**Mechanism and Robot Kinematics Online Test -2 (Spring Semester 2021). Time = 1 Hour**

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*Answer all questions. Be very brief. Please answer in this paper itself and submit online. If you prefer to make any drawing – make it on a separate paper, take a picture and insert it in the response. Insert appropriate lines in between questions / sub questions as needed – without disturbing the numbering.*

1. The Jacobian is used to describe important characteristics of robot kinematics – (5x2 marks)
   1. What are the rows and columns in Jacobian used in Kinematics of Robots?

Columns of the Jacobian matrix are associated with joints of the robot. Each column in the Jacobian matrix represents the effect on end-effector velocities due to variation in each joint velocity. Hence the number of columns in the Jacobian matrix is equal to the number of joints in the manipulator.  
  
rows of the Jacobian matrix can also be split into two part. The first three rows are associated with linear velocities of end-effector and the last three rows are associated with the angular velocities of end-effector due to change in velocities of all the joints combined.

* 1. In which situations are the rows and columns of a Jacobian unequal.  
       
     When the number of points in cartesian plane is not equal to number of joints in manipulator. In presence of external variables like control value, the traditional nxn square matrix gets an additional row of function derivative with respect to this control variable thereby making the rows and column of jacobian unequal
  2. How does one take an inverse of a non-square Jacobian?  
       
     In general, no. If A is a non-square mxn matrix, you have two cases:

1) If m<n, then the inverse image of y\in R^m usually exists but it is not unique. Therefore, the invese mapping of x \mapsto Ax does not exist (except as a set function).

2) If m>n, then the image set of R^n in the mapping x \mapsto Ax is a proper subspace of R^m, and if you pick a point from the orthogonal complement of this subspace, you can't find the inverse image.

* 1. What is the physical significance of the Jacobian having its determinant being null?  
       
     If the Jacobian is zero, it means that there is no change whatsoever, and this means you get an overall change of zero at that point (with respect to the rate of change with respect to the expansion and contraction with respect to the entire volume)
  2. What is the physical significance of the Jacobian losing its rank?  
       
     A configuration is singular if the manipulator Jacobian loses rank at that configuration. Examples for a general six degree of freedom arm include:

(a) Two collinear revolute joints

(b) Three parallel, coplanar revolute joint axes

(c) Four intersecting revolute joint axes

1. Why does one get multiple solutions in the Paden Kahan sub-problems to solve inverse kinematics? Explain their significance geometrically. (5 + 5 Marks)

The inverse kinematics solution in Denavit–Hartenberg convention is implicit. Instead, explicit solutions to inverse kinematics using the Paden–Kahan subproblems could be expressed which makes it applicable for multiple movement configurations. The extended subproblem is used to solve inverse kinematics of a manipulator that cannot be solved using only three basic Paden–Kahan subproblems

The inverse kinematic analysis is quite complex, due to its non-linear formulations and having multiple solutions. There is no unique solution for the inverse kinematics

Paden–Kahan subproblems are a set of solved geometric problems which occur frequently in inverse kinematics of common robotic manipulators. Although the set of problems is not exhaustive, it may be used to simplify inverse kinematic analysis for many industrial robots.

For certain arms, inverse kinematics solution may be found through the solution of a series of subproblems. Typically, arms containing a spherical joint (i.e. 3 consecutive rotational joints with rotational axes intersecting at a point) can be solved this way.

1. Write the Chebychev–Grübler–Kutzbach criterion (popularly known as Grubler criterion/ Kutzbach criterion) for a planar and a spatial mechanism and apply the same for the two mechanisms shown below derive the net degrees of freedom. (2x 5 marks)

|  |  |
| --- | --- |
|  |  |
| **(a)** Stewart Gough Platform with spherical and prismatic joints. | **(b)** Planar Mechanism used in an excavator with revolute and prismatic pairs) |

The Chebychev–Grübler–Kutzbach criterion determines the number of degrees of freedom of a kinematic chain, that is, a coupling of rigid bodies by means of mechanical constraints.

According to Kurtzbach criteria





For planar motion:

DOF = 6 - no of constraints = 3(l-1) -2j -h

l = no of links

j = no of joints

h= no of higher pairs

for (a): j=18, h=0, l=14, h=0

DOF = 3(14-1)-2\*18-0

DOF = 39-36

DOF = 3

3 Degrees of freedom

for (b): j = 14, h=0, l = 12

DOF = 3(12-1)-2\*14-0

DOF = 33-28

DOF = 5

5 degrees of freedom



1. What are the differences between Holonomic and Non-Holonomic constraints while solving robotic problems? Identify if a two wheeled robot (with front wheel steering) and real wheel drive has is holonomic or non-holonomic constraints. Justify your answer. (5+5 Marks)  
     
   A holonomic constraint is a constraint on configuration:  
   • It says there are places you cannot go. That is a reduction in freedoms.  
   • Holonomic system are systems for which all constraints are integrable into positional constraints.

A nonholonomic constraint is a constraint on velocity:

• There are directions you cannot go. But you can still get wherever you want.

• Nonholonomic systems are systems which have constraints that are nonintegrable into positional constraints.

A two wheeled robot (with front wheel steering) and real wheel drive has non-holonomic constraints as robot can move in some directions (forwards and backwards), but not others (side to side). This is most easily seen in wheeled robots.

1. Write in a short bulleted response: ( 2 Marks each)
   1. Difference in the joint reference description in a Standard Denavit-Hartenberg and Modified Denavit-Hartenberg representation of a kinematic chain.  
        
      The Denavit-Hartenberg method standard assign coordinates systems to the link i over the axis line that join the link and the articulation i+1, while the modified method assigns coordinates systems to the joint i over the line that join the articulation with the link i+1.  
        
      In standard Denavit-Hartenberg representation, the frame is fixed at the proximal end of the link.
   2. In modified Denavit-Hartenberg representation, the frame is fixed at the distal end of the link.
   3. What are the key differences in the kinematics modelling of a parallel (or closed chain) manipulator as compared to a serial (or open chain) manipulator?   
        
      Parallel manipulators are robotic devices that differ from the more traditional serial robotic manipulators by their kinematic structure. Parallel manipulators are composed of multiple closed kinematic loops. Typically, these kinematic loops are formed by two or more kinematic chains that connect a moving platform to a base, where one joint in the chain is actuated and the other joints are passive. This kinematic structure allows parallel manipulators to be driven by actuators positioned on or near the base of the manipulator. In contrast, serial manipulators do not have closed kinematic loops and are usually actuated at each joint along the serial linkage. Accordingly, the actuators that are located at each joint along the serial linkage can account for a significant portion of the loading experienced by the manipulator, whereas the links of a parallel manipulator generally need not carry the load of the actuators. This allows the parallel manipulator links to be made lighter than the links of an analogous serial manipulator.
   4. Enlist the different contact conditions under which grasping criteria are defined.

1. A point contact with friction model

2. A frictionless point contact

* 1. What is the relation between the Velocity Jacobian and the Force Jacobian?   
       
     Velocitiy and Force Jacobians are transpose of each other  
     Jv =( JF )T



* 1. List the different methods of inverse Kinematics of serial chain robots.