification - problem formulation – examples | 2 |
| 1.3 | Calculus of Variations: basic concepts - variation of a functional - extremals | 1 |
| 1.4 | fundamental theorem in calculus of variation - Euler equation- | 2 |
| 1.5 | Cases with various conditions on final state and time. | 2 |
| 1.6 | Review of numerical methods for the solution of nonlinear equations—static and dynamic optimization - Motivational example for optimal control problem (Optimal launch of a satellite) – Optimal control problem formulation using calculus of variations | Optional |
| 2 | | |
| 2.1 | Piecewise smooth extremals | 1 |
| 2.2 | constrained minimization of functionals – Point constraints, | 2 |
| 2.3 | differential equation constraints,isoperimetric constraints, | 2 |
| 2.4 | Hamiltonian -necessary conditions for optimal control,problems with different boundary conditions | 2 |

| | | |
|---|---|---|
| 2.5 | Constrained extremals-problems of Lagrange, Mayer and Bolza-Euler-Lagrange equation-Necessary conditions for optimal control, Pontryagin's minimum principle and state inequality constraints, classical numerical methods to solve optimal control problems. | Optional |
| 3 | | |
| 3.1 | Pontryagin's Minimum Principle | 1 |
| 3.2 | State variable inequality constraints | 1 |
| 3.3 | the set of reachable states, Minimum time problems-bang bang control, | 2 |
| 3.4 | Minimum Fuel problems-bang off bang control | 2 |
| 3.5 | Singular intervals- Numerical Examples. | 2 |
| 3.6 | Formulation and solution of these classes of optimal control problems with emphasis on aerospace systems. Linear quadratic regulator problems, Riccati Equation. | Optional |
| 4 | | |
| 4.1 | Dynamic Programming | 1 |
| 4.2 | Optimal control law-principle of optimality - Application to decision making problems-routing problem | 2 |
| 4.3 | application to typical optimal control problem | 2 |
| 4.4 | Interpolation, | 1 |

| | | |
|---|---|---|
| 4.5 | recurrence relation in dynamic programming | 1 |
| 5 | | |
| 5.1 | Hamilton Jacobi Bellman equation- | 1 |
| 5.2 | Standard Regulator Problem: Continuous linear regulator Problems Finite time Vs Infinite time regulator Problems | 2 |
| 5.3 | Discrete Linear Regulator Problems | 2 |
| 5.4 | Stability of linear regulator problems | 2 |
| 5.5 | Application of optimal control in aerospace systems - Linear optimal missile guidance using LQR-multiphase lunar landing trajectory with minimal fuel consumption; -Optimal control based on impact time and impact angle control; -UAV trajectory tracking with optimal control | Optional |

**Reference Books**

1. Donald E. Kirk, Optimal Control Theory - An Introduction, Prentice-Hall Inc. Englewood Cliffs, New Jersey, 1970.
2. Brian D. O. Anderson, John B. Moore, Optimal Control-Linear Quadratic Methods, Prentice-Hall Inc., New Delhi, 1991.
3. Athans M. and P. L. Falb, Optimal control- An Introduction to the Theory and its Applications, McGraw Hill Inc., New York, 1966.
4. Sage A. P., Optimum Systems Control, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1968.

5. D. S. Naidu, Optimal Control Systems, CRC Press, New York Washington D. C., 2003.

6. Arthur E Bryson Jr., Yu-Chi Ho, Applied Optimal Control: Optimization, Estimation and Control, Taylor & Francis, 2018.

7. Robert F Stengel, "Optimal Control and Estimation", Dover Publishers, 2012

8. David G Hull, Optimal Control Theory for Applications, Springer, 2003

9. Joseph Z Ben-Asher, Optimal Control Theory with Aerospace Applications, AIAA Education Series 2009.

| CODE 221EEE030 | MACHINE LEARNING | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | PROGRAM ELECTIVE 1 | 3 | 0 | 0 | 3 |

**Preamble:** This course enables the learners to understand the fundamental concepts in machine learning. The course covers the basic introduction, various estimation methods, most popular supervised and unsupervised learning algorithms. Course also throws light to neural network systems and classifier estimation process. This course will enable students to create machine learning based solutions to various real-world problems.

**Prerequisites:** Nil

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

| | |
|---|---|
| **CO 1** | Illustrate machine learning concepts and basic parameter estimation methods along with central tendency measures. **(Cognitive Knowledge Level: Apply)** |
| **CO 2** | Describe the underlying mathematical relationships within and across Machine Learning algorithms and the paradigms of supervised learning. **(Cognitive Knowledge Level: Apply)** |
| **CO 3** | Illustrate the basic concepts of neural networks in-line with feed forward neural network and its training process along with machine learning classifiers **(Cognitive Knowledge Level: Apply)** |
| **CO 4** | Demonstrate and describe the underlying mathematical relationships within and across Machine Learning algorithms and the paradigms of unsupervised learning. **(Cognitive Knowledge Level: Apply)** |
| **CO 5** | Demonstrate and illustrate how to compare various machine learning models along with the application of machine learning in control problems **(Cognitive Knowledge Level: Apply)** |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | 3 | | 2 | 3 | 2 | | |
| **CO 2** | 3 | | 2 | 3 | 2 | | |
| **CO 3** | 3 | | 2 | 3 | 2 | | |
| **CO 4** | 3 | | 2 | 3 | 2 | | |
| **CO 5** | 3 | 2 | 2 | | 2 | | |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 60 % |
| Analyse | 20% |
| Evaluate | 10% |
| Create | 10% |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |



**Continuous Internal Evaluation Pattern**:
ELECTIVE COURSES Evaluation shall only be based on application, analysis or design based questions (for both internal and end semester examinations).

**Continuous Internal Evaluation: 40 marks**
Preparing a review article based on peer reviewed Original publications (minimum 10 Publications shall be referred) : 15 marks
Course based task/Project/Seminar/Data Collection and interpretation: 15 marks Test paper, 1 no.: 10 marks Test paper shall include minimum 80% of the syllabus

**End Semester Examination Pattern:**

The end semester examination will be conducted by the respective College.
There will be two parts; Part A and Part B.
**Part A** will contain 5 numerical/short answer questions with 1 question from each module, having 5 marks for each question (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students). Students should answer all questions.
**Part B** will contain 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student should answer any five. Each question can carry 7 marks.

Note: The marks obtained for the ESE for an elective course shall not exceed 20% over the average ESE mark % for the core courses. ESE marks awarded to a student for each elective course shall be normalized accordingly. For example if the average end semester mark % for a core course is 40, then the maximum eligible mark % for an elective course is 40+20 = 60 %.

**Model Question paper**

QP CODE: PAGES:

Reg No:_______________ Name:_________________

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**
**___ SEMESTER ___ DEGREE EXAMINATION, MONTH &YEAR**

**Course Code: 221EEE030**

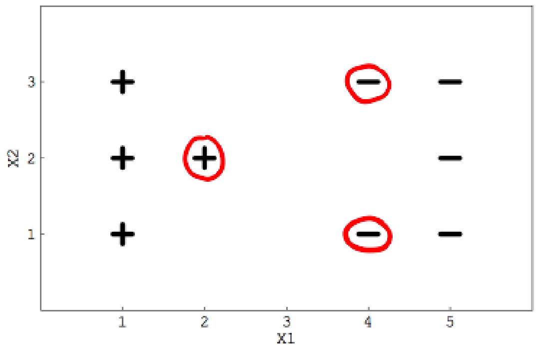
**Course Name: MACHINE LEARNING**

**Max.Marks:100** **Duration: 2.5Hrs**

**PART A**
**Answer all Questions. Each question carries 5 Marks**

1.Explain how a systemcan play a game of Chess using rrenforcement learning.
2. Suppose you have a dataset with m = 1000000 examples and n = 200000 features for each example. You want to use multivariate linear regression to fit the parameters to our data. Should you prefer gradient descent or the normal equation? Justify your answer.

3. Suppose you are using a Linear SVM classifier with 2 class classification problem and you are given the following data in which some points are circled red that are representing support vectors.




If you remove any one red points from the data. Does the decision boundary will change? Discuss in detail.
4. How can a generative model p(x|y) be used as a classifier? Also explain, why is dimensionality reduction useful?

5. A classifier has a high precision but low recall. What does this mean?

**(5x5=25)**

**PART B**

**Answer any FIVE Question. Each question carries 7 Marks**

6. Define supervised learning? Name and explain with suitable examples, the special cases of supervised learning depending on whether the inputs/outputs are categorical, or continuous.

7. How can you interpret the output of a two-class logistic regression classifier as a probability? Also, In a two-class logistic regression model, the weight vector w = [4, 3, 2, 1, 0]. We apply it to some object that we would like to classify; the vectorized feature representation of this object

is x = [−2, 0,−3, 0.5, 3]. What is the probability, according to the model, that this instance belongs to the positive class? Discuss.

8. Consider a support vector machine whose input space is 2-D, and the inner products are computed by means of the kernel K(x, y) = (x.y + 1)2-1, where x.y denotes the ordinary inner product. Show that the mapping to feature space that is implicitly defined by this kernel is the mapping to 5-D given by

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \rightarrow \phi(\mathbf{x}) = \begin{bmatrix} x_1^2 \\ x_2^2 \\ \sqrt{2}\, x_1 x_2 \\ \sqrt{2}\, x_1 \\ \sqrt{2}\, x_2 \end{bmatrix}$$



9.

| *a* | *b* | *c* | *d* | *e* | *f* | *g* | *h* | *i* | *j* |
|---|---|---|---|---|---|---|---|---|---|
| (2,0) | (1,2) | (2,2) | (3,2) | (2,3) | (3,3) | (2,4) | (3,4) | (4,4) | (3,5) |

Suppose that we have the following data:
Identify the cluster by applying the k-means algorithm, with k = 2. Try using initial cluster centers as far apart as possible.

10. Explain the various types of regression. Also, supposeif you are asked to perform linear regression to learn the function that outputs y, given the D-dimensional input x. You are given N independent data points, and that all the D attributes are linearly independent. Assuming that D is around 100, would you prefer the closed form solution or gradient descent to estimate the regressor?

11. Consider the two dimensional patterns (2, 1), (3, 5), (4, 3), (5, 6), (6, 7), (7, 8). Compute the principal component using PCA Algorithm.

12. (a) Define Precision, Recall, Accuracy and F-measure?
(b)Fill in the missing values in the accompanying three class confusion matrix. Given that model accuracy is 72% and classification error for class 2 is 20%. Find also the precision and recall for class1.

| | | **Predicted** | | |
|---|---|---|---|---|
| | | Class 1 | Class 2 | Class 3 |
| **Actual** | Class 1 | 14 | 2 | 5 |
| | Class 2 | ? (x) | 40 | 2 |
| | Class 3 | 1 | ?(y) | 18 |

**(5x7=35)**

## Syllabus

### Module I -Introduction

Introduction to Machine Learning - How do machines learn - Selecting the right features, understanding data: - numeric variables – mean, median, mode, Measuring spread.

Review of distributions: Uniform and normal. Categorical variables.

Machine learning paradigms-supervised, semi-supervised, unsupervised, reinforcement learning.

### Module II -Supervised Learning

Supervised Learning - Regression - Linear regression with one variable, Linear regression with multiple variables, solution using gradient descent algorithm and matrix method, basic idea of overfitting in regression.

Linear Methods for Classification- Logistic regression, Perceptron, Naive Bayes, Classification using Decision Trees and Rules - Decision Tree algorithm ID3

### Module-III - Neural Networks (NN) and Support Vector Machines (SVM)

NN - Multilayer feed forward network, Activation functions (Sigmoid, ReLU, Tanh), Back propagation algorithm.

SVM - Introduction, Maximum Margin Classification, Mathematics behind Maximum Margin Classification, Maximum Margin linear separators, soft margin SVM classifier, non-linear SVM, Kernels for learning non-linear functions, polynomial kernel, Radial Basis Function(RBF).

### Module-IV -Unsupervised Learning

Clustering - Similarity measures, Hierarchical Agglomerative Clustering, K-means partitional clustering, Expectation maximization (EM) for soft clustering. Dimensionality reduction – Principal Component Analysis, factor Analysis,

Multidimensional scaling, Linear Discriminant Analysis.

### Module-V - Classification Assessment and Appplications

Classification Performance measures - Precision, Recall, Accuracy, F-Measure, Receiver Operating Characteristic Curve(ROC), Area Under Curve(AUC. Bootstrapping, Cross Validation, Ensemble methods, Bias-Variance decomposition.

Applications to Control Problems: State estimation using neuro observer (single layer and multi layer), kalman filter and reinforcement learning, Identification of non-linear dynamical systems using neural networks (state space models and input-output models)

Optimal control problems using support vector machines, regression methods, monte-carlo method, model predictive control and adaptive reinforcement learning

Course Project: Develop a classifier for face detection application or similar simple problems.

## Course Plan

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | **Introduction to Machine Learning( 6 hrs)** | |
| 1.1 | Introduction to Machine Learning - How do machines learn -Selecting the right features. | 1 |
| 1.2 | Understanding data:- numeric variables – mean, median, mode, Measuring spread | 1 |
| 1.3 | Review of distributions: Uniform and normal. Categorical variables. | 1 |
| 1.4 | Machine learning paradigms-supervised, semi-supervised, unsupervised, reinforcement learning. | 1 |
| 1.5 | Machine learning paradigms-supervised, semi-supervised, unsupervised, reinforcement learning. | 2 |
| 2 | **Supervised Learning (10 hrs)** | |
| 2.1 | Supervised Learning - Regression - Linear regression with one variable, Linear regression with multiple variables. | 2 |
| 2.2 | Solution using gradient descent algorithm and matrix method, basic idea of overfitting in regression | 3 |
| 2.3 | Linear Methods for Classification- Logistic regression, Perceptron, | 2 |
| 2.4 | Naive Bayes, Classification using Decision Trees and Rules - Decision Tree algorithm ID3 | 3 |
| 3 | **Neural Networks (NN) and Support Vector Machines (SVM)(8 hrs)** | |
| 3.1 | NN - Multilayer feed forward network, Activation functions (Sigmoid, ReLU, Tanh) | 2 |
| 3.2 | Back propagation algorithm. | 2 |
| 3.3 | SVM - Introduction, Maximum Margin Classification, Mathematics behind Maximum Margin Classification, Maximum Margin linear separators, soft margin | 2 |
| 3.4 | SVM classifier, non-linear SVM, Kernels for learning non-linear functions, polynomial kernel, Radial Basis Function(RBF). | 2 |
| 4 | **Unsupervised Learning (8 hrs)** | |
| 4.1 | Clustering - Similarity measures, Hierarchical Agglomerative Clustering. | 2 |
| 4.2 | K-means partitional clustering, Expectation maximization (EM) for soft clustering. | 2 |
| 4.3 | Dimensionality reduction – Principal Component Analysis, factor Analysis, | 2 |
| 4.4 | Multidimensional scaling, Linear Discriminant Analysis | 2 |

| | | |
|---|---|---|
| 5 | **Classification Assessment and Appplications (8 hrs)** | |
| 5.1 | Classification Performance measures - Precision, Recall, Accuracy, F-Measure, Receiver Operating Characteristic Curve (ROC), Area Under Curve (AUC. Bootstrapping, Cross Validation,Ensemble methods, Bias-Variance decomposition. | 3 |
| 5.2 | Applications to Control Problems: State estimation using neuro observer (single layer and multi layer), kalman filter and reinforcement learning,; Identification of non-linear dynamical systems using neural networks (state space models and input-output models) | 3 |
| 5.3 | Optimal control problems using support vector machines, regression methods, monte-carlo method, model predictive control and adaptive reinforcement learning | 2 |



**Reference Books**

1. Frank Leroy Lewis, Suresh Jagannathan, A. Yeşildirek, Neural Network Control of Robot Manipulators and Non-Linear Systems, Taylor and Francis group, 1999.
2. Frank L. Lewis, Derong Liu, Reinforcement Learning and Approximate Dynamic Programming for Feedback Control, Wiley and IEEE press, 2013
3. Zi-Xing Cai, Intelligent Control: Principles, Techniques and Applications World Scientific, 1997.
4. Bishop, C. M., Pattern Recognition and Machine Learning, Springer, 2006.
5. Alexander S. Poznyak, Edgar N. Sanchez, Wen Yu, Differential Neural Networks for Robust Nonlinear Control Identification, State Estimation and Trajectory tracking, World Scientific, 2001.
6. Alex Smola, S.V.N. Vishwanathan, Introduction to Machine Learning, Cambridge University Press, 2010.
7. Simon Haykins, Neural Networks and Learning Machines, Prentice Hall, 2009.
8. Related Research Articles from Journals and Conferences.

| 221EEE049 | ROBOTIC SYSTEMS AND CONTROL | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | PROGRAM ELECTIVE I | 3 | 0 | 0 | 3 |

**Preamble:** To familiarize robotic configurations and develop kinematic and dynamic models to plan the trajectories of mobile robots with suitable controllers.

**Prerequisites**: Nil

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

| | |
|---|---|
| **CO 1** | Familiarise with anatomy, specifications and standard robot configurations |
| **CO 2** | Obtain the kinematic model of a robotic manipulator and to plan trajectories for a robot |
| **CO 3** | Develop dynamic model for robots |
| **CO 4** | Familiarise with different mobile robot configurations |
| **CO 5** | Design controllers for robotic manipulators |
| **CO 6** | Design controllers for mobile robots |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | 3 | | | | | | |
| **CO 2** | 3 | | | | | | |
| **CO 3** | 3 | | | | | | |
| **CO 4** | 3 | | | | | | |
| **CO 5** | 3 | | 3 | 3 | 2 | | |
| **CO 6** | 3 | | 3 | 3 | 2 | | |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 20 |
| Create | |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern:**

Preparing a review article based on peer reviewed original publications (minimum 10 publications shall be reffered: 15 marks
Course based task/Seminar/Data collection and Interpretation: 15 Marks
Test paper 1 No.: 10 Marks
Test paper shall include minimum 80% of the syllabus.

**End Semester Examination Pattern: 60 Marks**

There will be two parts; Part A and Part B. Part A contain 5 numerical questions (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students), with 1 question from each module, having 5 marks for each question. Students shall answer all questions. Part B contains 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student shall answer any five. Each question can carry 7 marks. Total duration of the examination will be 150 minutes.

**Model Question Paper**

**No. of Pages:** **D**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

FIRST SEMESTER M.TECH DEGREE EXAMINATION

MONTH & YEAR

*Branch:* **Electrical & Electronics Engineering**

**221EEE049 - ROBOTIC SYSTEMS AND CONTROL**

Answer all full questions from PART A and any 5 full questions from PART B

Limit answers to the required points.

Max. Marks: 60 Duration: 2.5 hours

**PART A**

1 Write a short note on the basic building blocks of a robotic manipulator. (5)

2 A single-link robot with a rotary joint is motionless at $\theta$ = 15 degrees. It is desired to move the joint in a smooth manner to $\theta$ = 75 degrees in 3 seconds. Determine the cubic polynomial to interpolate a smooth trajectory that accomplishes this motion and brings the manipulator to rest at the goal. Also obtain the velocity and acceleration profiles of the joint as a function of time. (5)

3 Obtain the kinematic model of a differentially driven mobile robot and compute the state space model of this system with x, y, θ as states and left wheel and right wheel velocities as control inputs. (5)

4 Write a short note on the computed torque control scheme of robotic manipulators. (5)

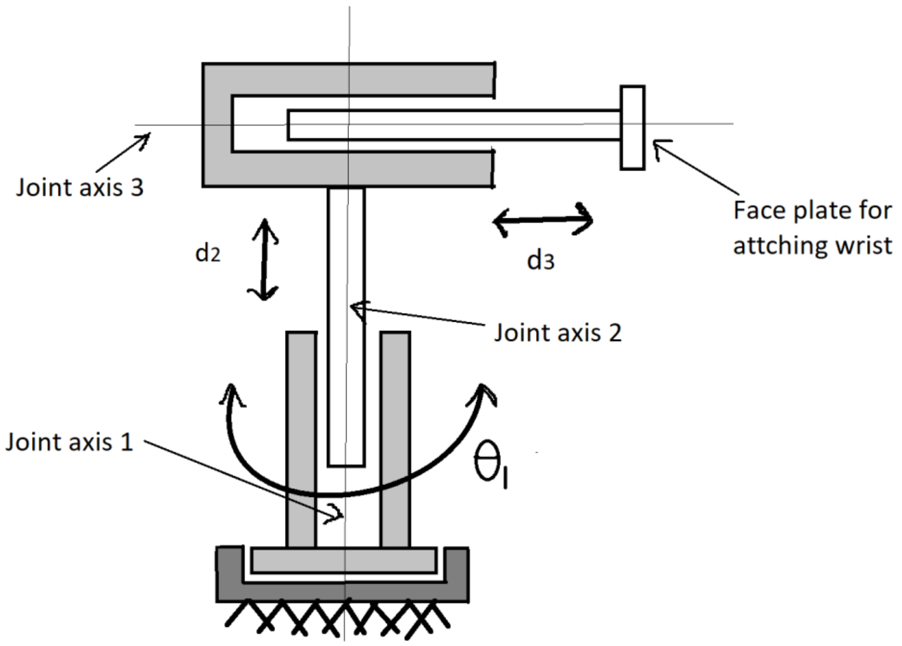
5 How will you drive a steered robot to a specified destination [xg, yg]? With the help of block schematic explain the control scheme. (5)

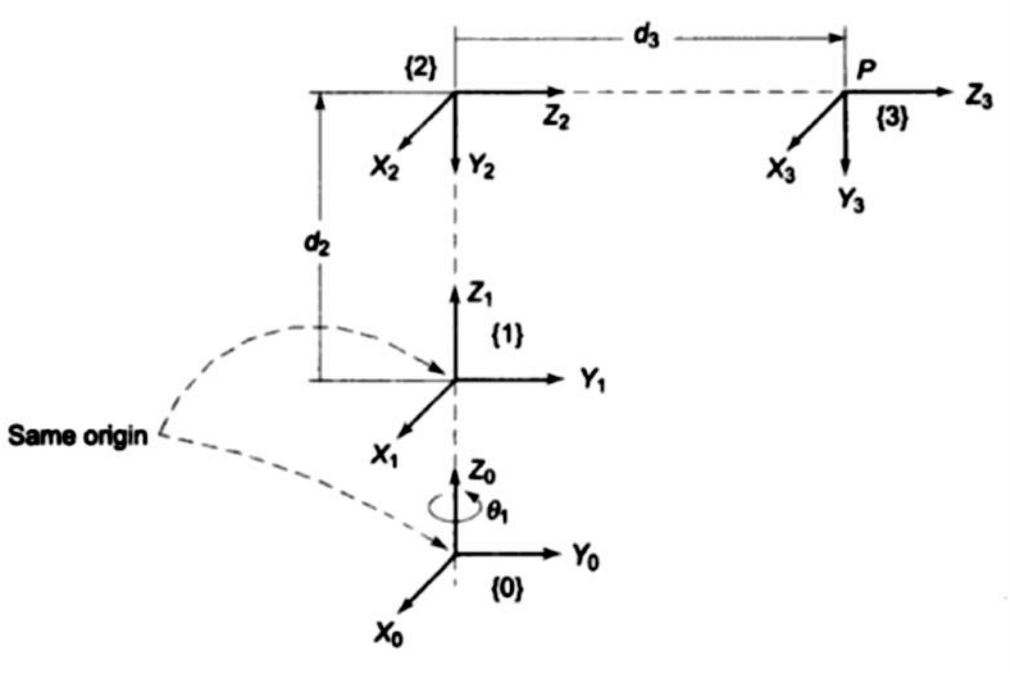
**PART B**

6 a. List and explain specifications of a robotic manipulator in detail. (4)

b. Briefly explain the classification of robotic manipulators based on motion control methods. (3)

7 For the following cylindrical robot arm, compute the position and orientation of the tool tip. (7)



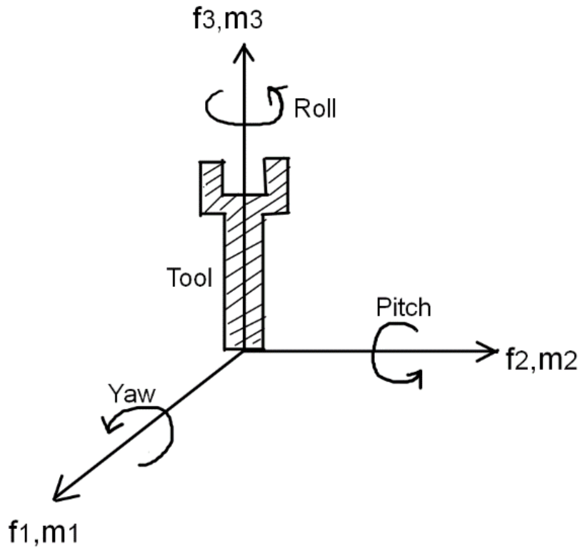



8 a. Suppose the point P at the tool tip shown in the below figure has mobile coordinates $[P]^M = [\,7,3,2\,]^T$ and is subjected to the transformations described next. Find the coordinates of the point relative to the fixed reference $F = \{f^1, f^2, f^3\}$ frame at the conclusion of transformations. (4)

i. Rotation of 90 degree about $f^3$ axis,

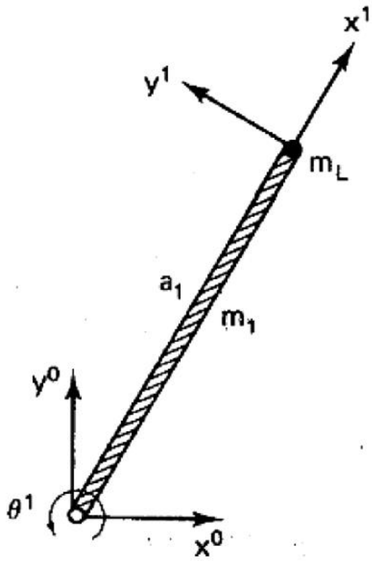
ii. Followed by a rotation of 90 degree about the $f^2$ axis,

iii. Followed by a translation of [4, -3, 7].




b. Differentiate between forward kinematics and inverse kinematics of a robot arm. (3)

9 Obtain the dynamic model of the single link manipulator of link length $a_1$ and mass $m_1$ handling a load of mass $m_L$. (7)




10 Explain in detail about any one linear control scheme of robotic manipulator. (7)

11 Suppose a robotic manipulator is to be designed to erase a white board. Which (7)

control scheme be used? Explain.

12 Design a controller for a steered mobile robot to follow a line in the plane given by $ax + by + c = 0$. With the help of a suitable block diagram explain how the controller can be implemented. (7)

**Syllabus**

**Module I:**

**Introduction**

Robots, Robotics; Types of Robots- Manipulators, Mobile Robots-wheeled & Legged Robots, Aerial Robots; Anatomy of a robotic manipulator-links, joints, actuators, sensors, controller; open kinematic vs closed kinematic chain; degrees of freedom; Robot considerations for an application- number of axes, work volume, capacity & speed, stroke &reach, Repeatability, Precision and Accuracy, Operating environment, point to point control or continuous path control.

Robot configurations-PPP, RPP, RRP, RRR; features of SCARA, PUMA Robots; Classification of robots based on motion control methods and drive technologies.

**Module II**

**Kinematics and Motion Planning**

Robot Coordinate Systems- Fundamental and composite rotations, homogeneous co-ordinates and transformations, Kinematic parameters, D-H representation, Direct Kinematics. The Arm equation- forward Kinematic analysis of a typical robots upto 3 DOF.

Motion Planning- joint space trajectory planning-cubic polynomial, linear trajectory with parabolic blends; Cartesian space planning, Point to point vs continuous path planning.

**Module III**

**Modelling of Robots**

Dynamics- Dynamic model of a robot using Lagrange's equation, dynamic modelling of 1DOF robot, including motor and gearbox, 2R planar manipulator.

Basic understanding of Differential-Drive WMR, Car-Like WMR, Three-Wheeled Omnidirectional Mobile Robot, Kinematic model of a differential drive and a steered mobile robot.

**Module IV**

**Control of robotic manipulators**

Necessity of a control system in a robot, block diagram typical robot control system, position control, force control.

PID control, PD gravity control, Computed torque control, Variable Structure control, Impedance control, digital control of a single link manipulator.

Case study- Feedback control of a single link manipulator using MATLAB. (Assignment/demo only)

**Module V**

**Control of mobile robots**

Control of mobile robots- Control of differential drive robot and steered robot based on its kinematic model, Control of differential drive robot to move to a point, follow a line, follow a trajectory, to achieve an orientation. Control of a steered robot to move to a point, follow a line, follow a trajectory, to achieve an orientation.

Case study- design and implementation of a differential drive robot capable of moving to a point, following a line and following a path using MATLAB (Assignment/demo only)

**References**


1. Robert. J. Schilling, "Fundamentals of robotics – Analysis and control", Prentice Hall of India 1996.
2. R K Mittal and I J Nagrath, "Robotics and Control", Tata McGraw Hill, New Delhi,2003.
3. Introduction to Robotics by S K Saha, Mc Graw Hill Eduaction
4. Introduction to Robotics (Mechanics and control), John. J. Craig, Pearson Education Asia 2002.
5. Ashitava Ghosal, "Robotics-Fundamental concepts and analysis", Oxford University press.
6. Peter Corke, Robotics, Vision and Control: Fundamental Algorithms in MATLAB
7. Introduction to Autonomous Mobile Robots, R Siegwart, IR Nourbakhsh, D Scaramuzza, , MIT Press, USA, 2011.


**Course plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | **Introduction** | |
| 1.1 | Robots, Robotics; Types of Robots- Manipulators, Mobile Robots-wheeled & Legged Robots, Aerial Robots; | 2 |
| 1.2 | Anatomy of a robotic manipulator-links, joints, actuators, sensors, controller; open kinematic vs closed kinematic chain; degrees of freedom; | 2 |
| 1.3 | Robot considerations for an application- number of axes, work volume, capacity & speed, stroke &reach, Repeatability, Precision and Accuracy, Operating environment, point to point control or continuous path control. | 2 |
| 1.4 | Robot configurations-PPP, RPP, RRP, RRR; features of SCARA, PUMA Robots; Classification of robots based on motion control methods and drive technologies. | 3 |
| 2 | **Kinematics and Motion Planning** | |
| 2.1 | Robot Coordinate Systems- Fundamental and composite rotations, homogeneous co-ordinates and transformations | 2.5 |
| 2.2 | Kinematic parameters, D-H representation, Direct Kinematics. The Arm equation- forward Kinematic analysis of a typical robots upto 3 DOF. | 4 |
| 2.3 | Motion Planning- joint space trajectory planning-cubic polynomial, linear trajectory with parabolic blends; Cartesian space planning, Point to point vs continuous path planning. | 2.5 |
| 3 | **Modelling of Robots** | |
| 3.1 | Dynamics- Dynamic model of a robot using Lagrange's equation, dynamic modelling of 1DOF robot, including motor and gearbox, 2R planar manipulator. | 3 |
| 3.2 | Basic understanding of Differential-Drive WMR, Car-Like | 2 |

| | | |
|---|---|---|
| | WMR, Three-Wheeled Omnidirectional Mobile Robot | |
| 3.3 | Kinematic model of a differential drive and a steered mobile robot. | 2 |
| 4 | **Control of robotic manipulators** | |
| 4.1 | Necessity of a control system in a robot, block diagram typical robot control system, position control, force control. | 2 |
| 4.2 | PID control, PD gravity control, Computed torque control, Variable Structure control, Impedance control, digital control of a single link manipulator. | 5 |
| 4.3 | Case study- Feedback control of a single link manipulator using MATLAB. (Assignment/demo only) | 1 |
| 5 | **Control of mobile robots** | |
| 5.1 | Control of mobile robots- Control of differential drive robot and steered robot based on its kinematic model, Control of differential drive robot to move to a point, follow a line, follow a trajectory, to achieve an orientation. | 4 |
| 5.2 | Control of a steered robot to move to a point, follow a line, follow a trajectory, to achieve an orientation. | 2 |
| 5.3 | Case study- design and implementation of a differential drive robot capable of moving to a point, following a line and following a path using MATLAB (Assignment/demo only) | 1 |

| CODE 221EEE058 | SPACECRAFT GUIDANCE NAVIGATION AND CONTROL | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | PROGRAM ELECTIVE I | 3 | 0 | 0 | 3 |

**Preamble:** To impart principles and various methods of guidance and control of space vehicles and satellites.

**Prerequisites**: Nil

**Course Outcomes:**

After the completion of the course the student will be able to

| | |
|---|---|
| **CO 1** | Identify the orbital parameters and describe the fundamentals of orbital mechanics. |
| **CO 2** | Design suitable orbits for satellites and analyse different orbit manoeuvres |
| **CO 3** | Choose appropriate guidance law for the launch phase and orbital transfer of a space vehicle |
| **CO 4** | Identify suitable re-entry mechanism and guidance schemes for reusable space vehicles |
| **CO 5** | Discuss various attitude control mechanisms and stabilization methods of satellites. |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | 1 | - | 1 | 2 | 1 | - | - |
| **CO 2** | 2 | - | 2 | 3 | 2 | - | - |
| **CO 3** | 2 | - | 3 | 3 | 3 | 1 | - |
| **CO 4** | 2 | - | 3 | 3 | 3 | 1 | - |
| **CO 5** | 1 | - | 1 | 1 | 2 | - | - |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 15 |
| Create | 5 |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern: 40 marks**

**Elective Course**

Preparing a review article based on peer reviewed original publications (minimum 10 publications shall be referred) : 15 Marks

Course based task/Seminar/Data collection and Interpretation: 15 Marks

Test paper 1 No.: 10 Marks

**End Semester Examination Pattern:**

There will be two parts; Part A and Part B. Part A contain 5 numerical questions (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students), with 1 question from each module, having 5 marks for each question. Students shall answer all questions. Part B contains 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student shall answer any five. Each question can carry 7 marks. Total duration of the examination will be 150 minutes.

**Model Question paper**

| | | | |
|---|---|---|---|
| **No. of Pages:** | | | **D** |
| | | | **APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**<br>FIRST SEMESTER M.TECH DEGREE EXAMINATION<br>MONTH & YEAR |
| | | | *Branch:* **Electrical & Electronics Engineering** |

***Course Code & Name: 221EEE058***
**SPACECRAFT GUIDANCE NAVIGATION AND CONTROL**

**Answer *all full* questions from *PART A and any 5 full* questions *from PART B***

**Limit answers to the required points.**

**Max. Marks: 60** **Duration: 2.5 hours**

**PART A**

| | | | |
|---|---|---|---|
| 1. | | Specific mechanical energy of a satellite placed in an orbit with eccentricity e= 0.2 is E=$-18.58\ km^2/s^2$. Determine its specific angular momentum, semi latus rectum, semimajor axis, perigee and apogee altitudes. | (5) |
| 2. | a. | Write a short note on GTO | (2) |
| | b. | A space probe is in a circular parking orbit of altitude of 200 km above the earth. What is the orbiting velocity and time period of the probe? As a mission requirement, the probe is to be launched on an escape trajectory. Calculate the minimum escape speed required to escape from the parking orbit altitude. | (3) |
| **3.** | | Explain in detail about Q guidance and Delta Guidance | (5) |
| **4** | | What do you mean by re-entry corridor? Discuss its importance in re-entry missions of space vehicles. | (5) |
| **5** | | Why is attitude control important for an operational satellite? Briefly explain any two attitude control mechanisms. | (5) |

**PART B**

| | | | |
|---|---|---|---|
| **6** | **a.** | Explain two body problems with the help of Newton's laws and formulate a trajectory equation for an orbiting body in space. | (5) |
| | **b.** | Describe the importance of orbital parameters in defining an orbit | (2) |
| **7** | **a.** | The expected disturbance acting on a satellite located in a circular orbit of altitude 450 km is  N. If the specific impulse is 250 seconds, how much fuel mass will be expended in one year? | (3) |
| | **b.** | Write a short note on<br>i.Patched Conics<br>ii. Sphere of Influence | (4) |
| **8** | | A 2000 kg spacecraft is in a 480 km by 800 km earth orbit. Find<br>1. The impulsive velocity required at perigee to place the spacecraft in a 480 km by 16,000 km transfer ellipse.<br>2. The impulsive velocity (apogee kick) required at the transfer orbit to establish a circular orbit of 16,000 km altitude. | (7) |
| **9** | | Explain in detail about the closed loop guidance schemes for launch vehicles during the exo-atmospheric phase. | (7) |
| **10** | **a.** | List and explain the basic design inputs for a launch vehicle guidance scheme. | (3) |
| | **b.** | Describe the rendezvous guidance scheme in view of docking a human space flight module with the international space station. | (4) |
| **11** | | Explain in detail about different methods of re-entry for a space vehicle | (7) |
| **12** | | Briefly explain different satellite stabilization methods. | (7) |

## Syllabus

### Module I

Fundamentals of Orbital Mechanics- Review of basic laws, N-body Problem, Two-body Problem, Constants of the motion. The trajectory equations - Circular, Elliptical, Parabolic, Hyperbolic orbit., Orbital Elements, Orbital perturbations and application, Types of orbits (SSPO, GTO, GSO, Molniya orbits). Orbital Transfers- Coplanar Transfer Manoeuvres, Non-Coplanar Transfer Manoeuvres, Injection into Interplanetary Orbit. Patched Conics, Spheres of Influence.

### Module II

Launch phase guidance: The Guidance and Navigation System, Launch Vehicle Guidance- Booster phase guidance objectives and constraints, requirement of multi-staging, rocket equation, Implicit and Explicit Guidance-Open loop and Closed loop Guidance optimal control based guidance, linear tangent steering law and applications, (Flat earth, Iterative Guidance Mode (IGM), Powered Explicit Guidance (PEG)), polynomial guidance, velocity based guidance based on cross product steering law, Delta guidance, Q guidance

### Module III

Orbit transfer guidance: Midcourse Manoeuvres- Fixed Time Guidance, Variable Time Guidance, Velocity based guidance for circularization manuevers, guidance for de-orbit maneuvers, Rendezvous Guidance, Guidance on Low Thrust Trajectories

### Module IV

Entry and landing: Re-Entry of Space Vehicle, Re-Entry Dynamics, Ballistic Re-Entry, Skip Re-Entry, Double-Dip Re-Entry, Aerobraking, Lifting Body Re-Entry, Entry Corridor, Equilibrium Glide, Thermal and Structural Constraints. Atmospheric Entry- Flight Equations, Entry Corridors, Ballistic Entry with No Lift, Guided Entry using Lift- modulation Guidance in the Upper and Lower Atmosphere (shuttle guidance), guidance for TAEM, approach and landing phases of horizontal landing missions, vertical landing guidance in lunar surface and earth. The Nominal Trajectory, Feedback Guidance in the Upper and Lower Atmosphere

### Module V

Spacecraft Control: Translational vs rotational control, Attitude representation –Direction of Cosines, Euler angles, quaternions, Dual quaternions, Attitude Control and Stabilization of Satellites: Reaction Wheel, Momentum Wheel, Thrusters, Spin Stabilization, Gravity Gradient Stabilisation, Yo-Yo Mechanism, Control Moment Gyros.

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | Fundamentals of Orbital Mechanics | |
| 1.1 | Review of basic laws, N-body Problem | 1 |
| 1.2 | Two-body Problem, Constants of the motion | 1 |
| 1.3 | The trajectory equations - Circular, Elliptical, Parabolic, Hyperbolic orbit, Orbital Parameters, LEO, MEO, GTO, GSO, SSPO orbits | 2 |
| 1.4 | Orbital Transfers: Coplanar Transfer Manoeuvres, Non-Coplanar Transfer Manoeuvres, | 5 |
| 1.5 | Injection into Interplanetary Orbit, Patched Conics, Spheres of Influence | 2 |
| 2 | | |
| 2.1 | Launch Vehicle Guidance- Booster phase guidance objectives and constraints, requirement of multi-staging, rocket equation | 4 |
| 2.2 | Implicit and Explicit Guidance- Open loop and Closed loop Guidance - optimal control based guidance linear tangent steering law and applications, (Flat earth, Iterative | 4 |

| | | |
|---|---|---|
| | Guidance Mode (IGM), Powered Explicit Guidance (PEG)) | |
| 2.3 | polynomial guidance, velocity based guidance based on cross product steering law, Delta guidance, Q guidance | 2 |
| 3 | Orbit transfer guidance | |
| 3.1 | Midcourse Manoeuvres- Fixed Time Guidance, Variable Time Guidance, Velocity based guidance for circularization manuevers | 2 |
| 3.2 | Guidance for de-orbit maneuvers, Rendezvous Guidance, Guidance on Low Thrust Trajectories | 2 |
| 4 | Entry and landing: | |
| 4.1 | Re-Entry of Space Vehicle, Re-Entry Dynamics, Ballistic Re-Entry, Skip Re-Entry, Double-Dip Re-Entry, Aerobraking, Lifting Body Re-Entry, Entry Corridor, Equilibrium Glide, Thermal and Structural Constraints. | 4 |
| 4.2 | Atmospheric Entry- Flight Equations, Entry Corridors, Ballistic Entry with No Lift, Guided Entry using Lift-modulation | 3 |
| 4.3 | Guidance in the Upper and Lower Atmosphere (shuttle guidance), guidance for TAEM, approach and landing phases of horizontal landing missions, vertical landing guidance in lunar surface and earth. The Nominal Trajectory, Feedback Guidance in the Upper and Lower Atmosphere | 3 |
| 5 | Attitude Control and Stabilization of Satellites | |
| 5.1 | Translational vs rotational control, Attitude representation –Direction of Cosines, Euler angles, quaternions - overview, Dual quaternions | 1 |
| 5.2 | Attitude Control and Stabilization of Satellites: Reaction Wheel, Momentum Wheel, Thrusters | 2 |
| 5.3 | Spin Stabilization, Gravity Gradient Stabilisation, Yo-Yo Mechanism, Control Moment Gyros | 2 |

**Reference Books**


1. Roger R. Bate, Donald D. Mueller, Jerry E. White, “Fundamentals of astrodynamics”, Dover Publications, 1971.
2. Dr. Maxwell Noton, “Spacecraft Navigation and Guidance”, Springer, Advances in Industrial Control, Verlag London, 1998.
3. Weiduo Hu, “Fundamental Spacecraft Dynamics and Control”, Wiley, 2015.
4. Wie, Bong, “Space Vehicle Dynamics and Control”, American Institute of Aeronautics and Astronautics, 2008.
5. Curtis, Howard D, “Orbital mechanics for engineering students”, Elsevier Aerospace Engineering Series, Butterworth-Heinemann, 2020.
6. Yongchun Xie · Yongjun Lei, Jianxin Guo, Bin Meng, “Spacecraft Dynamics and Control”, Springer Space Science and Technologies series, Beijing Institute of technology Press, 2022.
7. Hughes, P.C., Spacecraft Attitude Dynamics, John Wiley, 1986.
8. Sidi, M.J., Spacecraft Dynamics and Control, Cambridge University Press, 1997
9. Bryson, A.E., Control of Spacecraft and Aircraft, Princeton University Press, 1994
10. Kaplan, M.H., Modern Spacecraft Dynamics and Control, John Wiley, 1976
11. Damaren, Christopher, De Ruiter, Anton H. J. Forbes, James R, “Spacecraft dynamics and control- an introduction”, Wiley, 2013.

| CODE | COURSE NAME | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| 221EIA002 | EMBEDDED SYSTEMS AND APPLICATIONS | PROGRAM ELECTIVE 1 | 3 | 0 | 0 | 3 |

**Preamble:** Nil

**Prerequisites:** Nil

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

| | |
|---|---|
| **CO 1** | Design real time embedded systems by analysing the characteristics of different computing elements in embedded system. (LEVEL 3) |
| **CO 2** | Identify the unique characteristics of real time operating systems and evaluate the need for real time operating system (LEVEL 3) |
| **CO 3** | Identify and characterize architecture of ARM MCU (LEVEL 3) |
| **CO 4** | Apply the knowledge gained for Programming ARM Processor for different applications. (LEVEL 3) |
| **CO 5** | Analyse various examples of embedded systems based on ARM processor. (LEVEL 4) |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | 3 | | 3 | 3 | 2 | | |
| **CO 2** | 3 | | 3 | 3 | 2 | | |
| **CO 3** | 3 | | 3 | 3 | 2 | | |
| **CO 4** | 3 | | 3 | 3 | 2 | | |
| **CO 5** | 3 | | 3 | 3 | 2 | | |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | |
| Analyse | |
| Evaluate | |
| Create | |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern:**

Preparing a review article based on peer reviewed Original publications (minimum 10 publications shall be referred) : 15 marks
Course based task/Seminar/Data collection and interpretation: 15 marks
Test paper, 1 no. : 10 marks
Test paper shall include minimum 80% of the syllabus.

**End Semester Examination Pattern:**

The end semester examination will be conducted by the respective College.
There will be two parts; Part A and Part B.
Part A will contain 5 numerical/short answer questions with 1 question from each module, having 5 marks for each question (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students). Students should answer all questions.
Part B will contain 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating

to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student should answer any five. Each question can carry 7 marks.

Note: The marks obtained for the ESE for an elective course shall not exceed 20% over the average ESE mark % for the core courses. ESE marks awarded to a student for each elective course shall be normalized accordingly. For example, if the average end semester mark % for a core course is 40, then the maximum eligible mark % for an elective course is 40+20 = 60 %.

**Model Question Paper**

**Pages** **SLOT**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

**FIRST SEMESTER B.TECH DEGREE EXAMINATION, MONTH & YEAR**

**221EIA002- EMBEDDED SYSTEMS AND APPLICATIONS**

**Max. Marks: 60** **Time: 2.5 hrs**

| | **Part A (Answer all questions)** | **Marks** |
|---|---|---|
| 1 | Differentiate between independent design and codesign concepts | (5) |
| 2 | Illustrate with examples the advantages of writing embedded firmware in C. | (5) |
| 3 | Compare features of various ARM architectures | (5) |
| 4 | Generate an asymmetric square wave at four pins of PORT P0 using software delay | (5) |
| 5 | Develop a block schematic diagram for implementing vison-controlled ROBOT application and explain each block | (5) |
| | **Part B (Answer any five questions)** | |
| 6 | Choose appropriate hardware units needed for the following embedded applications a) Robot b) Motor Control and c) Digital camera. Justify your answer, | (7) |
| 7 | With a flow chart model illustrate the embedded program development process from high level language to machine level language | (7) |
| 8 | Analyse the distinct features of real time operating system that makes it suitable for embedded applications | (7) |
| 9 | With the help of a neat diagram explain the architecture ARM processor | (7) |
| 10 | Generate PWMs at the six output pins of PWM unit with duty cycles of 40 and 50% | (7) |
| 11 | Design an embedded system for Adaptive cruise control and explain the details | (7) |

| | | |
|---|---|---|
| 12 | Write an embedded C program to interface a single switch and display its status through a relay, Buzzer and LED | (7) |

**Syllabus**

**Module 1**

**Embedded System Organization**

Embedded computing – characteristics of embedded computing applications – Introduction to embedded system design- architecture embedded system - Overview of Processors and hardware units in an embedded system – Selection of processor, Memory- I/O devices, Communication protocols SPI, I2C, CAN etc.

Embedded system design and development process- Embedded System On Chip(SOC)- Build process- Challenges in embedded system design, optimizing design metrices- Hardware software co-design- Design technologies, Design examples

Software Tools, IDE, Linking and Locating software, Choosing the right platform-Testing, Simulation Debugging Techniques and Tools, Laboratory Tools and target hardware debugging, Emulators

**Module 2**

**Embedded Programming Concepts and RTOS**

Programming Concepts -Assembly language, C program elements, Macros and functions, data types data structures Loops and Pointers Object oriented Programming, Embedded programming in C++

Operating System Basics, Types of Operating Systems, Real Time Operating System, Tasks, Process and Threads, Multi processing and Multi-tasking

RTOS Task scheduling models, Handling of task scheduling and latency and deadlines as performance metrics, Co-operative Round Robin Scheduling, Case Studies of Programming with RTOS

**Module 3**

**Architecture and Programming of ARM**

Introduction to ARM core architectures, ARM extension, family, Pipeline, memory management, Bus architecture, Programming model, Registers, Operating modes, instruction set, Addressing modes, memory interface.

Programming of ARM, Read Write Memory Access, Basic programming using Online/Offline platforms

**Module 4**

**On Chip Peripherals and Interfacing Lpc2148**

Internal Architecture of ARM LPC 2148, Study of on-chip peripherals – Input/ output ports, Timers, Interrupts, on-chip ADC, DAC, RTC modules, WDT,PLL, PWM,USB, I2C, SPI, CAN etc
Programming GPPIO, Timer programming, PWM Unit programming
ARM 9, ARM Cortex -M3

**Module 5**

**Embedded Control Applications -Case Studies**

Embedded Controller Programmable interface with A/D & D/A interface; Digital voltmeter, -PWM motor speed controller, serial communication interface Feedback control system, relay control unit, driving electrical appliances like motors, bulb, pump, etc.

Case Studies- Embedded system in automobile, Adaptive cruise control, Vison controlled Robot, Ball following Robot

Course Project: Develop an embedded control application using ARM Platform

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | **Embedded System Organization (8 hours)** | |
| 1.1 | Embedded computing – characteristics of embedded computing applications – Introduction to embedded system design- architecture embedded system - Overview of Processors and hardware units in an embedded system – Selection of processor, Memory- I/O devices | 2 |
| 1.2 | Communication protocols SPI, I2C, CAN etc. | 1 |
| 1.3 | Embedded system design and development process - Embedded System On Chip(SOC),Build process, Challenges in embedded system design, optimising design metrices, Hardware software co-design, Design technologies, design examples | 2 |
| 1.4 | Software Tools, IDE, Linking and Locating software, Choosing the right platform | 1 |
| 1.5 | Testing, Simulation Debugging Techniques and Tools, Laboratory Tools and target hardware debugging, Emulators | 2 |
| 2 | **Programming Concepts and RTOS(10 hours)** | |
| 2.1 | Programming Concepts -Assembly language, C program elements, Macros and functions, data types data structures Loops and Pointers. | 2 |
| 2.2 | Object oriented Programming, Embedded programming in C++ and JAVA | 2 |
| 2.3 | Operating System Basics, Types of Operating Systems, Real Time Operating System (RTOS), Tasks, Process and Threads, Multi processing and Multi-tasking | 2 |
| 2.4 | RTOS Task scheduling models, Handling of task scheduling and latency and deadlines as performance metrics | 2 |
| 2.5 | Co-operative Round Robin Scheduling, Case Studies of Programming with RTOS | 2 |
| 3 | **Architecture and Programming of ARM (8 hours)** | |
| 3.1 | Features and Architecture of ARM, RISC vs CISC, Modes of operation | 2 |
| 3.2 | ARM assembly language, Addressing Modes, Instruction set | 2 |
| 3,3 | Programming of ARM, ALP, C, Basic programming using Online/Offline platforms | 2 |
| 3.4 | Read Write Memory Access, Multiple register load and store | 2 |
| 4 | **Peripheral programming of ARM((8 hours)** | |
| 4.1 | Internal Architecture and features of ARM LPC 214X family | 2 |
| 4.2 | Peripherals inside the chip, GPIO, Timer, Interrupt, UART, PWM | 2 |
| 4.3 | Programming GPPIO, Timer programming | 2 |
| 4.4 | PWM Unit programming, ARM 9, ARM Cortex -M3 | 2 |
| 5 | **Embedded Control Applications -Case Studies (8 hours)** | |
| 5.1 | Embedded Controller Programmable interface with A/D & D/A interface, Digital voltmeter, -PWM motor speed controller, serial communication interface | 2 |
| 5.2 | Feedback control system, relay control unit, driving electrical appliances like motors, bulb, pump, etc. | 2 |
| 5.3 | Case study -Embedded system in automobile, Adaptive cruise control | 2 |
| 5.4 | Case study -Vison controlled Robot, Ball following Robot | 2 |

**Reference Books**


1. Jonathan Valvano, Embedded Microcomputer Systems Real Time Interfacing, Third Edition Cengage Learning, 2012

2. Raj Kamal, Embedded Systems-Architecture, programming and design, 3rd edition, TMH.2017

3. Lyla B Das, Embedded Systems an Integrated Approach, Pearson, 2013

4. David E. Simon, An Embedded Software Primer‖, Pearson Education,2000.

5. Steve Heath, Butterworth Heinenann, Embedded systems design: Real world design Newton mass USA 2002

| 221EEE052 | MOTION PLANNING AND COORDINATION OF AUTONOMOUS SYSTEMS | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | Program Elective 1 | 3 | 0 | 0 | 3 |

**Preamble:** To familiarize with motion planning strategies and coordination of multiple mobile systems to achieve a specific task.

**Prerequisites**: Nil

**Course Outcomes:**

After the completion of the course the student will be able to

| | |
|---|---|
| **CO 1** | Analyse the geometric representation of rigid bodies with its transformation in configuration space |
| **CO 2** | Familiarize with robot control architecture and dynamics |
| **CO 3** | Familiarize with the multi agent system and coordination strategies |
| **CO 4** | Evaluate coordination algorithms and coordination strategies |
| **CO 5** | Analyse cooperative control problems and familiarize robotic sensors |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | 2 | - | 1 | - | - | - | - |
| **CO 2** | 2 | - | 2 | 2 | - | - | - |
| **CO 3** | 3 | - | 2 | 1 | 2 | - | - |
| **CO 4** | 3 | - | 1 | 2 | 2 | - | - |
| **CO 5** | 2 | - | 1 | 1 | - | - | - |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 10 |
| Create | 10 |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern:**

Preparing a review article based on peer reviewed original publications (minimum 10 publications shall be referred) : 15 marks

Course based task/Seminar/Data collection and interpretation: 15 marks

Test paper, 1 no.: 10 marks

**End Semester Examination Pattern:**

The end semester examination will be conducted by the respective College. There will be two parts; Part A and Part B. Part A will contain 5 numerical/short answer questions with 1 question from each module, having 5 marks for each question (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students). Students should answer all questions. Part B will contain 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student should answer any five. Each question can carry 7 marks.

**Model Question paper**

**No. of Pages:** **D**

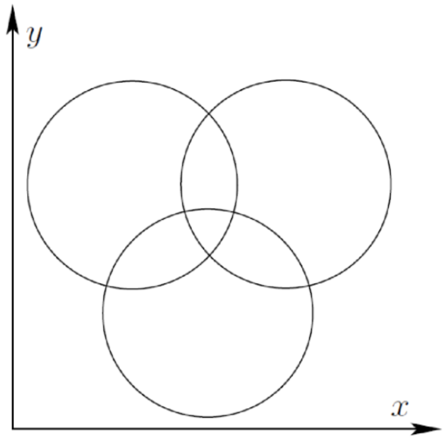
**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

FIRST SEMESTER M. TECH DEGREE EXAMINATION

MONTH & YEAR

*Branch:* **Electrical & Electronics Engineering**

| | | | |
|---|---|---|---|
| *Course Code & Name:* ***221EEE052*** | | | |
| **MOTION PLANNING AND COORDINATION OF AUTONOMOUS SYSTEMS** | | | |
| Answer all full questions from PART A and any 5 full questions from PART B<br>Limit answers to the required points. | | | |
| Max. Marks: 60 | | | Duration: 2.5 hours |
| **PART A** | | | |
| 1 | | For distinct values of yaw, pitch, and roll, it is possible to generate the same rotation. In other words, $R(\alpha,\beta,\gamma)R(\alpha,\beta,\gamma)$= $R(\alpha',\beta',\gamma')$ $R(\alpha',\beta',\gamma')$ for some cases in which at least $\alpha \neq \alpha'\alpha \neq \alpha'$, $\beta \neq \beta'\beta \neq \beta'$, $\gamma \neq \gamma'\gamma \neq \gamma'$. Characterize the sets of angles for which this occurs. | (5) |
| 2 | | Briefly explain about the complexity of motion planning problems. | (5) |
| 3 | | Classify and give a short note on Multi Agent Systems in detail. | (5) |
| 4 | | Describe the elementary concepts and notations of distributed algorithms. | (5) |
| 5 | | Write a short note on cooperative control problems by the level and type of coupling involved. | (5) |
| **PART B** | | | |
| 6 | | Let A be a unit disc, centred at the origin, and $W = \mathbb{R}^2 W = \mathbb{R}^2$. Assume that A is represented by a single, algebraic primitive, $H = \{(x,y) \| x^2 + y^2 \leq 1\} H = \{(x,y) \| x^2 + y^2 \leq 1\}$. Show that the transformed primitive is unchanged after any rotation is applied. | (7) |
| 7 | | Suppose five polyhedral bodies float freely in a 3D world. They are each capable of rotating and translating. If these are treated as “one” composite robot, what is the topology of the resulting C-space (assume that the bodies are not attached to each other)? What is its dimension? | (7) |

| | | | |
|---|---|---|---|
| 8 | | Determine the cylindrical algebraic decomposition for the three intersecting circles shown in Figure. How many cells are obtained?   | (7) |
| 9 | | Explain in detail about different multi agent coordination strategies. | (7) |
| 10 | | Given a weighted digraph G of order n, choose an arbitrary ordering of its edges. Define the incidence matrix $H(G) \in R^{\|E\| \times n}$ $H(G) \in R^{\|E\| \times n}$ of G by specifying that the row of H(G) corresponding to edge (i, j) has an entry 1 in column i, an entry −1 in column j, and all other entries equal to zero. Show that $H(G)^T W H(G) = L(G) + L(rev(G))$ $H(G)^T W H(G) = L(G) + L(rev(G))$, where $W \in \mathbb{R}^{\|E\| \times \|E\|}$ $W \in \mathbb{R}^{\|E\| \times \|E\|}$ is the diagonal matrix with $a_{ij}$ $a_{ij}$ in the entry corresponding to edge (i, j). | (7) |
| 11 | | Explain in detail about graph connectivity and stability of vehicle formations. | (7) |
| 12 | a | With the help of a neat diagram, explain the structure of an electronic sensor. | (4) |
| | b | Write a short note on obstacle sensors used in mobile robots. | (3) |

**Syllabus**

**Module I**

Geometric Representations and Transformations: Geometric Modelling, Rigid-Body Transformations - Kinematic Chains of Bodies and Kinematic Trees - Configuration space of a robot - Basic Topological Concepts-Obstacles - Transforming Configuration and Velocity Representations

**Module II**

Review of motion planning methods: Potential Functions, Roadmaps - Cell Decomposition, Sampling Technique-Discrete planning algorithm, Bug Algorithms - Incremental Voronoi Graph

**Module III**

Introduction to multi-agent systems: Planning and Coordination- Terminologies, Classification - multi-agent coordination strategies: leader follower, Potential field Theory - Algebraic Graph Theory

**Module IV**

Introduction to distributed algorithms: Basics of Matrix theory and Graph Theory - Overview of Consensus Algorithms - Overview of Consensus Algorithms - Design of Coordination

Strategies - Algorithm for Dynamic systems

**Module V**

Cooperative control: Dimensions of cooperative control, Coupling in Cooperative Control Problems - Formation Control - Basic Scheme of Sensors, Obstacle Sensor, Odometry Sensor, Distance Sensors

## Course Plan

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | Geometric Representations and Transformations | |
| 1.1 | Geometric Modelling, Rigid-Body Transformations | 2 |
| 1.2 | Kinematic Chains of Bodies and Kinematic Trees | 2 |
| 1.3 | Configuration space of a robot - Basic Topological Concepts-Obstacles | 2 |
| 1.4 | Transforming Configuration and Velocity Representations | 2 |
| 2 | Review of motion planning methods | |
| 2.1 | Potential Functions, Roadmaps | 2 |
| 2.2 | Cell Decomposition, Sampling Technique | 3 |
| 2.3 | Discrete planning algorithm, Bug Algorithms | 3 |
| 2.4 | Incremental Voronoi Graph | 1 |
| 3 | Introduction to multi-agent systems | |
| 3.1 | Planning and Coordination- Terminologies, Classification | 2 |
| 3.2 | multi-agent coordination strategies: leader follower, Potential field Theory | 4 |
| 3.3 | Algebraic Graph Theory | 2 |
| 4 | Introduction to distributed algorithms | |
| 4.1 | Basics of Matrix theory and Graph Theory | 2 |
| 4.2 | Overview of Consensus Algorithms | 2 |
| 4.3 | Design of Coordination Strategies | 2 |
| 4.4 | Algorithm for Dynamic systems | 2 |
| 5 | Cooperative control | |
| 5.1 | Dimensions of cooperative control, Coupling in Cooperative Control Problems | 3 |
| 5.2 | Formation Control | 3 |
| 5.3 | Basic Scheme of Sensors, Obstacle Sensor, Odometry Sensor, Distance Sensors | 2 |

## Reference Books


1. Principles of Robot Motion: Theory, Algorithms and Implementation, Howie Choset and Others MIT Press, 2005

2. Planning Algorithms, Cambridge University Press, Steven M. LaValle, Cambridge University Press

3. Francesco Bullo, Jorge Cortes, Sonia Martinez - Distributed control of robotic networks_ a mathematical approach to motion coordination algorithms-Princeton University press, 2009.

4. Wei Ren, Randal W. Beard- Distributed Consensus in Multi-vehicle Cooperative Control_ Theory and Applications-Springer-Verlag London (2008)

5. Kagan, Eugene - Autonomous mobile robots and multi-robot systems motion-

planning, communication, and swarming-Wiley (2020)

6. Arup Kumar Sadhu, Amit Konar - Multi-Agent Coordination_ A Reinforcement Learning Approach-Wiley (2020)

7. Jeff Shamma - Cooperative Control of Distributed Multi-Agent Systems-Wiley-Interscience (2008)

| 221EEE053 | DISCRETE TIME CONTROL SYSTEMS | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | Program Elective 2 | 3 | 0 | 0 | 3 |

**Preamble:** To design a suitable digital controller and observer for the system to meet the performance specifications and to evaluate its performance

**Prerequisites**: Nil

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

| | |
|---|---|
| **CO 1** | Analyse a discrete-time system and evaluate its performance |
| **CO 2** | Design suitable digital controller for the system to meet the performance specifications |
| **CO 3** | Design a digital controller and observer for the system and evaluate its performance |
| **CO 4** | Analyse a MIMO discrete-time system and evaluate its performance |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | | | 3 | 3 | 2 | | |
| **CO 2** | | | 3 | 3 | 3 | | |
| **CO 3** | | | 3 | 3 | 3 | | |
| **CO 4** | | | 3 | 3 | 2 | | |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 20 |
| Create | |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

## Continuous Internal Evaluation: 40 marks

Preparing a review article based on peer reviewed original publications (minimum 10 publications shall be referred: 15 marks

Course based task/Seminar/Data collection and interpretation : 15 marks

Test paper, 1 no. : 10 marks

The project shall be done individually. Group projects not permitted. Test paper shall include a minimum 80% of the syllabus.

## End Semester Examination: 60 marks

There will be two parts; Part A and Part B. Part A contains 5 numerical questions (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students), with 1 question from each module, having 5 marks for each question. Students shall answer all questions. Part B contains 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving.

**Model Question paper**

**No. of Pages:3** **E**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

FIRST SEMESTER M.TECH DEGREE EXAMINATION

MONTH & YEAR

*Branch:* **Electrical &Electronics Engineering**

*Course Code & Name:* **221EEE053 DISCRETE TIME CONTROL SYSTEMS**

Answer *all* questions from part A and any five questions from part B.

Limit answers to the required points.

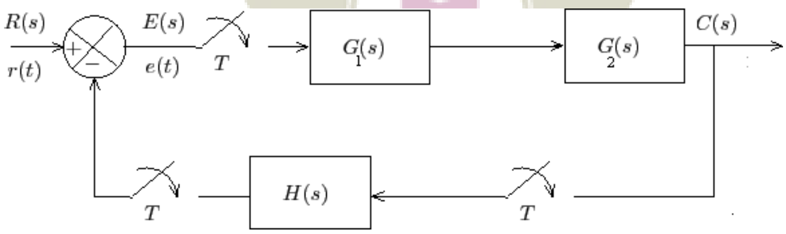
Max. Marks: 60 Duration: 2.5 hours

**PART A**

1. a Explain the sampling process and loss of information and noise due to sampling 2

 b Obtain the z-transform of the function $f(k) = k^2 u(k)$, *where*, $u(k) = 1,\ k \geq 0,\ k < 0$ 3

2. Obtain the pulse transfer function of the system shown below: 5




3. For a unity feedback system, with sampling time T=1sec, open loop pulse transfer 5

$$G(z) = \frac{K(0.3679z + 0.2542)}{(z - 0.3679)(z - 1)}.$$

function is Determine the value of K for stability by use of Jury'sstability test. Also determine the frequency of oscillations at the output

4. Explain controllability & observability of digital systems. 5

5. Consider a multi output linear system described by the state model 5

$x(k + 1) = Fx(k) + Gu(k)$

$y(k) = Cx(k) - Du(k)$

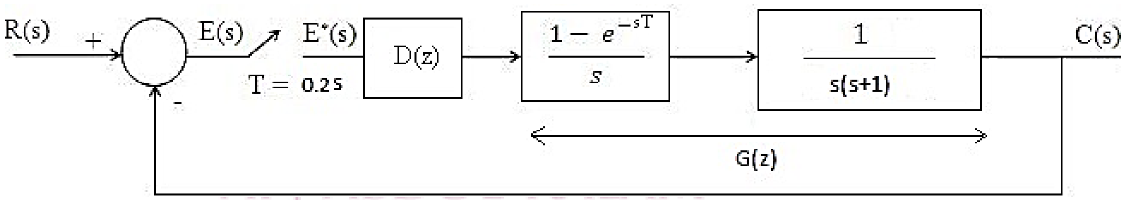
*where,*

$$F = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -2 & 1 & -1 \end{bmatrix}, G = \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 1 & 1 \end{bmatrix}, C = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}, D = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

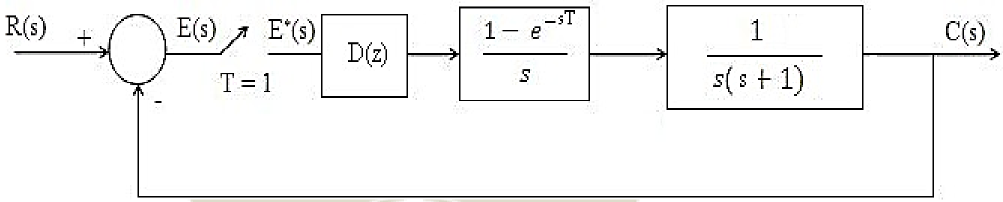
Check whether the system is observable

## PART B

6. Consider the digital control system shown in figure. Design a digital controller D(z) such that the closed loop system has a damping ratio 0.5 and the number of samples per cycle of damped sinusoidal oscillation to be 0.8 7




7. For the system shown, find 7
   a. Phase margin of the system when D(z) =1
   b. Design a unity dc gain phase lag compensator D (z) that yields a phase margin of approximately 45 degrees.




8. Explain the concept and procedure for designing a lag compensator using root locus method. 7

9. For the system G( s )=1/(s (s+1) ),design a lead compensator in z plane such that the compensated system will have a Phase margin of 45°.Assume the sampling period T to be 1 sec 7

10 Consider the discrete time system defined by the equations 7

$$x(k+1) = Gx(k) + Hu(k)$$
$$y(k) = Cx(k)$$

where

$$G = \begin{bmatrix} 0 & 0 & -0.25 \\ 1 & 0 & 0 \\ 0 & 1 & 0.5 \end{bmatrix}, H = \begin{bmatrix} 1 \\ 0 \\ 1 \end{bmatrix}, C = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}$$

. Assuming that the output y(k) is measurable,

design a minimum order observer, such that the error will exhibit deadbeat response

| | | |
|---|---|---|
| 11 | Prove that if a discrete system is completely state controllable and observable, then there is no pole zero cancellation in the pulse transfer function. | 7 |
| 12 | Explain the algorithm for placing poles in a multivariable system. | 7 |

## Syllabus

### Module I

z-Plane Analysis of Discrete-Time Systems - Review of Z Transforms - Sampling Theorem, Impulse Sampling and Data Hold, Sampling Rate Selection - Pulse Transfer Function - Mapping between the s-plane and the z-plane - Stability analysis of closed-loop system in the z-plane - Jury's test, Schur-Cohn test - Bilinear Transformation, Routh-Hurwitz method in w-plane.

### Module II

Digital Controller Design Based on Root locus Approach: Direct design based on root locus - Design of Lag Compensator - Design of Lead Compensator - Design of Lead-Lag Compensator

### Module III

Digital Controller Design in Frequency Domain - Direct design based on frequency response - Design of Lag Compensator - Design of Lead Compensator - Design of Lag-Lead Compensator

### Module IV

Design using State Space approach - Discretization of continuous time state-space equations - Controllability - Observability - Design via Pole Placement - State Observer Design - Full order observers - Reduced order observers

### Module V

Multivariable Digital Systems: Solution of Linear Digital State Equations - Controllability/ Observability Indices - State feedback for MIMO systems

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1.1 | z-Plane Analysis of Discrete-Time Systems | |
| 1.1.1 | Review of Z Transforms | 2 |
| 1.1.2 | Sampling Theorem, Impulse Sampling and Data Hold, Sampling Rate Selection | 1 |
| 1.1.3 | Pulse Transfer Function, | 2 |
| 1.1.4 | Mapping between the s-plane and the z-plane | 1 |
| 1.2 | Stability analysis of closed-loop system in the z-plane | |
| 1.2.1 | Jury's test, Schur-Cohn test, | 2 |
| 1.2.2 | Bilinear Transformation, Routh-Hurwitz method in w-plane | 1 |
| | | |
| | | |
| 2 | Digital Controller Design Based on Root locus Approach | |
| 2.1 | Direct design based on root locus | 2 |
| 2.2 | Design of Lag Compensator | 2 |

| | | |
|---|---|---|
| 2.3 | Design of Lead Compensator | 2 |
| 2.4 | Design of Lead-Lag Compensator | 2 |
| | | |
| | | |
| 3 | Digital Controller Design in Frequency Domain | |
| 3.1 | Direct design based on frequency response | 2 |
| 3.2 | Design of Lag Compensator | 2 |
| 3.3 | Design of Lead Compensator | 2 |
| 3.4 | Design of Lag-Lead Compensator | 2 |
| | | |
| 4 | Design using State Space approach | |
| 4.1 | Discretization of continuous time state-space equations | 1 |
| 4.2 | Controllability | 1 |
| 4.3 | Observability | 1 |
| 4.4 | Design via Pole Placement | 2 |
| 4.5 | State Observer Design, | |
| 4.5.1 | Full order observers | 2 |
| 4.5.2 | Reduced order observers | 2 |
| | | |
| 5 | Multivariable Digital Systems | |
| 5.1 | Solution of Linear Digital State Equations | 2 |
| 5.2 | Controllability/ Observability Indices | 1 |
| 5.3 | State feedback for MIMO systems | 3 |
| | | |
| | | |

**Reference Books**

1. C. L. Philips, H. T. Nagle, Digital Control Systems, Prentice-Hall, Englewood Cliffs, New Jersey, 1995.
2. M. Gopal, Digital Control and State Variable Methods, Tata McGraw-Hill, 1997.
3. K. Ogata, Discrete-Time Control Systems, Pearson Education, Asia.
4. R. G. Jacquot, Modern Digital Control Systems, Marcel Decker, New York, 1995.
5. Benjamin C. Kuo, Digital Control Systems, 2/e, Saunders College Publishing, Philadelphia, 1992.
6. Gene F. Franklin, J. David Powell, Michael Workman, Digital Control of Dynamic Systems, Pearson, Asia.
7. J. R. Liegh, Applied Digital Control, Rinchart& Winston Inc., New Delhi.
8. Frank L. Lewis, Applied Optimal Control& Estimation, Prentice-Hall, Englewood Cliffs NJ, 1992.

| CODE 221EEE054 | Modelling and Simulation of Aerospace Systems | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | Program elective 2 | 3 | 0 | 0 | 3 |

**Preamble:** To Apply the basic knowledge of flight controls in the development of aerospace vehicle simulation models and critically evaluate its performance by integrating guidance and sensor subsystems.

**Prerequisites**: Nil

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

| | |
|---|---|
| **CO 1** | Apply the basic knowledge of flight controls in the development of aerospace vehicle models |
| **CO 2** | Develop aircraft simulation models and evaluate its performance |
| **CO 3** | Conduct critical reviews of simulations by a comparison with real aircraft models |
| **CO 4** | Analyse performance of aerospace systems by integrating the guidance and sensor subsystems |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | 3 | | 3 | 3 | 3 | | 3 |
| **CO 2** | 2 | 2 | 3 | 3 | 3 | | 2 |
| **CO 3** | 3 | 2 | 3 | 3 | 3 | | 3 |
| **CO 4** | 3 | | 3 | 3 | 3 | | 2 |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 15 |
| Create | 5 |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern: 40**

**Elective Course**

Preparing a review article based on peer reviewed original publications (minimum 10 publications shall be referred: 15 Marks

Course based task/Seminar/Data collection and Interpretation: 15 Marks

Test paper 1 No.: 10 Marks

**End Semester Examination Pattern: 60**

There will be two parts; Part A and Part B. Part A contain 5 numerical questions (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students), with 1 question from each module, having 5 marks for each question. Students shall answer all questions. Part B contains 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student shall answer any five. Each question can carry 7 marks. Total duration of the examination will be 150 minutes.

**Model Question paper**

**No. of Pages:** **E**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

FIRST SEMESTER M. TECH DEGREE EXAMINATION

MONTH & YEAR

*Branch:* **Electrical & Electronics Engineering**

**221EEE054 MODELING AND SIMULATION OF AEROSPACE SYSTEMS**

Max. Marks: 60 Duration: 2.5 hours

**PART A**

*(Answer **All** Questions)* (5X5 = 25 Marks)

1. A T-37 aircraft is executing a loop at the following conditions:
Euler angles: ψ = 0 deg, θ = 30 deg, Φ = 0 deg
The pilot observes a pure pitch rate at a constant velocity in the body axis system:

$$\bar{\omega}_B = \begin{Bmatrix} 0 \\ 0.1 \\ 0 \end{Bmatrix}_B \text{rad/s} \qquad \bar{V}_B = \begin{Bmatrix} 200 \\ 0 \\ 0 \end{Bmatrix}_B \text{ft/s}$$

Find the acceleration in the Earth-Fixed reference frame.

2. Given the following vectors, find the Inertial acceleration in Body axis system:

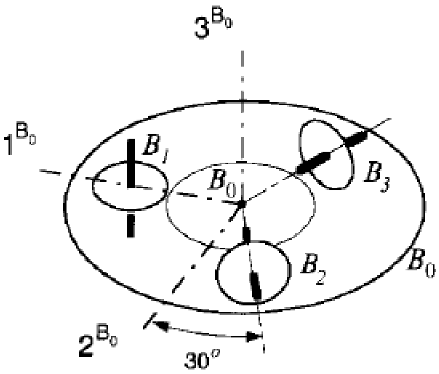
$$\bar{a}_I = \dot{\bar{V}}_B + \bar{\omega}\, x\, \bar{V}_B$$

$$\dot{\bar{V}}_B = \begin{Bmatrix} 10 \\ 0 \\ 0 \end{Bmatrix} \frac{\text{ft}}{\text{s}^2} \qquad \bar{\omega} = \begin{Bmatrix} 0 \\ 0 \\ 0.3 \end{Bmatrix} \frac{\text{rad}}{\text{s}} \qquad \bar{V}_B = \begin{Bmatrix} 300 \\ 0 \\ 0 \end{Bmatrix} \frac{\text{ft}}{\text{s}}$$

3. The Hubble Space Telescope, $B_0$, is stabilized by three control moment gyros(CMG) B1, B2 and B3. The CMG mass centres have the same distance x from The center B0 and are equally spaced, starting with gyro #1 aligned with the $1^{B0}$ axis of the telescope. The directions of the spin axes are shown in the Figure. The given quantities are: mass of telescope, $m_0$; mass of one CMG, m; Spin MOI of CMG, $I_s$; transverse MOI of CMG, I; angular rate of CMG with respect to B0, ω; distance of CMG from B0, x; Moment of inertia of telescope is given by

$$[I_{B_0}^{B_0}]^{B_0} = \begin{bmatrix} I_0 & 0 & 0 \\ 0 & I_0 & 0 \\ 0 & 0 & I_{03} \end{bmatrix}$$

Velocity of the telescope with respect to inertial frame, $[\overline{v_{B_0}^I}]^I = [0 \;\; v_0 \;\; 0]$; angular velocity of telescope wrt to inertial frame, $[\overline{\omega^{B_0 I}}]^I = [0 \;\; 0 \;\; \omega_0]$. For the cluster, k = 0,1,2,3, determine in tensor format, the linear momentum.




4. The attitude of a missile B0 is controlled by its swivelling rocket engine B1 with thrust $[\bar{t}]^{B_1} = [T \;\; 0 \;\; 0]$ and known swivel angle δ(t). Neglecting all other forces and moments, determine the differential eqaution that governs the pitch angular velocity $[\overline{\omega^{B_0 I}}]^{B_0} = [0 \;\; q \;\; 0]$ of the missile. The mass properties are given

$$m^{B_0}, [I_{B_0}^{B_0}]^{B_0} = \text{diag}(I_1, I_2, I_3)$$

$$m^{B_1}, [I_{B_1}^{B_1}]^{B_1} = \text{diag}(J_1, J_2, J_3)$$



5. Using the thrust and induced power computations, find an exact solution for thrust and power for the special case of hover over a fixed point with no wind.

*BI*, respectively.

**PART B**

*(Answer* ***Any Five*** *Questions)* (7X5 = 35 Marks)

6. Show that, for a quaternion product, the norm of the product is equal to the product of the individual norms.

7. An airfoil is tested in a subsonic wind tunnel. The lift is found to be zero at a geometrical angle of attack $\alpha = -1.5°$. At $\alpha = 5°$, the lift coefficient is measured as 0.52. Also, at $\alpha = 1°$ and 7.88°, the moment coefficients about the center of gravity are measured as −0.01 and 0.05, respectively. The center of gravity is located at 0.35*c*. Calculate the location of the aerodynamic center and the value of *Cmac*.



8. Using the first-order flapping dynamics for the stabilizer bar presented, derive a corresponding expression for the main rotor flapping angles using the approximation that the main rotor time constant is negligibly small. That is, we treat the main rotor flapping as responding instantly to input.

9. Derive the pitch attitude equations of the space shuttle $\boldsymbol{B_o}$ as it launches a satellite $\boldsymbol{B_I}$. Assume that the release is parallel and in the opposite direction of the space shuttle's 3rd axis. The satellite's displacement vector from the shuttle's centre of mass $\boldsymbol{B_O}$ is $[\overline{s_{B_1 B_0}}]^{B_0} = [-a \;\; 0 \;\; \eta]$, where $a$ is a positive constant and $\eta(t)$ a known function of $\boldsymbol{t}$ **.** Determine the differential equation of motion of the shuttle's pitch angular velocity.

10. Develop three dimensional equations of motion of space vehicles in Cartesian and polar coordinates.

11. List out necessary steps to model and simulate the subsystems of three stage rocket ascent to 300 km orbit. All the necessary assumptions can be made.

12. Develop Pseudo-five degrees of freedom model for a space vehicle system.

**Syllabus**

**Module I**

Kinematics and dynamics of aircraft motion: Rotational kinematics – translational kinematics – rigid body dynamics. Aircraft modelling: forces and moments – nonlinear aircraft model – linear models and stability derivatives. Modeling, Design and Simulation tools: State-space models - transfer function models – numerical solution – simulation of aircraft models – steady state flight – aircraft dynamic behaviour – feedback control. Aircraft rigid body modes – handling qualities – stability augmentation – control augmentation – autopilots – nonlinear simulation

**Module II**

Three-Degrees of freedom Simulation: Equations of Motion – Subsystem Models – Atmosphere and Gravity models, Hypersonic Vehicle Simulation, Three-stage Rocket Simulation.

**Module III**

Five–Degrees of Freedom Simulation: Pseudo–Five-Degrees of freedom – Coordinate transformation and angular rates – Kinematics – Equations of motion with rotating and flat Earth – Subsystem models. Trimmed aerodynamics for tetragonal missiles and planar aircrafts. Autopilots.

**Module IV**

Guidance – implementation of line guidance, Sensors – Kinematic and Dynamic seekers – Radar and electro optical sensors- Simulation of Air intercept missile – Short range air to air intercept missile – Cruise missiles.

**Module V**

Modeling and Simulation of Miniature Aerial Vehicles, Forces and Moments – modelling rotor flapping, Motor modelling – Small aerobatic airplane model – Simulations, Quadrotor model – Small helicopter model - Simulations

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | | |
| 1.1 | Kinematics and dynamics of aircraft motion: Rotational kinematics – translational kinematics – rigid body dynamics | 2 |
| 1.2 | Aircraft modelling: forces and moments – nonlinear aircraft model – linear models and stability derivatives | 2 |
| 1.3 | Modeling, Design and Simulation tools: State-space models - transfer function models – numerical solution – simulation of aircraft models – steady state flight – aircraft dynamic behaviour – feedback control | 3 |
| 1.4 | Aircraft rigid body modes – handling qualities – stability augmentation – control augmentation – autopilots – nonlinear simulation | 2 |
| 2 | Three-Degrees of freedom Simulation | |
| 2.1 | Equations of Motion – Subsystem Models – Atmosphere and Gravity models | 3 |
| 2.2 | Hypersonic Vehicle Simulation | 2 |
| 2.3 | Three-stage Rocket Simulation | 2 |
| 3 | Five–Degrees of Freedom Simulation | |
| 3.1 | Pseudo–Five-Degrees of freedom – Coordinate transformation and angular rates – Kinematics – Equations of motion with rotating and flat Earth – Subsystem models | 3 |
| 3.2 | Trimmed aerodynamics for tetragonal missiles and planar aircrafts | 2 |
| 3.3 | Autopilots | 3 |
| 4 | | |

| | | |
|---|---|---|
| 4.1 | Guidance – implementation of line guidance | 3 |
| 4.2 | Sensors – Kinematic and Dynamic seekers – Radar and electro optical sensors | 2 |
| 4.3 | Simulation of Air intercept missile – Short range air to air intercept missile – Cruise missiles | 3 |
| 5 | Modeling and Simulation of Miniature Aerial Vehicles | |
| 5.1 | Forces and Moments – modelling rotor flapping | 4 |
| 5.2 | Motor modelling – Small aerobatic airplane model - Simulations | 2 |
| 5.3 | Quadrotor model – Small helicopter model - Simulations | 2 |

**Reference Books**


1. B. L. Stevens, F. L. Lewis, and E. N. Johnson, “Aircraft Control and Simulation”, Wiley Publishers, Third Edition, 2015.
2. Peter H. Zipfel, “Modelling and Simulation of Aerospace Vehicle Dynamics”, AIAA Education Series, 3rd Edition, 2014
3. Blakelock, J. H, “Automatic Control of Aircraft and Missiles”, 2nd Edition, Wiley, 1991.
4. Thomas Yechout, “Introduction to Aircraft Flight Mechanics”, A1AA Education Series, 2003.
5. E. Bryson, “Control of Spacecraft and Aircraft”, Princeton University Press, 1994
6. B. Wie, “Space Vehicle Dynamics and Control”, AIAA Education Series, 2008

| CODE | COURSE NAME | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| 221EEE055 | ADVANCED CONTROL SYSTEM DESIGN | PROGRAM ELECTIVE 2 | 3 | 0 | 0 | 3 |

**Preamble:** To give a foundation to design robust controllers for multivariable feedback systems and to develop fractional order models and controllers for physical systems.
**Prerequisites:** Nil
**Course Outcomes:**
After the completion of the course the student will be able to

| | |
|---|---|
| **CO 1** | Design robust controller for feedback systems. |
| **CO 2** | Analyse multivariable feedback systems. |
| **CO 3** | Design state feedback controllers for multivariable systems. |
| **CO 4** | Develop fractional order models for physical systems. |
| **CO 5** | Design fractional order state feedback controllers. |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | | | 3 | 3 | 3 | 2 | |
| **CO 2** | | | 3 | 3 | 3 | 2 | |
| **CO 3** | | | 3 | 3 | 3 | 2 | |
| **CO 4** | | | 3 | 3 | 3 | 2 | |
| **CO 5** | | | 3 | 3 | 3 | 2 | |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 20 |
| Create | |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern:**
Preparing a review article based on peer reviewed Original publications (minimum 10 publications shall be referred) : 15 marks
Course based task/Seminar/Data collection and interpretation : 15 marks
Test paper, 1 no. : 10 marks
Test paper shall include minimum 80% of the syllabus.

**End Semester Examination Pattern:**
The end semester examination will be conducted by the respective College. There will be two parts; Part A and Part B. Part A will contain 5 numerical/short answer questions with 1 question from each module, having 5 marks for each question (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students). Students should answer all questions. Part B will contain 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student should answer any five. Each question can carry 7 marks.

**Model Question paper**

**Pages** **E**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**
**FIRST SEMESTER M.TECH DEGREE EXAMINATION, MONTH & YEAR**

**221EEE055: Advanced Control System Design**

**Max. Marks: 60** **Time: 2.5 hrs**

| | **Part A**<br>**(Answer all questions)** | **Marks** |
|---|---|---|
| 1 | Explain with examples the basic rules for evaluating transfer function matrices for MIMO systems. | (5) |
| 2 | Explain the different ways of representing uncertainties in a system. | (5) |
| 3 | List out the algebraic and control properties of RGA. | (5) |
| 4 | Explain the general control configuration for MIMO systems with uncertainty | (5) |
| 5 | Explain non- Gaussian probability density function and the development of corresponding FO model | (5) |
| | **Part B**<br>**(Answer any five questions)** | |
| 6 | Describe the loop shaping technique for a closed loop transfer function. | (7) |
| 7 | Explain the superiority of fractional order control over the conventional integer order control in terms of closed-loop performance with a suitable example. | (7) |
| 8 | Explain in detail the procedure for analyzing input-output controllability for MIMO systems. | (7) |
| 9 | Using singular value decomposition method, obtain the singular values of the system matrix A= $[3\ 1\ 1\ \ -1\ 3\ 1]$ | (7) |
| 10 | Given the system $x = A\dot{x} + Bu$ , where $A = [1\ 0\ 0\ 0\ 2\ 0\ 0\ 0\ 3\ ]$ and $B = [1\ 0\ 0\ 1\ 1\ 1\ ]$<br>Design a state feedback controller such that the closed loop poles are located at -1, -2 and -3. | (7) |
| 11 | Compute the condition number and RGA for a system with<br>$G = [87.8\ \ -86.4\ 108.2\ \ -109.6\ ]$ | (7) |
| 12 | Consider a system with three inputs m1=20, m2=40 and m3=70, with system constants T1=423, T2=293, T3=293, C1=10, C2=4, C3=0. The three outputs are given as<br>y1= m1+m2+m3<br>y2=(T1m1+T2m2+T3m3)/y1<br>y3=(C1m1+C2m2+C3m3)/y1<br>Calculate the RGA using steady state gain matrix method and use it to determine the best control scheme for the system. | (7) |

## Syllabus

### Module 1

**Feedback Control:**

One degree-of-freedom controller, Two degrees-of-freedom and feedforward controllers-Shaping of open loop and closed loop transfer functions, Loop shaping for disturbance rejection,Loop shaping design with examples

### Module 2

**Multivariable Feedback Control:**

Transfer functions for MIMO systems,Singular Value Decomposition - interpretation of singular values and associated input directions with physical applications ,Relative Gain Array – Physical interpretation with examples Control Properties of RGA

### Module 3

**Pole Placement for MIMO systems**-Controllability of MIMO systems-Robust Eigen structure Assignment – MIMO design case studies

### Module 4

**Fractional-order Modeling:**

Analysis of fractional-order modeling of: electrical circuit elements like inductor, capacitor, electrical machines like transformer, induction motor and transmission lines, FO modeling of viscoelastic materials, concept of fractional damping-Models of basic circuits and mechanical systems using FO elements, Concept of anomalous diffusion, non-Gaussian probability density function and the development of corresponding FO model-A brief overview of FO models of biological systems.

### Module 5

**Fractional-order Control**

Detailed discussion and analysis of superiority of FO control over the conventional IO control in terms of closed-loop performance, robustness and stability, FO PID control, Design of FO state-feedback controllers

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | Feedback Control | |
| 1.1 | One degree-of-freedom controller, **Two degrees-of-freedom and feedforward controllers** | 2 |
| 1.2 | Shaping of open loop and closed loop transfer functions, Loop shaping for disturbance rejection | 2 |
| 1.3 | Loop shaping design with examples | 3 |
| 1.4 | Inverse-based controller design with examples | 3 |
| 2 | Multivariable Feedback Control | |
| 2.1 | Transfer functions for MIMO systems | 2 |
| 2.2 | Singular Value Decomposition - interpretation of singular values and associated input directions with physical applications | 3 |
| 2.3 | Relative Gain Array – Physical interpretation with examples | 3 |
| 2.4 | Control Properties of RGA | 2 |
| 3 | Pole Placement for MIMO systems | |
| 3.1 | Controllability of MIMO systems | 2 |
| 3.2 | Robust Eigen structure Assignment – MIMO design case studies | 3 |
| 4 | Fractional-order Modeling | |
| 4.1 | Analysis of fractional-order modeling of: electrical circuit | 2 |

| | | |
|---|---|---|
| | elements like inductor, capacitor, electrical machines like transformer, induction motor and transmission lines, FO modeling of viscoelastic materials, concept of fractional damping | |
| 4.2 | Models of basic circuits and mechanical systems using FO elements, Concept of anomalous diffusion, non-Gaussian probability density function and the development of corresponding FO model | 3 |
| 4.3 | A brief overview of FO models of biological systems. | 2 |
| 5 | Fractional-order Control | |
| 5.1 | Detailed discussion and analysis of superiority of FO control over the conventional IO control in terms of closed-loop performance, robustness and stability | 2 |
| 5.2 | FO PID control | 3 |
| 5.3 | Design of FO state-feedback controllers | 3 |

**Reference Books**

1. S Skogestad and I. Postlethwaite, Multivariable Feedback Control, Analysis and design, second edition. New York: Wiley, 2005
2. U. Mackenroth, Robust Control Systems Theory and Case studies, Springer-Verlag, Berlin, Heidelberg, New York:, 2004
3. J. M. Maceijowski, Multi-Variable Feedback Design, Addision-Wesely Pub, 1989
4. R. Caponetto, G. Dongola, L. Fortuna, and I. Petras. Fractional Order Systems: Modeling and Control Applications. World Scientific, Singapore, 2010.
5. K. S. Miller and B. Ross. An Introduction to the Fractional Calculus and Fractional Differential Equations. John Wiley & Sons, USA, 1993.
6. C. A. Monje, Y. Q. Chen, B. M. Vinagre, D. Xue, and V. Feliu. Fractional-order Systems and Control: Fundamentals and Applications Springer-Verlag London Limited, UK, 2010

| 221EEE056 | GAME THEORY | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | PROGRAM ELECTIVE 2 | 3 | 0 | 0 | 3 |

**Preamble:** The course introduces the basic concepts of game theory, and its applications.

**Prerequisites:** Nil

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

| | |
|---|---|
| **CO 1** | Acquire fundamental knowledge of the game theory formulations like strategic form, extensive form, zero sum, non-zero sum games etc. |
| **CO 2** | Understand the type of game theoretic formulation to be utilized in solving various problems |
| **CO 3** | Compute pure strategy Nash equilibria. |
| **CO 4** | Compute mixed strategy Nash equilibria. |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | | | | 2 | | | |
| **CO 2** | | | | 2 | 3 | | |
| **CO 3** | 2 | | | 3 | 2 | | |
| **CO 4** | | | | 3 | 2 | | |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 20 |
| Create | |

**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern:**
Continuous Internal Evaluation: 40 marks
Preparing a review article based on peer reviewed
Original publications (minimum 10 publications shall be referred) : 15 marks
Course based task/Seminar/Data collection and interpretation : 15 marks
Test paper, 1 no. : 10 marks
Test paper shall include minimum 80% of the syllabus.

**End Semester Examination Pattern:**

There will be two parts; Part A and Part B.
Part A will contain 5 numerical/short answer questions with 1 question from each module, having 5 marks for each question. Students should answer all questions.
Part B will contain 7 questions with minimum one question from each module of which student should answer any five. Each question can carry 7 marks.

**Model Question paper**

**Reg. No:** **Slot : E**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

**FIRST SEMESTER M TECH DEGREE EXAMINATION**

**Month and Year**

Course Code: **221EEE056**

Course Name: **Game Theory**

**Part A**

**(Answer all questions, each carry 5 marks, 5 * 5 = 25 marks)**

1. What are the different classifications of games?
2. There are two players, Chooser (player I) and Hider (player II). Hider has two gold coins in his back pocket. At the beginning of a turn, he puts his hands behind his back and either takes out one coin and holds it in his left hand (strategy L1) or takes out both and holds them in his right hand (strategy R2). Chooser picks a hand and wins any coins the hider has hidden there. She may get nothing (if the hand is empty), or she might win one coin, or two. Model the game between chooser and hider.

3. Show the relation between reaction curves, best responses and pure strategy Nash equilibrium for an N-player non-zero sum game.
4. John has no job and might try to get one. Or he might prefer to take it easy. The government would like to aid John if he is looking for a job but not if he stays idle. The payoffs are

| government | jobless John: try | jobless John: not try |
|---|---|---|
| aid | (3,2) | $(-1, 3)$ |
| no aid | $(-1, 1)$ | (0,0) |

Find the Nash equilibria.
5. Explain any one algorithm to compute pure strategy Nash equilibrium for finite number of strategies.

**Part B**

**(Answer any 5 questions, each carry 7 Marks, 5 * 7 = 35 marks)**

6. Differentiate strategic form and extensive form games with an example each.
7. Find the pure strategy Nash equilibria for two player non-zero sum game with player 1 (P1) and player 2 (P2) payoffs are given as follows.
P1 = [1 0; 2 -1], P2 = [2 3; 1 0]
8. Find the value of the zero-sum game given by the following matrix, and determine all the optimal strategies of both players.

A= [3 0; 0 3; 2 2]

9. Find the saddle point in mixed strategy for the following zero sum game with the payoff matrix given below

Payoff matrix = [1 3 0; 6 2 7]

10. State and prove the existence theorem of mixed strategy Nash Equilibrium using fixed point theorem.
11. Illustrate with an example that every finite game of perfect information has Nash equilibrium
12. Discuss the complexity of computing pure strategy and mixed strategy Nash equilibrium.

**Syllabus**

**Module 1**

*Notions in Game Theory:* Definition of a Game - Strategic Interactions – Strategic Form Games – Preferences – Utilities – Rationality – Intelligence – Classification of Games. *Strategic Form and Extensive Form Games:* Strategic Form Games: Definition and Examples – Extensive Form Games: Definition and Examples.

**Module 2**

*Zero Sum Games and Non-zero-Sum Games:* Definition and Examples of Zero sum and Non-zero sum games in Strategic and Extensive Form. *Dominant Strategy Equilibria:* Strong Dominance and Weak Dominance Equilibria : Definition and Examples.

**Module 3**

*Pure Strategy Nash Equilibrium:* Definition and Illustrative Examples of Pure Strategy Nash Equilibria in Zero Sum and Non-zero Sum Games – Best Responses and Reaction Curves. Nash Equilibrium as a Fixed Point - Saddle Point and Pure Strategy Nash Equilibria - Existence of Pure Strategy Nash Equilibria – Interpretations of Nash Equilibria.

**Module 4**

*Mixed Strategy Nash Equilibrium:* Mixed Strategies – Mixed Strategy Nash Equilibrium in Zero sum and Non-zero sum games - Maxmin and Minmax Values in Mixed Strategies. Existence of Mixed Strategy Nash Equilibrium – Graphical Approach to compute Mixed Strategy Nash Equilibrium.

**Module 5**

Example for Computing Nash Equilibria: Pure and Mixed Strategy Nash Equilibria – General Algorithm For Finding Nash Equilibria of Finite Strategic Games. Complexity of Computing Nash Equilibria – Introduction of software tools for computing Nash Equilibria.

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| **1** | **Introduction to Game Theory** | |
| 1.1 | *Notions in Game Theory:* Definition of a Game - Strategic Interactions – Strategic Form Games – Preferences – Utilities – Rationality – Intelligence – Classification of Games | 4 |
| 1.2 | *Strategic Form and Extensive Form Games:* Strategic Form Games: Definition and Examples – Extensive Form Games: Definition and Examples. | 4 |
| **2** | **Zero Sum and Non-zero Sum Games** | |
| 2.1 | *Zero Sum Games and Non-zero Sum Games:* Definition and Examples of Zero sum and Non-zero sum games in Strategic and Extensive Form | 4 |
| 2.2 | *Dominant Strategy Equilibria:* Strong Dominance and Weak Dominance Equilibria : Definition and Examples. | 3 |
| **3** | **Pure Strategy Nash Equilibrium** | |
| 3.1 | *Pure Strategy Nash Equilibrium:* Definition and Illustrative Examples of Pure Strategy Nash Equilibria | 4 |

| | | |
|---|---|---|
| | in Zero Sum and Non-zero Sum Games – Best Responses and Reaction Curves | |
| 3.2 | Nash Equilibrium as a Fixed Point - Saddle Point and Pure Strategy Nash Equilibria - Existence of Pure Strategy Nash Equilibria – Interpretations of Nash Equilibria. | 4 |
| **4** | **Mixed Strategy Nash Equilibrium** | |
| 4.1 | *Mixed Strategy Nash Equilibrium:* Mixed Strategies – Mixed Strategy Nash Equilibrium in Zero sum and Non-zero sum games - Maxmin and Minmax Values in Mixed Strategies | 5 |
| 4.2 | Existence of Mixed Strategy Nash Equilibrium – Graphical Approach to compute Mixed Strategy Nash Equilibrium. | 4 |
| **5** | **Computation of Nash Equilibrium** | |
| 5.1 | Example for Computing Nash Equilibria: Pure and Mixed Strategy Nash Equilibria – General Algorithm For Finding Nash Equilibria of Finite Strategic Games | 5 |
| 5.2 | – Complexity of Computing Nash Equilibria – Introduction of software tools for computing Nash Equilibria. | 3 |

**Reference Books**


1. Y Narahari – Game Theory and Mechanism Design – IISc Press and World Scientific
2. Anna R. Karlin and Yuval Peres – Game Theory, Alive (Available Online https://homes.cs.washington.edu/~karlin/GameTheoryBook.pdf )
3. Osborne, M.J. An Introduction to Game Theory, Oxford University Press, 2004
4. Tamer Basar – Dynamic Non-cooperative Game Theory, SIAM Publishers
5. Gibbons, R. A Primer in Game Theory, Pearson Education, 1992
6. Drew Fudenberg and Jean Tirole – Game Theory

| CODE | Automatic Control of Aerospace Systems | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| 221EEE057 | | Program Elective 2 | 3 | 0 | 0 | 3 |

**Preamble:** To demonstrate the concepts of automatic control of flight control systems and different actuation systems for aerospace vehicles.

**Prerequisites**: Nil

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

| | |
|---|---|
| **CO 1** | Derive rigid body equations of motion and develop a linearized form of these equations |
| **CO 2** | Demonstrate the concepts of automatic control; find out the roles and objectives of flight control systems; and recognize the different actuation systems for aerospace vehicles |
| **CO 3** | Compute and analyze the aerospace system response to longitudinal and lateral-directional control inputs. |
| **CO 4** | Develop the aerospace vehicle equations of motion (nonlinear model, linear model in transfer function and state space forms), and derive the aircraft's response modes (short- and long period dynamics, roll dynamics, Dutch roll dynamics). |
| **CO 5** | Apply classical control techniques to design aerospace vehicle control systems, and apply the modern control techniques to design enhanced flight control systems |
| **CO 6** | Derive the equations of motion for a spacecraft and understand active and passive spacecraft control methods |

**Mapping of course outcomes with program outcomes**

| | **PO 1** | **PO 2** | **PO 3** | **PO 4** | **PO 5** | **PO 6** | **PO 7** |
|---|---|---|---|---|---|---|---|
| **CO 1** | 3 | 1 | 3 | 3 | 1 | | |
| **CO 2** | 2 | | 2 | 3 | 2 | | |
| **CO 3** | 3 | | 2 | 3 | 3 | | |
| **CO 4** | 2 | 1 | 3 | 3 | 3 | | |
| **CO 5** | 3 | 1 | 2 | 3 | 3 | | |
| **CO 6** | 2 | | 2 | 3 | 1 | | |

**Assessment Pattern**

| **Bloom's Category** | **End Semester Examination** |
|---|---|
| Apply | 20 |
| Analyse | 20 |
| Evaluate | 20 |
| Create | |

**Mark distribution**

| **Total Marks** | **CIE** | **ESE** | **ESE Duration** |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern: 40 Marks**

**Preparing a Review Article based on peer reviewed original publications (minimum 10 publications shall be referred): 15 Marks**

**Course based task/Seminar/Data collection and Interpretation: 15 Marks**

**Test paper 1 No.: 10 Marks**

**End Semester Examination Pattern: 60 Marks**

There will be two parts; Part A and Part B. Part A contain 5 numerical questions (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students), with 1 question from each module, having 5 marks for each question. Students shall answer all questions. Part B contains 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student shall answer any five. Each question can carry 7 marks. Total duration of the examination will be 150 minutes.

**Model Question paper**

**No. of Pages:** **E**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY**

FIRST SEMESTER M.TECH DEGREE EXAMINATION

MONTH & YEAR

*Branch:* **Electrical & Electronics Engineering**

**221EEE057 AUTOMATIC CONTROL OF AEROSPACE SYSTEMS**

Max. Marks: 60 Duration: 2.5 hours

**PART A**

*(Answer **All** Questions)* (5X5 = 25 Marks)

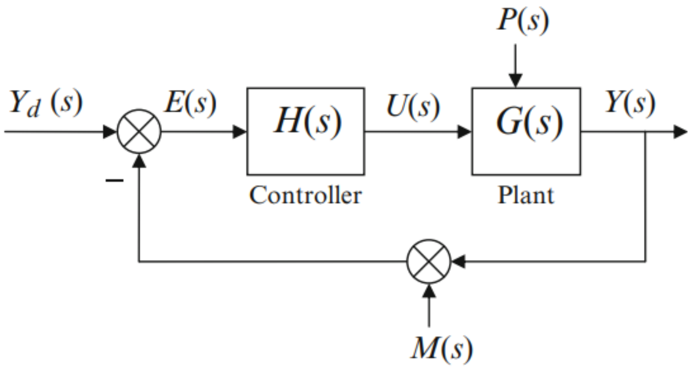
1. Derive the kinematic equations of motion for the 3-2-1 Euler angle sequence, $(\psi)_3$, $(\theta)_2$, $(\Phi)_1$, in terms of the body rates, (P, Q, R). Identify the singular points of this attitude representation.
2. Design a feedback compensator for the roll dynamics of a fighter aircraft described by the transfer function, G(s) = 1000/(s(s+5)), such that closed-loop step response settles down in 1 second with a zero steady-state error, and a damping ratio of 0.7.
3. An airplane of mass 10,000 kg, with a wing of planform area 50 $m^2$, wing's mean aerodynamic chord 3 m, and tail planform area 10 $m^2$ is flying straight having a standard sea level with a constant speed of 500 km/h. A wind-tunnel test carried out on a scaled model of the airplane reveals the lift-curve slopes of the wing–fuselage combination and the tail to be 0.1 per deg. and 0.08 per deg., respectively. The test also indicates that the tail efficiency factor is 0.96, the zerolift pitching moment coefficient of the wing–fuselage combination is 0:09, the airplane's center of mass is located 10% of the wing's mean aerodynamic chord aft of the wing–fuselage aerodynamic center, and the derivative of downwash angle with angle-of-attack is 0.4. The distance between the aerodynamic centers of the wing and the tail is 8.5 m. Calculate: (a) The equilibrium tail lift coefficient (b) The equilibrium lift coefficient of wing–fuselage combination (c) The controls fixed static margin (d) Static stability derivative, $C_{m\alpha}$.
4. Why do rockets need a guide-rail (or launcher) when being launched vertically, and not when launched at an angle? Try to answer this in the light of translational dynamics in a vertical plane.
5. Compare momentum wheel and reaction wheel for the automatic control of space crafts.

**PART B**

*(Answer **Any Five** Questions)* (7X5 = 35 Marks)

6. A spacecraft is in an elliptical orbit around the Earth ($\mu$ = 398600.4 $km^3/s^2$, mean radius, $R_0$ = 6378.14 km) with an eccentricity of 0.2 and a semi major axis of 15,000 km. Determine the radius, speed, and flight path angle when the true anomaly is $60^o$.
7. A closed-loop control system of Figure, without any process or measurement noise has the following plant's transfer function: G(s) = (2s – 1)/($s^2$ + 2s - 3)

(a) Can a compensator with transfer function, $H(s) = (s-1)/(s+1)$, stabilize this plant?
(b) If the compensator of Part (a) is used, what are the locations of the closed-loop poles?
(c) Can a proportional-integral-derivative (PID) compensator transfer function, $H(s)$, be selected such that the closed-loop step response settles down with a zero steady-state error? Why?




8. Consider an LTI system with the following state-space coefficient matrices:

$$A = \begin{pmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{pmatrix} ; \quad B = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 0 & -1 \end{pmatrix}$$

(a) Design a full-order observer for this plant using $C = (1; 0; -1)$ with poles at $s_1 = -2$, $s_{2,3} = -2 \pm 2i$.
(b) Based upon the direct measurement of any two state variables, design a reduced order observer for this plant with pole at $s = -2$.

9. Show that the longitudinal plant is controllable with the elevator input alone.

10. Consider a roll dynamics plant with $J_{xx} = 300$ kg m$^2$ and $L_p = -400$ N m s/rad. Design a suitable roll controller for achieving a desired step change of roll angle by $10^\circ$ in about 1 s, without exceeding the maximum control rolling moment, $|\tau_x| \leq 4$ Nm.

11. Using the polar coordinates, derive the planar equations of translational motion of a vectored thrust spacecraft in a scalar form.

12. Formulate the problem of guiding a spacecraft from an initial circular orbit to a final, coplanar circular orbit by the application of a small but continuous, constant thrust acceleration, $u = T/m$. The direction of the thrust vector from the local flight direction is given by angle, $\alpha(t)$ and can be regarded as the input variable. The total time of flight is a free variable.

## Syllabus

### Module I

Flight Dynamic Models: Rigid Body dynamics, Attitude Kinematics- Euler angles – Quaternions, Flight dynamics – translational kinematics – attitude flight dynamics - Space flight dynamics, Atmospheric flight dynamics.

### Module II

Control Design Techniques: Transfer function and singularity inputs – Impulse- step and frequency response - Single variable design – steady state error – PID control – feedforward/feedback tracking – robustness analysis from frequency response- Multivariable design – Regulator design – LQR – LQG, Digital Control System

### Module III

Automatic Control of Aircraft: Aircraft Dynamics - Longitudinal Stability and Control- Automatic longitudinal control - Single input longitudinal control systems

### Module IV

Automatic Control of Rockets: Thrust vectoring for attitude control - Attitude control plant – Numerical problems and Simulations - Roll Control – Numerical problems and Simulations - Pitch – Yaw Control – Numerical problems and Simulations.



### Module V

Automatic Control of Spacecraft: Planar orbit control with vectored orbit thrust - Orbital plane control with vectored rocket thrust - Attitude control by Torque impulses - Attitude control of spacecraft under gravity gradient torque.

**Course Plan**

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | Flight Dynamic Models | |
| 1.1 | Rigid Body dynamics | 1 |
| 1.2 | Attitude Kinematics- Euler angles - Quaternions | 2 |
| 1.3 | Flight dynamics – translational kinematics – attitude flight dynamics - Space flight dynamics | 3 |
| 1.4 | Atmospheric flight dynamics | 2 |
| 2 | Control Design Techniques | |
| 2.1 | Transfer function and singularity inputs – Impulse- step and frequency response | 2 |
| 2.2 | Single variable design – steady state error – PID control – feedforward/feedback tracking – robustness analysis from frequency response | 2 |
| 2.3 | Multivariable design – Regulator design – LQR - LQG | 2 |
| 2.4 | Digital Control System | 2 |
| 3 | Automatic Control of Aircraft | |
| 3.1 | Aircraft Dynamics | 2 |
| 3.2 | Longitudinal Stability and Control | 2 |
| 3.3 | Automatic longitudinal control | 2 |
| 3.4 | Single input longitudinal control systems | 2 |
| 4 | Automatic Control of Rockets | |
| 4.1 | Thrust vectoring for attitude control | 2 |
| 4.2 | Attitude control plant – Numerical problems and Simulations | 2 |
| 4.3 | Roll Control – Numerical problems and Simulations | 2 |
| 4.4 | Pitch – Yaw Control – Numerical problems and Simulations | 2 |
| 5 | Automatic Control of Spacecraft | |
| 5.1 | Planar orbit control with vectored orbit thrust | 2 |

| | | |
|---|---|---|
| 5.2 | Orbital plane control with vectored rocket thrust | 2 |
| 5.3 | Attitude control by Torque impulses | 2 |
| 5.4 | Attitude control of spacecraft under gravity gradient torque | 2 |

**Reference Books**

1. Ashish Tewari, "Automatic Control of Atmospheric and Space Flight Vehicles", Birkhäuser Boston, 2011.

2. Arthur E. Bryson, JR. "Control of Spacecraft and Aircraft", Princeton University Press, New Jersy, 1994

3. Robert C. Nelson, 'Flight Stability and Automatic Control', McGraw-Hill. Copyright © 1998.

4. W. A. Wolovich, Automatic Control Systems: Basic Analysis and Design, Saunders College Publishing, 1994

5. J. H. Blakelock, Automatic Control of Aircraft & Missiles, 2nd ed., 1991

6. R. S. Stengel, Flight Dynamics, Princeton University Press, 2004; Overseas Press, 2009

7. Robert H. Dishop, Modern Control Systems Analysis and Design Using MATLAB&SIMULINK, Addision-Wesley Publication Company, 2006.

8. M. Sami Fadali, and Antonio Visioli, Digital Control Engineering, Copyright © 2009 by Elsevier Inc. ISBN 13: 978-0-12-374498-2

9. Myron Kayton and Walter R Fried, 'Avionics Navigation Systems', John Wiley & Sons Inc., Second Edition, 1997.

10. Manuel Fernadez and George R. Macomber, 'Inertial Guidance Engineering', Prentice-Hall, Inc., Engle Wood Cliffs, New Jersey, 1962.

| 221EEE029 | SYSTEMS THEORY | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| | | PROGRAM ELECTIVE 2 | 3 | 0 | 0 | 3 |

**Preamble:** The concepts in this course are considered advanced in the field of modern control theory. This course provides design of controllers, filters and stability analysis of nonlinear systems

**Prerequisites:** Nil

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

| | |
|---|---|
| **CO 1** | Design controllers and observers satisfying desired specifications |
| **CO 2** | Estimate the states of the system using Kalman filter |
| **CO 3** | Analyze the stability of the system using Lyapunov theorem |
| **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 |
|---|---|---|---|---|---|---|---|
| **CO 1** | 3 | | 2 | 3 | 3 | 2 | |
| **CO 2** | 3 | | 2 | 3 | | | |
| **CO 3** | 3 | | 2 | | | | |
| **CO 4** | 3 | | 2 | 3 | | | |
| **CO 5** | 3 | | 2 | 3 | | | |

**Assessment Pattern**

| Bloom's Category | End Semester Examination |
|---|---|
| Apply | 30 |
| Analyse | 50 |
| Evaluate | 20 |
| Create | |



**Mark distribution**

| Total Marks | CIE | ESE | ESE Duration |
|---|---|---|---|
| 100 | 40 | 60 | 2.5 hours |

**Continuous Internal Evaluation Pattern:**

Preparing a review article based on peer reviewed Original publications (minimum 10 publications shall be referred) : 15 marks

Course based task/Seminar/Data collection and interpretation : 15 marks

Test paper, 1 no. : 10 marks

Test paper shall include minimum 80% of the syllabus.

**End Semester Examination Pattern:**

The end semester examination will be conducted by the respective College. There will be two parts; Part A and Part B. Part A will contain 5 numerical/short answer questions with 1 question from each module, having 5 marks for each question (such questions shall be useful in the testing of knowledge, skills, comprehension, application, analysis, synthesis, evaluation and understanding of the students). Students should answer all questions. Part B will contain 7 questions (such questions shall be useful in the testing of overall achievement and maturity of the students in a course, through long answer questions relating to theoretical/practical knowledge, derivations, problem solving and quantitative evaluation), with minimum one question from each module of which student should answer any five. Each question can carry 7 marks

Note: The marks obtained for the ESE for an elective course shall not exceed 20% over the average ESE mark % for the core courses. ESE marks awarded to a student for each elective course shall be normalized accordingly. For example if the average end semester mark % for a core course is 40, then the maximum eligible mark % for an elective course is 40+20 = 60 %.

**Model Question Paper**

**Pages** **SLOT**

**APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY FIRST SEMESTER M.TECH DEGREE EXAMINATION, MONTH & YEAR**

**221EEE029: SYSTEM THEORY**

**Max. Marks: 60** **Time: 2.5 hrs**

| | **Part A (Answer all questions)** | **Marks** |
|---|---|---|
| 1 | A state equation of the system is given as $x' = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -2 & -3 \end{bmatrix} x + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u$ <br> $y = [3 \quad 4 \quad 1]\, x$. Check whether the system is completely controllable and observable | (5) |
| 2 | Consider the task of estimating the states of a double integrator where noise with intensity 1 affects the input only and we have measurement noise of intensity 1. Determine the Kalman filter. What are the Kalman filter poles? | (5) |
| 3 | A nonlinear system described by the differential equation $y'' + y'(y^2 + (y')^2) + y = 0$. Check the stability of the system using Lyapunov stability criterion | (5) |
| 4 | 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) | (5) |
| 5 | Design a MRAC for a first order system using MIT rule. | (5) |
| | **Part B** <br> **(Answer any five questions)** | |
| 6 | Consider the system defined by $x' = Ax + bu$ , where $A = \begin{bmatrix} -1 & 0 & 0 \\ 1 & -2 & 0 \\ 0 & 1 & -3 \end{bmatrix}$ <br> $b = \begin{bmatrix} 10 \\ 1 \\ 0 \end{bmatrix}$. Design a state feedback controller that places the eigen values at s = $-1 \pm$ | (7) |

| | | |
|---|---|---|
| | $j2$, -6. | |
| 7 | Design a controller observer transfer function of the plant $\frac{Y(s)}{U(s)} = \frac{1}{(s+3)(s+2)}$ to place the eigen values are at $s = -1 \pm j3$ and the observer poles at s= -8, -8 | (7) |
| 8 | A Kalman filter should be designed for the second-order system<br>$\dot{x}(t) = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(t) + w_1(t)$ ; $y(t) = [1 \quad 0]x(t) + w_2(t)$<br>where $w_1$ and $w_2$ are uncorrelated white noise processes with intensities $R_1 = \begin{bmatrix} 3 & 0 \\ 0 & 3 \end{bmatrix}$ and $R_2 = 1$, respectively. Calculate the minimum observer error covariance *P* and the Kalman filter gain *K*. Also Write down the resulting filter equations for $\hat{x}_1 nd\ \hat{x}_2$. | (7) |
| 9 | Construct a Lyapunov function for the given system using variable gradient method $x_1' = x_2, \quad x_2' = -x_1^3 - x_2$ | (7) |
| 10 | Consider the system given by<br>$x' = \begin{bmatrix} 0 & 1 \\ 4 & 5 \end{bmatrix} x + \begin{bmatrix} 0 \\ 1 \end{bmatrix} (u + 0.5cost)$ . Design a stable sliding surface for a given system | (7) |
| 11 | Obtain the equivalent control for a simple pendulum with a friction when torque is applied. | (7) |
| 12 | . a) Explain the design of Self Tuning Regulator by pole placement design.<br>b) Explain the least square estimation for parameter estimation. | (7) |

**Syllabus**

**Module 1**

**State Variable Analysis and Observer design of Linear Systems (6 hrs):**

Review of State variable representation of continuous time system- Controllable and observable and Jordan canonical form representation - Controllability and Observability- controller design using pole placement.

Observers: Asymptotic observers for state measurement. Implementation of full order and reduced order observers , separation principle, the combined observer-controller.

*MATLAB experiments: state-space, controllability and observability, combined controller observer-design*

**Module 2**

**Filter Design (8 hours):**

Sample Spaces and Events - Random-Variables. - Bayes' Formula- Expectation - Variance - Covariance - White and Colored Noises-Correlated Noise. Least Square Estimation-Weighted Least Square Estimation, Recursive Least Square Estimation.Wiener filtering - Propagation of States and Co-Variance - Kalman filter design. Extended Kalman filter design Introduction to Linear Quadratic Regulator (LQR) and Linear Quadratic Gaussian (LQG) techniques

## Module 3

**Nonlinear System Analysis (8 hours):**

Nonlinear systems: Introduction, equilibrium/singular points, concept of stability. Stability: Lyapunov theory, asymptotic stability and instability, Lyapunov's direct and indirect methods. Lyapunov's stability analysis of LTI continuous-time systems. Construction of Lyapunov function using variable gradient method.

## Module 4

**Controller design (9 hours):**

PID controllers: Effect of proportional, integral and derivative gains on system performance, PID tuning - Ziegler Nichols Methods, integral windup and solutions.

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

**Adaptive Controllers (8 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.

### Course Plan

| No | Topic | No. of Lectures |
|---|---|---|
| 1 | **State Variable Analysis and Observer design of Linear Systems (7 hrs):** | |
| 1.1 | Review of State variable representation of continuous time system | 1 |
| 1.2 | Controllable and observable and Jordan canonical form representation - Controllability and Observability | 1 |
| 1.3 | controller design using pole placement. | 1 |
| 1.4 | Observers: Asymptotic observers for state measurement. Implementation of full order observer | 2 |
| 1.5 | Implementation of reduced order observer, separation principle, the combined observer-controller. | 2 |
| 2 | **Filter Design (8 hours):** | |
| | | |
| 2.1 | Sample Spaces and Events - Random-Variables. - Bayes' Formula-Expectation | 1 |
| 2.2 | Covariance - White and Colored Noises-Correlated Noise. Least Square Estimation-Weighted Least Square Estimation | 2 |
| 2.3 | Recursive Least Square Estimation.Wiener filtering - Propagation of States and Co-Variance - Kalman filter design | 3 |
| 2.4 | Extended Kalman filter design Introduction to Linear Quadratic Regulators (LQR) and Linear Quadratic Gaussian (LQG) | 3 |
| 3 | **Nonlinear System Analysis (8 hours):** | |
| 3.1 | Nonlinear systems: Introduction, equilibrium/singular points, | 1 |

| | | |
|---|---|---|
| | concept of stability | |
| 3.2 | Stability: Lyapunov theory, asymptotic stability and instability, | 2 |
| 3.3 | Lyapunov's direct and indirect methods. Lyapunov's stability analysis of LTI continuous-time systems. | 2 |
| 3.4 | Construction of Lyapunov function using variable gradient method | 3 |
| 4 | **Controller design (9 hours):** | |
| 4.1 | PID controllers: Effect of proportional, integral and derivative gains on system performance | 1 |
| 4.2 | PID tuning - Ziegler Nichols Methods, integral windup and solutions | 1 |
| 4.3 | Introduction to Variable Structure Systems ( VSS)- examples , Introduction to sliding mode control- -sliding surface | 2 |
| 4.4 | Examples of dynamical systems with sliding modes , reachability condition, Invariance conditions- chattering-equivalent control | 3 |
| 4.5 | Design of sliding mode controllers using pole placement, LQR method | 2 |
| 5 | **Adaptive Controllers (8 hours):** | |
| 5.1 | Adaptive Control, effects of process variation - Adaptive Schemes - Adaptive Control problem - Applications | 2 |
| 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 |

**Reference Books**


1. M. Gopal, "Modern Control System Theory", Tata McGraw-Hill, 2nd Edition, 1993.
2. H. Khalil, "Nonlinear Control Systems", Prentice Hall Inc, New Jersey, 2002.
3. Katsuhiko Ogata, "Modern Control Engineering", Prentice-Hall of India, New Delhi, 2009.
4. J. Nagarath and M. Gopal, "Control system Engineering", New Age International (P) Ltd, 2007.
5. Katsuhiko Ogata, "State Space Analysis of Control Systems", Prentice Hall Inc, New Jersey, 1996.
6. Benjamin C. Kuo and Farid Golnaraghi, "Automatic Control Systems", 9th Edition, John Wiley & Sons, 2010.
7. Jean-Jacques E, Slotine, Weiping Li, "Applied Nonlinear Control", Prentice Hall Inc., New Jersey, 2005.
8. C Edwards and Sarah Spurgeon, " Sliding Mode Control: Theory And Applications", Taylor and Francis,1998
9. K. J. Astrom and B. Wittenmark, "Adaptive Control", 2nd Edition, Addison-Wesley, 1995
10. . S. Sastry and M. Bodson, "Adaptive Control", Prentice-Hall, 1989

| CODE | COURSE NAME | CATEGORY | L | T | P | CREDIT |
|---|---|---|---|---|---|---|
| **221LEE004** | **Design and Simulation Lab** | **Lab I** | **0** | **0** | **2** | **2** |

**Preamble:** This Laboratory Course provides a platform for modelling and analysis of linear and nonlinear systems with the help of hardware and software tools in the control framework.

**Prerequisite:** Basic knowledge of modern control theory and simulation tools

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

| | |
|---|---|
| **CO 1** | Develop the mathematical model of a given physical system by conducting appropriate experiments. |
| **CO 2** | Analyse the performance and stability of physical systems using classical and advanced control approaches. |
| **CO 3** | Design controllers for physical systems to meet the desired specifications. |
| **CO 4** | Design Observers for feedback systems |
| **CO 5** | Apply appropriate techniques and modern tools for modelling and analysis of physical systems |

**Mapping of course outcomes with program outcomes**

| | PO 1 | PO 2 | PO 3 | PO 4 | PO 5 | PO 6 | PO 7 |
|---|---|---|---|---|---|---|---|
| **CO 1** | | | 3 | 3 | | | |
| **CO 2** | | | 3 | 3 | 2 | | |
| **CO 3** | | | 3 | 3 | 2 | | |
| **CO 4** | | | 3 | 3 | 3 | | |

**Reference Books**


1. Richard C. Dorf and Robert H. Bishop, Modern Control Systems, Eleventh Edition, Pearson Education 2009.

2. Katsuhiko Ogata, Modern Control Engineering, Fourth Edition, Pearson Education,2002.

**List of Exercises/Experiments**:

Simulation tools like MATLAB/ SCILAB or equivalent may be used.

10 experiments are mandatory.

| Experiment No. | Name of the experiment |
|---|---|
| **1** | **Control Design by PID ( Eg. DC Motor speed control)**<br><br>Objective:<br>Derive the transfer function of Armature Controlled DC motor<br>Study the effect of tuning of PID controller on the above system using MATLAB/SIMULINK |
| **2** | **PMDC motor modeling, identification, speed control**<br><br>Objective:<br><br>1. Develop a physics-based model for a PMDC motor.<br>2. For the PMDC motor develop a model based on system identification using open-loop (OL) step response.<br>3. Design a speed controller for the physics-based model using Bode plot-based loop-shaping techniques. Simulate this controller |
| **3** | **Ziegler-Nichols tuning of speed controller of PMDC motor**<br><br>Objective:<br><br>To apply a Ziegler-Nichols tuning (ZNT) methods to tune the parameters of a PID controller of the speed of a PMDC motor. |
| **4** | **PMDC speed control**<br><br>Objective:<br><br>To control the speed of the PMDC motor using feedback of current by simulation and experiment. |
| **5** | **PMDC armature current control**<br><br>Objective:<br><br>To control the armature current of the PMDC motor at the desired value by simulation and experiment. |
| **6** | **Control Design by pole-placement ( Eg. DC Motor speed control).**<br>Objective:<br>A. Derive the state space model of Armature Controlled DC motor.<br>B. Obtain the state space model in MATLAB |

| | |
|---|---|
| | C. Analyse the open loop stability, controllability and observability.<br>D. Design a controller by pole-placement technique and verify. |
| **7** | **Disturbance observer**<br><br>Objective:<br><br>To implement a disturbance observer (DOB) for a PMDC motor. |
| **8** | **Disturbance observer without feedback of current**<br><br>Objective:<br><br>To build and test a PMDC motor speed control system that uses a disturbance observer (DOB) but does not use the feedback of armature current. |
| **9** | **Stability analysis of nonlinear autonomous systems using phase plane.**<br>Objective:<br>A. Simulate the given nonlinear autonomous system using state space model<br>B. Theoretically determine the various singular points and verify the same from phase portraits using simulations.<br>C. Analyse the stability of the system at various singular points from phase portraits. |
| **10** | **Closed loop performance of inverted pendulum.**<br>Objective: Study of performance characteristics of inverted pendulum by experiment.<br>Determine the various unknown parameters of an inverted pendulum experimentally. Obtain the non-linear and linearised models. Design implement and analyse the performance of the system with various state feedback controllers while regulation/tracking |
| **11** | **Performance analysis of magnetic levitation system.**<br>Objective: Study of performance of magnetic levitation system by experiment.<br><br>Understand the dynamics of a magnetic levitation system. Design implement and analyse the performance of this experimental system with various loop controllers while tracking in presence/absence of disturbance |

| | |
|---|---|
| **12** | **Closed loop performance of Twin rotor system**<br>Objective: Study of performance characteristics of Twin rotor system by experiment. |
| **13** | **Mass Spring Damper system**<br>Objective: Understand the dynamics and determine the various unknown parameters of a mass spring damper system experimentally and obtain transfer function/ state space models. Design implement and analyse the performance of the system with various state feedback controllers while regulation and tracking |