KUMARAGURU
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M.TECH DEGREE EXAMINATIONS: NOV/DEC 2023
(Regulation 2018)
First Semester
DEFENCE TECHNOLOGY
P18DTE0006**:** Autonomy and Navigation Technology

COURSE OUTCOMES

CO1: Describe the basic principle of operation of inertial navigation system and derive the inertial navigation equations.
CO2: Explain the operation of inertial sensors.
CO3: Describe the basic principle of operation of a global navigation satellite system and solve the equations for calculating a position estimate from a given satellite constellation.
CO4: Explain the integrated navigation techniques and guidance laws for autonomous vehicles.
CO5: Carry out the path planning for UGV/UAV.

Time: Three Hours   **Maximum Marks: 100**

Answer all the Questions:-
PART A (10 x 1 = 10 Marks)

1. Identify the correct sequence of steps in the process of estimating the states of a linear stochastic system using a discrete Kalman filter: CO4   [K2]
    1. Compute the Kalman gain
    2. Predict the states ahead
    3. Update the estimate with measurement(s)
    4. Predict the error covariance ahead

    a) 2-3-1-4   b) 4-3-1-2
    c) 2-1-4-3   d) 2-4-1-3

2. The basic information provided by satellite navigation systems are   CO3   [K1]
    a) Position and velocity   b) Position, velocity, and time
    c) Position, velocity, and attitude   d) Position, velocity, attitude, and time

3. With a strapdown inertial navigation system, the velocity of a fixed-wing UAV in straight and level flight in a body coordinate frame is Vx = 10 m/s and Vy = Vz = 0. Now, without roll and yaw, the UAV is making a nose-up manoeuvre with a pitch angle of 30 degrees. With that nose-up position, what is the velocity of the UAV in a selected NED navigation frame?   CO1   [K3]
    a) Vn = 8.66 m/s, Ve = 0, Vd = 5 m/s   b) Vn = 8.66 m/s, Ve = 0, Vd = –5 m/s
    c) Vn = 5 m/s, Ve = 0, Vd = 8.66 m/s   d) Vn = 5 m/s, Ve = 0, Vd = –8.66 m/s

4. Match the given geodetic coordinates in List I with the corresponding xyz position in the ECEF frame given in List II.   CO3   [K2]

List I	List II
(A) Latitude = 0º, Longitude = 0º, Height = 0 meters	(i) x = 0 km, y = 6378 km, z = 0 km
(B) Latitude = 0º, Longitude = 90º, Height = 0 meters	(ii) x = 0 km, y = 0 km, z = 6356 km
(C) Latitude = 90º, Longitude = 0º, Height = 0 meters	(iii) x = 6378 km, y = 0 km, z = 0 km

    a) (A)-(ii), (B)-(iii), (C)-(i)   b) (A)-(iii), (B)-(i), (C)-(ii)
    c) (A)-(ii), (B)-(i), (C)-(iii)   d) (A)-(iii), (B)-(ii), (C)-(i)

5. In PN guidance, the PN constant for which a missile is turning at the same rate as LOS   CO4   [K2]

is _____.
a) 0.5   b) 1
c) 2   d) 4

6. Which one of the following sensors measures the angular rates of rotation of a vehicle   CO2   [K1]
    about its roll, pitch, and yaw axes?
    a) Rate gyros   b) Rate integrating gyros

    c) Linear accelerometers   d) Rotary encoders

7. Assertion (A): Inertial navigation systems are self-contained and autonomous.   CO1   [K2]
    Reason (R): Position errors are not accumulated in inertial navigation systems.
    a) Both A and R are Individually true and R   b) Both A and R are Individually true but
        is the correct explanation of A   R is not the correct explanation of A
    c) A is true but R is false   d) A is false but R is true

8. The total number of bits in a GPS navigation message of 20 frames is   CO3   [K2]
    a) 30000   b) 37500
    c) 43500   d) 56000

9. Which of the following are true about an inertial navigation system (INS)?   CO1   [K2]
    (i) In inertial navigation, accelerometers will measure the gravitational acceleration.
    (ii) In strapdown inertial navigation, gyroscopes will sense the vehicle body rate.
    (iii) A gimballed INS does not require coordinate transformation.
    (iv) In a practical navigation system, even though the power is on, the output of a
         gyroscope is zero when there is no body rotation.
    a) (i) and (ii) only   b) (ii) and (iii) only
    c) (iii) and (iv) only   d) (ii) and (iv) only

10. Which one of the following is required to calculate the pseudorange in GPS?   CO3   [K1]
    a) Satellites' position and velocity   b) Satellites' orbital data
    c) Ionospheric correction terms   d) C/A code and/or P-code

PART B (10 x 2 = 20 Marks)

11. What is the principle of dead reckoning navigation?   CO1   [K2]
12. Why an inertial navigation system is called "autonomous" and "self-contained"?   CO1   [K2]
13. What is the major drawback of an inertial navigation system for position   CO1   [K2]
    determination?
14. What is Coriolis acceleration for a vehicle?   CO1   [K2]
15. What are the advantages of quaternion over the DCM and Euler angle methods for the   CO1   [K2]
    attitude representation of a vehicle?
16. What is the function of the Kalman filter in integrated navigation for autonomous   CO4   [K2]
    vehicles?
17. Show the relationship between the guidance, navigation, and control systems for an   CO4   [K2]
    autonomous unmanned aerial vehicle.
18. Define **guidance law** for an unmanned aerial vehicle.   CO4   [K2]
19. Show the architecture of a tightly coupled GPS-aided inertial navigation system using   CO4   [K2]
    the Kalman filter.
20. What is path planning for autonomous vehicles? Mention the two important steps   CO5   [K2]
    involved in path planning.

PART C (6 x 5 = 30 Marks)

21. The body frame of an autonomous vehicle can be obtained from a reference local   (5)   CO1   [K3]
    geographic NED frame by performing three rotations with the rotation sequence
    of ϕ-θ-ψ about x, y, z axes, respectively. Assume the vehicle is now
    performing a turn maneuver from its level flight without pitching through a roll
    angle of 30 degrees and a yaw angle of 20 degrees. With these measurements,

obtain the transformation matrix for transforming the measurements from the vehicle body frame to the NED navigation frame.

22. Explain the force sensed by the MEMS gyroscopes to measure the angular rate. (5) CO2 [K2]

23. Explain the complete algorithm used in strapdown inertial navigation to compute the position of a vehicle in a NED coordinate frame (5) CO1 [K2]

24. With the help of an equation, explain the raw output of an accelerometer when it is sitting on a table and in a free fall. (5) CO2 [K2]

25. The linear Kalman filter equations are given by (5) CO4 [K3]

$$\left.\begin{array}{l} \hat{x}_k^- = A\hat{x}_{k-1} + Bu_k + w_k \\ P_k^- = AP_{k-1}A^T + Q \end{array}\right\} \text{Prediction}$$

$$\left.\begin{array}{l} K_k = P_k^- H^T \left(H P_k^- H^T + R\right)^{-1} \\ \hat{x}_k = \hat{x}_k^- + K_k\left(z_k - H\hat{x}_k^-\right) \\ P_k = \left(I - K_k H\right)P_k^- \end{array}\right\} \text{Correction}$$

Given the process and measurement equations

$$x_k = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} x_{k-1} + w_{k-1} \quad \text{(Gaussian and white)},$$

$$z_k = \begin{bmatrix} 1 & 0 \end{bmatrix} x_k + v_k \quad \text{(Gaussian and white)},$$

$$P_0 = \begin{bmatrix} 10 & 0 \\ 0 & 10 \end{bmatrix},$$

$$E(w_k) = 0, \quad Q_k = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix},$$

$$E(v_k) = 0, \quad R_k = 2$$

calculate the Kalman gain and the new covariance matrix P.

(**Note:** The inverse of a 1x1 matrix is simply the reciprocal of the single entry in the matrix.)

26. Consider Figure 1, which shows nodes connected by edges along with the distance between them. Assume the starting node is "A". (5) CO5 [K3]
Using Dijkstra's algorithm, find the following:
   (i) The shortest distance between the starting node and all other nodes by visiting all the nodes and their neighbors.
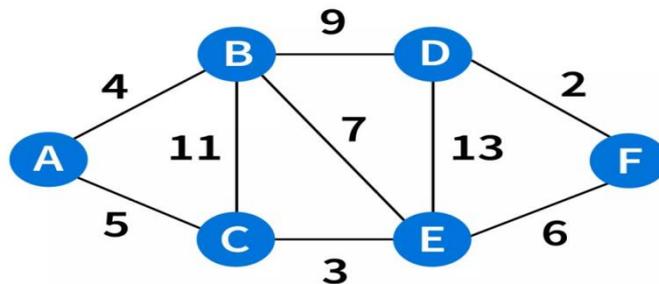   (ii) The shortest path from node "A" to node "F".

Figure 1.

27. Consider a guided missile ready to launch from a launch site located at 20.758º   10   CO1   [K₃]
N, 87.09º E. The initial conditions of the missile are given as follows:
    - Roll angle $(\phi_0) = 0°$
    - Pitch angle $(\theta_0) = 80°$
    - Yaw angle $(\psi_0) = 0°$
    - Velocity $(v_0) = 0$

The missile relies on an inertial navigation computer for its position determination, and the navigation computer is using a quaternion algorithm for the attitude computation. The quaternion parameters are expressed as $\begin{bmatrix} a & b & c & d \end{bmatrix}^T$. For the given initial conditions, find the initial quaternion parameters and initial DCM using quaternions. After launch, the first measurements of the body mounted rate gyros in rad/s are expressed in vector form as $\begin{bmatrix} 0.0349 & 0.5236 & 0.0087 \end{bmatrix}^T$. With the gyro measurements, find the rate of change of quaternion parameters. (The earth's rotation rate is 7.292×10^{-5} rad/s).

28. A vector quantity defined in body axes, r^b, may be expressed in reference axes   10   CO1   [K₃]
as r^n using the quaternion, q directly. (where, $q = a + b\vec{i} + c\vec{j} + d\vec{k}$ and $r^b = x\vec{i} + y\vec{j} + z\vec{k}$). For the vector transformation, find the C_b^n in terms of quaternion elements.

29. Describe the four main modules of an autonomous vehicle and show the   10   CO5   [K₂]
interaction among the modules.

30. With neat geometry, explain the proportional navigation and line-of-sight   10   CO4   [K₂]
guidance methods for autonomous vehicles.

31. Consider the map shown in Figure 2 with its grid of nodes. The white nodes   10   CO5   [K₃]
represent the movable areas in the map, and the black nodes represent the obstacles. Using the A* algorithm, find the shortest path from node "A" to node "B".
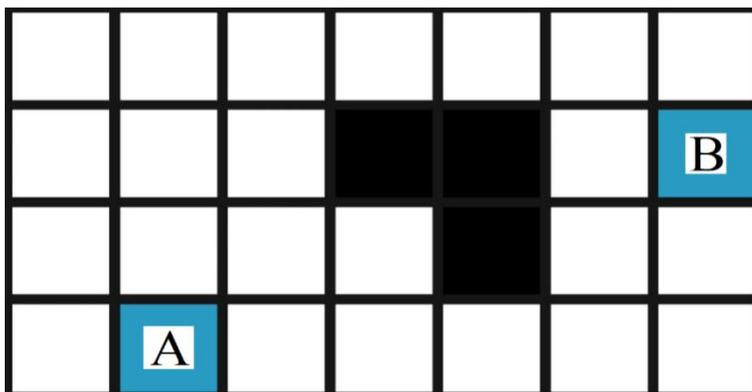

Figure 2.

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