**Written Comprehensive (Closed-book) Examination for**
Mr. Alinjar Dan (2018MEZ8288)
Sept. 30, 2019 (Monday)

**Total Duration: 3 hours** (9:30-12:30 hrs) **Total Marks: 100**

[Write answers in two different answer books]

Time: 90 mins Part I (By S.K. Saha) Marks 50

1. Answer the following:
   (a) What is dexterity of a manipulator? How it is related to the condition of a matrix?
   (b) Briefly explain the steps of QR decomposition. Where is it used?
   (c) Define poles and zeros of a dynamical systems. How are they useful?
   (d) What is factor of safety in mechanical design of a component? In case of fatigue failure what is the basis for designing a component?

   [4×3=12]

2. a) Find the rank of the matrix shown below; b) Find its LU decomposition.

$$\begin{bmatrix} 9 & 2 & 3 & 12 \\ 9 & 0 & 5 & 12 \\ 0 & 1 & -4 & 0 \end{bmatrix}$$

   (c) Find the solution of 2[nd] order differential equation numerically for the values of $x = 1$.
   $2y'' - 3y' + 5y = 0$ with initial conditions $y(0) = 2, y'(0) = 3$
   Choose appropriate method and step sizes.

   [5+10+8=23]

3. Derive the DeNOC-based equations of motion of a 2-link Revolute-Prismatic spatial robotic arm. Assume all parameters. [15]

**[For Part IIA questions by Prof. K. Rama Krishna please see additional pages]**

Take home Examination [Report Submission Deadline: Oct. 3, 2019, Wednesday, 10am]
By S.K. Saha

Marks: 50

Write your own programmes using MATLAB to generate numerical results for the questions in 2 and 3 above. Choose a suitable trajectory the joints in question 3. Write a hand-written reports separately for S.K. Saha and K. Rama Kirshna with printout of the plots. Justify all assumptions. Verify the results of question 3 using ReDySim software.

**[For Prof. K. Rama Krishna please see additional pages]**

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Venue: ***** | Odd Semester 2019-2020 | 30 September 2019

Department of Mechanical Engineering
Indian Institute of Technology Delhi
2018MEZ8288: Alinjar Dan

Time: 90 minutes | Comprehensive Examination - Part II | Maximum Marks: 50

**Instructions**

*Assume appropriately any missing data*

## Section A

1. Reason out why there are 24 sets of Euler angles. Sketch $ZYZ$ body-fixed representation [05]

2. A rigid body is first rotated about the body-attached $w$-axis by 30° and then about the rotated $v$-axis by 45°. Find the resulting orientation matrix. [05]

3. Consider a vector ${}^F\mathbf{p}_1$ rotated about ${}^F\hat{\mathbf{e}}$ by an angle $\alpha$ to form the vector ${}^F\mathbf{p}_2$.
   (a) Show that ${}^F\mathbf{p}_2 = {}^F\mathbf{p}_1 \cos\alpha + ({}^F\hat{\mathbf{e}} \times {}^F\mathbf{p}_1)\sin\alpha + ({}^F\hat{\mathbf{e}} \cdot {}^F\mathbf{p}_1)(1-\cos\alpha){}^F\hat{\mathbf{e}}$. [05]
   (b) Use the above result to derive the matrix form of Rodrigues' formula:
   $[Q] = [I] + [E]\sin\alpha + [E]^2(1-\cos\alpha)$ [03]

4. For the 3RRR manipulator shown in Fig. 1, write the sufficient constraint equations to solve for the direct kinematics of the platform for a given input angles $\theta_1$, $\theta_2$, and $\theta_3$. [10]

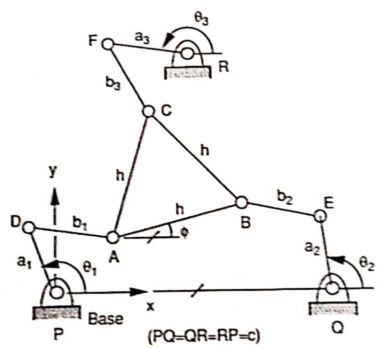


Fig. 1: 3RRR Manipulator

5. A particle of mass $m$ can slide down on a smooth rigid wire having the form $x^2 + y^2 = a^2$, where gravity acts in the direction of negative $y$ axis. Using Lagrange's equations of motion of the second-kind, derive the equations of motion and also solve for the constraint forces. [10]

6. Explain the advantage of forward control taking an example of 1R manipulator [02]

## Section B

4. Explain briefly why RK4 with adaptive step size requires more computations than RK45. [02]
5. Is the kinematic constraint between two gears holonomic or nonholonomic? Give reasons. [02]
6. What do you understand by stability of a numerical solution? [02]
7. Comment on the eigen values of a proper orthogonal matrix of even order [02]
8. Why do you understand by the statement: "DAE systems are stiff to solve" ? [02]

## Take Home Simulation [50]

Consider a $4R$ four-bar crank rocker mechanism in a vertical plane under gravity. Choose some appropriate link lengths and mass per unit length. Assume the center of gravity of each binary link lies at the mid point of the line joining the two eyes of the link. Write the constraint equations while breaking the closed loop at the motion transfer point on the rocker. Simulate the dynamics of the mechanism under gravity load. Plot all the relevant variables including lagrange multiplers and constraint forces varying with time. Comment on the plots when the rocker dwells instantaneously up to first-order kinematics.