Foundations of Robotics Final Exam

- Link to recorded session here: https://nyu.zoom.us/rec/share/DXDc0tmOJfV7HuICloeUNDg61tt1_yeXFTF3Ge_oVV7T2UPRzC3BapkK15wmzy3h.u-CGsU7Z0ADa5GkY
- Final exam is **not** cumulative.
- Covers Chapters 5 and 6 only.
    - You will still need to remember the DH method:
        - How to assign DH frames
        - How to create DH table and DH transformation matrices (required for Jacobian!)

Chapter 5: Major Topics to Study

- Two frames: observer vs. writer frame
- General planar motion (linear and angular velocity)
- Angular velocity matrix (remember difference between angular velocity vector and Euler angle rates)
- Jacobian:
  - Analytical Jacobian
  - Geometric Jacobian
  - Determinant of Jacobian (meaning of singularity)
  - Kineto-static duality (note the sign)

Chapter 5: Major Topics to Study

- The final exam will include a problem to compute the Jacobian for a given robot like we did the exam review session today

Chapter 5: Excluded Topics

- Topics that are **not** covered in the exam:
  - E matrix for converting between angular velocity vector and Euler angle rates

$$\mathbf{\Omega} = E_{Z'Y'Z'}(\mathbf{\Theta}_{Z'Y'Z'})\dot{\mathbf{\Theta}}_{Z'Y'Z'}$$

  - Iterative equations for linear and angular velocity such as:

$$^{i+1}\omega_{i+1} = {}^{i+1}R_i({}^i\omega_i + \dot{\theta}_{i+1}\, {}^i\hat{Z}_i) \qquad {}^{i+1}\upsilon_{i+1} = {}^{i+1}R_i({}^i\upsilon_i + {}^i\omega_{i+1} \times {}^iP_{i+1})$$

  - Or these equations: $\boxed{\omega_n = \sum_{i=1}^{n} \dot{\theta}_i \hat{Z}_{i-1}}$ $\boxed{\upsilon_n = \sum_{i=1}^{n} [\dot{\theta}_i \hat{Z}_{i-1} \times (P_n - P_{i-1}) + \dot{d}_i \hat{Z}_{i-1}]}$

  - Pseudo-inverse

Chapter 5: Excluded Topics (continued)

- Topics that are **not** covered in the exam:
  - Velocity transformations such as:

$$\begin{bmatrix} {}^{B}\mathbf{v}_{B} \\ {}^{B}\boldsymbol{\omega}_{B} \end{bmatrix} = \left[\begin{array}{c:c} {}^{B}R_{A} & -{}^{B}R_{A}\,{}^{A}P_{BORG}\times \\ \hdashline 0 & {}^{B}R_{A} \end{array}\right] \begin{bmatrix} {}^{A}\mathbf{v}_{A} \\ {}^{A}\boldsymbol{\omega}_{A} \end{bmatrix}$$

  - Or Force-moment transformations

$$\begin{bmatrix} {}^{A}f_{A} \\ {}^{A}n_{A} \end{bmatrix} = \left[\begin{array}{c:c} {}^{A}R_{B} & 0 \\ \hdashline -({}^{A}P_{\mathrm{joint}A}\times)\cdot\,{}^{A}R_{B} & {}^{A}R_{B} \end{array}\right] \begin{bmatrix} {}^{B}f_{B} \\ {}^{B}n_{B} \end{bmatrix}$$

Chapter 6: Major Topics to Study

- Basic vector kinematics for acceleration (without Newton-Euler)

$$ {}^{A}\dot{\mathbf{V}}_{Q} = {}^{A}\dot{\mathbf{V}}_{BORG} + {}^{A}R_{B}\,{}^{B}\dot{\mathbf{V}}_{Q} + 2\,{}^{A}\mathbf{\Omega}_{B} \times {}^{A}R_{B}\,{}^{B}\mathbf{V}_{Q} + {}^{A}\dot{\mathbf{\Omega}}_{B} \times {}^{A}R_{B}\,{}^{B}\mathbf{Q} + {}^{A}\mathbf{\Omega}_{B} \times ({}^{A}\mathbf{\Omega}_{B} \times {}^{A}R_{B}\,{}^{B}\mathbf{Q}) $$

  - Coriolis acceleration (when does $2\,{}^{A}\mathbf{\Omega}_{B} \times {}^{A}R_{B}\,{}^{B}\mathbf{V}_{Q}$ appear?)
  - Be careful with what are frames A and B

- Be aware that these two equations exist and what these terms are: (could possibly helpful to check your dynamics solutions)

$$ \sum f = F = m\dot{v}_{C} \qquad \sum n = N = {}^{C}I\dot{\omega} + \omega \times {}^{C}I\omega $$

- Lagrangian Dynamics

Chapter 6: Major Topics to Study

- There will be an exam problem asking you to solve for the linear/angular acceleration of a system.
- There will be an exam problem where you derive the equations of motion for a robot/mechanism with Lagrangian dynamics

Chapter 6: Excluded Topics

- Topics that are **not** covered in the exam:
  - Moment of Inertia tensor theory (you will only be expected to know the minimum that is needed to derive the equations of motion through Lagrangian dynamics)
  - Newton-Euler method
  - General closed form dynamics

$$\boldsymbol{\tau} = M(\mathbf{q})\ddot{\mathbf{q}} + \mathbf{V}(\mathbf{q},\dot{\mathbf{q}}) + \mathbf{G}(\mathbf{q}) - \sum_k J_k^T \begin{bmatrix} {}^0\mathbf{f}_k^{ext} \\ {}^0\mathbf{n}_k^{ext} \end{bmatrix} + \mathbf{F}(\mathbf{q},\dot{\mathbf{q}})$$

  - Dynamic simulation