INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B. Tech Seventh Semester ECE – Quiz 2 – October 2023
AV411 – Navigation Systems and Sensors
Time: One hour Date: 19/10/2023 Max. Marks: 15

Read **ALL** the instructions in this **NOTE**. Write your name and ID number on Answer Papers. Do **NOT** panic. Answer **ALL** questions. All the steps must be stated clearly. The steps carry more marks than the final answer. Provide illustrations wherever required.

If anything is **NOT** clear, make relevant assumptions and solve the problem. In that case state your assumptions clearly. If you feel that a particular question is wrong then solve the "nearest" correct question by stating your version of question clearly.

The students are allowed to bring one A4 sized cheat sheet with formulas (no derivations and no drawings) written in their own handwriting. This sheet must be submitted with the answer scripts.

1. Define angular momentum and torque and show that torque is the rate of change of angular momentum. (3)

2. State the assumptions made in deriving the solution of Focault's pendulum. Describe the behaviour of the solution. An experiment is conducted at the equator of the Planet Mars to determine its rotation using Focault's pendulum. Will the experiment succeed. Justify your answer. (3)

3. The first stage empty fuel tank of a launch vehicle weighing 14 tons is dropped from a height of 75km above a certain location in northern hemisphere. Assuming free fall and negligible wind velocity, would it fall directly below the positon from where it was dropped? Justify. Compute the position of the fuel tank on the ground in relation to the position from where it was dropped. Assume that the latitude and longitude of the point above the earth from where the fuel tank was dropped is 60° and 30°, respectively. (3)

4. Let OXYZ be an inertial frame. Let Oxyz be initially coincident with OXYZ and rotate with constant angular velocity $|\Omega|$ about Oz. Consider a fixed point 'A' in space at a radius r from Oz. Compute the absolute acceleration of 'A', a_A. (3)

5. Quaternion
   (a) Let p and q be two quaternions. Show that $(pq)^{-1} = q^{-1}p^{-1}$ (1)
   (b) Consider the two quaternions (1)

$$p = \frac{\sqrt{3}}{2} + i\frac{1}{2}$$
$$q = -\frac{\sqrt{3}}{2} - i\frac{1}{2}$$

   What are the angle and axis of rotation of p and q when interpreted as rotation representation? What do you conclude from this?

   (c) What are the rotation angle and axis represented by the quaternions (1)
      1. i, j and k
      2. ijk

End of exam.

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B. Tech Seventh Semester ECE – Quiz 1 – September 2023
AV411 – Navigation Systems and Sensors
Time: One hour Date: 11/09/2023 Max. Marks: 15

Read **ALL** the instructions in this **NOTE**. Write your name and ID number on Answer Papers. Do **NOT** panic. Answer **ALL** questions. All the steps must be stated clearly. The steps carry more marks than the final answer. Provide illustrations wherever required.

If anything is **NOT** clear, make relevant assumptions and solve the problem. In that case state your assumptions clearly. If you feel that a particular question is wrong then solve the "nearest" correct question by stating your version of question clearly.

The students are allowed to carry one A4 sheet written in their own handwriting containing formulas. However, no block diagrams and derivations are allowed. The sheet shall carry the student's name and SC code and should be submitted along with the answer script.

1. Navigation Systems and Sensors
   (a) Explain strapdown navigation system with a neat diagram. (2)
   (b) Explain the working principle of a mechanical gyroscope and what is it used for? (2)
2. What are the key features required to define a cartesian co-ordinate system? Define synodic coordinate system using the above features. (3)
3. Consider the following DCM matrix

$$Q = \begin{bmatrix} C\psi C\theta & s\psi C\theta & -S\theta \\ C\psi S\theta S\phi - S\psi C\phi & S\psi S\theta S\phi + C\psi C\phi & C\theta S\phi \\ C\psi S\theta C\phi + S\psi S\phi & S\psi S\theta C\phi - C\psi S\phi & C\theta C\phi \end{bmatrix}$$

   (a) Determine the sequence and angle of elementry rotations for the above matrix. (1)
   (b) Explain gimbal lock in a coordinate transformation sequence using the above matrix and determine the gimbal lock angle. (2)
4. Consider the following matrix

$$\begin{bmatrix} 0 & 0 & -1 \\ \sin(\psi) & \cos(\psi) & 0 \\ \cos(\psi) & -\sin(\psi) & 0 \end{bmatrix}$$

   (a) Determine weather the above matrix is a rotation matrix and justify. If the above matrix is not a rotation matrix modify it to a rotation matrix. (2)
   (b) Determine the axis and angle of rotation for the above/converted matrix. (3)

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B. Tech Seventh Semester ECE – End Semester – November 2023
AV411 – Navigation Systems and Sensors
Time: Three hours Date: 29/11/2023 Max. Marks: 50

Read **ALL** the instructions in this **NOTE**. Write your name and ID number on Answer Papers. Do **NOT** panic. Answer **ALL** questions. All the steps must be stated clearly. The steps carry more marks than the final answer. Provide illustrations wherever required.

If anything is **NOT** clear, make relevant assumptions and solve the problem. In that case state your assumptions clearly. If you feel that a particular question is wrong then solve the "nearest" correct question by stating your version of question clearly.

The students are allowed to carry two A4 sheets written in their own handwriting containing formulas. However, no block diagrams and derivations are allowed. The sheet shall carry the student's name and SC code and should be submitted along with the answer script.

Tensor of Inertia

1. State the properties of Tensor of Inertia matrix. (2)

2. Let Θ be tensor of inertia with respect to unit vectors in the directions $e^1 = (2,1,1)$, $e^2 = (1,-1,-1)$, $e^3 = (0,1,-1)$ where (5)

$$\Theta = \begin{bmatrix} 5 & -2 & -1 \\ -2 & 6 & -2 \\ -1 & -2 & 4 \end{bmatrix}$$

Compute the moment of inertia about the axis $n = (2,-1,3)$ which is expressed in the axes $(1,0,0)$, $(0,1,0)$, $(0,0,1)$.

3. The tensor of inertia matrix for a certain rigid body with respect to the standard basis is given to be (2)

$$\Theta = \begin{bmatrix} 4 & -2 & -1 \\ -2 & 5 & -2 \\ -1 & -2 & 6 \end{bmatrix}$$

It is given that moment of inertia about a particular axis $\hat{n}$ is 12.

Is $\hat{n}$ unique? If so justify and compute $\hat{n}$. Otherwise, state/derive the equations which lead to computing the vector $\hat{n}$.

4. Determine the candidate shape of the object of mass M and the co-ordinate axes for which the TOI takes the form $\Theta = \begin{bmatrix} 3M & 0 & 0 \\ 0 & 3M & 0 \\ 0 & 0 & 0 \end{bmatrix}$ (5)

5. A gyroscope consists of two identical uniform disks with mass M and radius R mounted on a rigid axle with length $2D$ as shown in Figure 5. The axle is fixed to the outer disk, while the inner disk is allowed to spin freely but is constrained to remain at a distance D from the pivot (at left) by a collar. The axle spins about the pivot freely on a frictionless mount. The outer disk and axle are initially spun up to an angular frequency ω_0 . Assume that the mass of the axle and pivot mount are negligible. Gravity points downward. Ignore nutation. Calculate the precession rate $\vec{\Omega}$ of the gyroscope assuming that the inner disk is not spinning. (5)

6. Let Θ be the tensor of inertia matrix in some orthogonal co-ordinate frame. Determine the new tensor of inertia matrix when the co-ordinate system is translated by a constant vector r_0. (5)

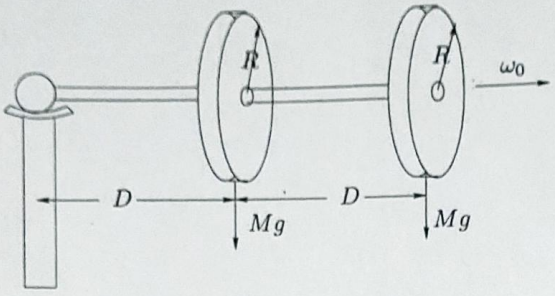

Figure 1: Double Wheel

Coordinate-systems

7. Show that rotation matrices are orthogonal matrices with determinant 1. (2)

8. Show that for any $t \in \mathbb{R}$ the matrix Q_t defined below is a rotation matrix. Find its axis of rotation and cosine of the angle of rotation. (3)

$$Q_t = \frac{1}{1+t+t^2}\begin{bmatrix} -t & t+t^2 & 1+t \\ 1+t & -t & t+t^2 \\ t+t^2 & 1+t & -t \end{bmatrix}$$

9. The IRNSS 1A satellite was launched into geosynchronous orbit with an inclination of 27.47 degrees with equator, Perigee 35,704Km and Apogee 35,866 Km. On 31st Dec., 2020 at 12:35 IST IRNSS makes an observation of Sun and the Star Sirius. The co-ordinates as measured by IRNSS of the Sun are $(2,1,3)$ and $(1,-1,1)$ in the body and ECI frame respectively and that of the Sirius are $(1,0,1)$ and $(-1,1,0)$ in the body and ECI frame respectively.

   (a) Is it possible to determine the orientation of IRNSS body frame with respect to the ECI frame with the above given measurements? Justify (1)

   (b) If the answer to the above question is yes then justify by determining the transformation matrix between the IRNSS body frame and ECI frame. If the answer to the previous question is no then how many additional vector measurements are required to obtain the transformation matrix between IRNSS body frame and ECI frame? Give an example of additional measurement vectors and the corresponding transformation matrix. (2)

10. An inertial measuring unit consisting of three rate gyroscopes and three servo accelerometers are placed in a rocket at the launchpad located in Sydney, 33.8600° S, 151.2094° E Australia. The input axes of the inertial measuring unit are aligned with North, East and Zenith axis. Determine the measurements obtained by all the gyroscopes and accelerometers. (1)

11. Find the quaternion corresponding to the DCM matrix (1)

$$\begin{bmatrix} -\frac{5}{8} & \frac{\sqrt{3}}{4} & \frac{3^{3/2}}{8} \\ \frac{\sqrt{3}}{4} & -\frac{1}{2} & \frac{3}{4} \\ \frac{3^{3/2}}{8} & \frac{3}{4} & \frac{1}{8} \end{bmatrix}$$

Kalman filter

12. Given the following scalar Kalman filter state space model,

$$x_k = ax_{k-1} + w_k, \quad w_k \sim \mathcal{N}(0, \sigma_w^2)$$
$$y_k = x_k + v_k, \quad w_k \sim \mathcal{N}(0, \sigma_w^2)$$

and the Kalman equations

$$\begin{aligned} \widehat{x}_{k|k-1} &= a\widehat{x}_{k-1|k-1} \\ P_{k|k-1} &= a^2 P_{k|k-1} + \sigma_w^2 \\ K_k &= \frac{P_{k|k-1}}{P_{k|k-1} + \sigma_v^2} \\ \widehat{x}_{k|k} &= a\widehat{x}_{k|k-1} + K_k(y_k - \widehat{x}_{k|k-1}) \\ P_{k|k} &= (1 - K_k)P_{k|k-1} \end{aligned}$$

Using the above equations, prove the following

(a) Show $0 \leq K_k \leq 1$. (1)

(b) Therefore, show that $P_{k|k} \leq P_{k|k-1}$. (2)

(c) Compute the following (2)

$$\lim_{\sigma_w^2 \to \infty} K_k = ? \qquad \lim_{\sigma_v^2 \to \infty} K_k = ?$$

Inertial Sensors

13. (a) What are the major gasses of contamination inside the active medium of ISROs Laser Gyro (ILG)? A. O2 and Ne B. O2 and H2 C. N2 and H2 D. O2 and N2 (2)

(b) A closed loop null balanced analog accelerometer has a torquer coil to counter balance the pendulum deflection and the amount of current required to rebalance the pendulum is a measure of acceleration. It is a fact that the permanent magnet used in the sensor will naturally losses its properties gradually over a period of time. Assuming all other parameters are time invariant, what would happen to the sensor scale factor?

A. The requirement of rebalancing force current will decrease and hence scale factor will increase.

B. The requirement of rebalancing force current will decrease and hence scale factor will decrease.

C. The requirement of rebalancing force current will increase and hence scale factor will increase.

D. The requirement of rebalancing force current will increase and hence scale factor will decrease

(c) A single axis accelerometer is used as an INS to navigate a 1-D world. A person living there wants to travel 1000m with an uncertainty of 1m in a vehicle that produces 1mg constant thrust. What should be the maximum unmodelled residual bias that the accelerometer is allowed to have?

A. 1μ g B. 10μ g C. 100μ g D. 0.1μ g

(d) A 1000Kg satellite equipped with a 440N thruster is injected in to an elliptical transfer orbit and it is planned to circularize the orbit by adding a ΔV of 100m/s. How much duration thruster should be fired and where should this maneuver be executed?

A. 227.273 s at Apogee point B. 227.273 s at Perigee point C. 44 s at Apogee point D. 44 s at Perigee point

14. With neat diagrams explain the working principles of any two of the following sensors: (4)

(a) Momentum wheel gyros

(b) Laser Gyros

(c) Accelerometer

15. Write your own question and answer with diagrams if necessary in the area of Navigation Systems and Sensors and not covered in the above questions. (5)

End of exam.

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547

B.Tech ECE (Avionics) Quiz-I – September 2023

AV 412 – Satellite and Optical Communication

Time: 1 hour Date: 12/09/2023 Max. Marks: 15

Note: Write Part A and Part B in separate sheet

PART - A - Satellite Communication

Answer the following

1. Design an $(n, k) = (5, 2)$ linear block code.
   (a) Calculate the generator matrix for the codeword set and the parity-check matrix with the goal of maximizing d_{min}.[2]
   (b) What are the error-correcting and error-detecting capabilities of the code? Justify your answer. [1]
   (c) Make a syndrome table for the correctable error patterns [1]
2. IF communication signal is transmitted at carrier frequency 14.125 MHz and carries a symbol stream at $Rs = 16Msps$. The transmitter and receiver have RRC filters with $\alpha = 0.25$. What is the bandwidth occupied by the RF signal and what is the frequency range of the transmitted RF signal? [1.5]
3. If there is no restriction in using bandwidth can we transmit with a high data rate with a low probability of error or no error? Justify your answer with a proper explanation. [1.5]
4. Draw the block diagram for an SDR-based QPSK real-time communication system with error control coding (15,11). If R_b is the bit rate, mark the change in rate in the block diagram. [3]

PART - B - Optical Communication

Answer the following

5. Consider a planar dielectric waveguide whose substrate has a refractive index (RI) of 1.56, guiding layer of $RI = 1.6$ and free space as its cover material. Calculate the minimum angle with respect to the normal with which a ray of light can be incident at the guide-cover or guide-substrate interface so that it still remains confined to the guiding layer and can undergo total internal reflection. [2.5]
6. An optical fiber of core refractive index n_1 and cladding index n_2 is placed in a medium whose index is given by n. For this arrangement, obtain an expression for the maximum acceptance angle so that light launched from the facet of the optical fiber can undergo total internal reflection. [2.5]

End of exam.

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
DEPARTMENT OF AVIONICS

Satellite and Optical Communication (AV412)

B.Tech ECE (Avionics), **Quiz 2**

Total marks=15

Date: 20/10/23

Part-A Satellite Communication [5 marks]

1. Draw the convolutional encoder circuit for rate 1/3 code for the given generator polynomial and draw the state diagram [5 marks]
   G1(D)= D+D²
   G2(D)= 1+D
   G3(D)= 1+D+D²

Part-B Optical Communication [10 marks]

2. In which optical fiber do you have the intermodal dispersion absent? How can you design such a waveguide/optical fiber? Explain. [3 marks]
3. A student was asked to plot the modes of a planar waveguide whose core index is n_g and cladding index is n. While doing so, the student calculated the value of κ [kappa] and β [beta], and both of them were imaginary. Explain whether the propagation constant which the student obtained will result in a guided mode in the given waveguide. [Rather than a mere YES or NO, explain your argument clearly.] [3 marks]
4. An optical source has a spectral linewidth of $\Delta\lambda_0$ and a free space wavelength of λ_0. The output of this source is made to propagate through a dispersive medium of length L leading to temporal broadening of the pulse. Obtain an expression for this broadening. How can you minimize this broadening? [4 marks]

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY
THIRUVANANTHAPURAM, 695 547
B.Tech End Semester Exam – December 2023

AV 412 – Satellite and Optical Communication

Time: 3 hour Date: 1/12/2023 Max. Marks: 100

Note: Write Part A and Part B in a separate sheet

PART - A - Satellite Communication

Answer the following

1. A receiver front end (RF front end) has a noise figure of 10 dB, a gain of 80 dB, and a bandwidth of 6 MHz. The input signal power is 10^{-11}W. Assume that the line is lossless and the antenna temperature is 150 K.
   (i) Find system noise temperature and (C/N) [4]
   (ii) If a preamplifier is used before the receiver front end with a noise figure of 3 dB, a gain of 13 dB. Find the improvement in (C/N) [2]
   (iii) If a coaxial feeder is connected between the preamplifier and receiver front end and has a loss of 2 dB, calculate the system noise temperature [2]
   (iv) If a feeder cable is connected between the antenna and the preamplifier, calculate the system noise temperature and Comment on the result. [2]
2. (i) What is the advantage and disadvantage, if communication satellites are placed in LEO and GEO orbit? [3]
   (ii) Derive the overall C/N ratio for bent-pipe transponder. [3]
   (iii) The following parameters apply to a satellite downlink: EIRP 22.5 dBW, free-space loss 195dB, other losses 1.5 dB, earth station (G/T) 37.5 dB/K. Calculate the (C/N_o) at the earth station. Assuming an output Back off power of 6dB is applied, what is the new value of (C/N_o)? [4]
3. (i) Explain the different multiple access technique used in Satellite Communication. [3]
   (ii) Explain how rain attenuation affects the computation of the C/N ratio in the uplink and downlink scenarios. [3]
4. Consider a (127, 92) linear block code capable of triple error corrections.
   (i) What is the probability of message error for an uncoded block of 92 bits if the channel symbol error probability is 10^{-3}? [2]
   (ii) What is the probability of message error when using the (127, 92) block code if the channel symbol error probability of 10^{-3}? [2]
5. Consider a (7, 4) code whose generator matrix is

$$G = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

(a) Find any two codewords of the code. [2]

(b) Find H, the parity-check matrix of the code. [2]

(c) Compute the syndrome for the received vector 1 1 0 1 1 0 1. Is this a valid code vector? [4]

(d) What is the error-correcting capability of the code? [1]

(e) What is the error-detecting capability of the code? [1]

6. A convolutional code is described by $g_1 = [110]$ $g_2 = [101]$ $g_3 = [111]$. Find the transfer function and free distance for this code. [10]

PART - B - Optical Communication

Answer the following

1. For a light ray that undergoes total internal reflection at the interface between two planar mediums of refractive index n_1 and n_2 ($n_1 > n_2$), find out an expression for the depth of penetration of the light ray into the rarer medium as well as the lateral shift of the reflected ray. Using this information, draw the ray picture and the wave picture for the first higher order mode that propagates inside a multimode step index fiber. [5]

2. In two or three sentences, explain why in reality, two level laser systems are impossible to make. [4]

3. A semiconductor heterojunction laser is made of p-$Al_{0.3}Ga_{0.7}As$/GaAs/n-$Al_{0.3}Ga_{0.7}As$. The active region is GaAs. The bandgap of $Al_xGa_{1-x}As$ in eV can be expressed as $1.424+1.266x+0.26x^2$ where x is the aluminium composition, and $x<0.45$ for direct bandgap.

   (i) Calculate the minimum voltage required to turn on this laser diode. [1 Marks]

   (ii) If the GaAs active region is replaced with $Al_xGa_{1-x}As$ having an Aluminium concentration of 0.1, calculate the minimum turn on voltage and the emission wavelength. [1]

   (iii) Qualitatively plot the Current vs Output light power for the laser in problem (a) and (b) in the same plot and explain the reason for their difference. [3]

   (iv) With reference to problem (ii), what happens to optical field confinement and carrier confinement when we increase the Aluminium concentration of the active region? Explain your reason. [3]

   (v) If the Aluminium concentration of the active region is made as 0.5 in problem (ii), will the diode function as a 1) laser and 2) as an optical waveguide? Explain. [4]

4. A fibre optic communication link has to be laid between Trivandrum and Cochin with the following parameters. (i) Source power = 0 dBm (ii) Detector sensitivity = -45 dBm (iii) Connector loss = 1 dB/connector (iv) Splice loss = 0.06 dB/Splice. Assume that the distance between the two cities is 200km and is spanned by connecting two-hundred 1000 m cables of attenuation coefficient 0.15 dB/km. If a system margin of 5 dB is required, determine whether or not an amplification of the optical signals is required in the link. If yes, determine the required minimum amount of amplification in dB. Assume that the fibre cables are connected to the source, detector and amplifier using connectors and individual fibre cables are connected through splicing. [5]

5. Define quantum efficiency and responsivity for a photodiode. Qualitatively draw the responsivity vs operating wavelength for a photodiode made of GaAs and $Al_{0.7}Ga_{0.3}As$ and explain your drawing. Indicate the respective cut-off wavelengths in the figure. [8]

6. A laser diode made of InP has a bandgap of 0.8eV and is directly modulated at 1Gbps. Qualitatively draw the light output vs wavelength assuming that the linewidth of this laser is 0. The laser is now directly modulated at 15Gbps. Redraw the light output vs wavelength in this case. Again, assume a 0 linewidth. Explain why the figures you have drawn are different. [6]

7. A laser based on $Al_{0.3}Ga_{0.7}As/GaAs$ quantum-well with GaAs as the inversion region has to be designed for a WDM system. Calculate the emission wavelength λ_1 for this laser if the width of the quantum-well is 5nm assuming ground state transitions. Assume that the electron and the hole effective masses are $0.066m_0$ and $0.45m_0$, respectively where m_0 is the rest mass of the electron. How will you design a second laser emitting at λ_2 where its emission wavelength is red-shifted by 0.8 nm from λ_1? Which wavelength among these would you select if you want to minimize waveguide dispersion? Explain in one sentence. Which wavelength would you select if you want to minimize Rayleigh scattering loss? Explain in one sentence. [10] [Hint: particle energy=$E_n = \frac{n^2h^2}{8md^2}$ where m is the mass of the particle, n is the level number and d is the width of the well.]

End of exam.