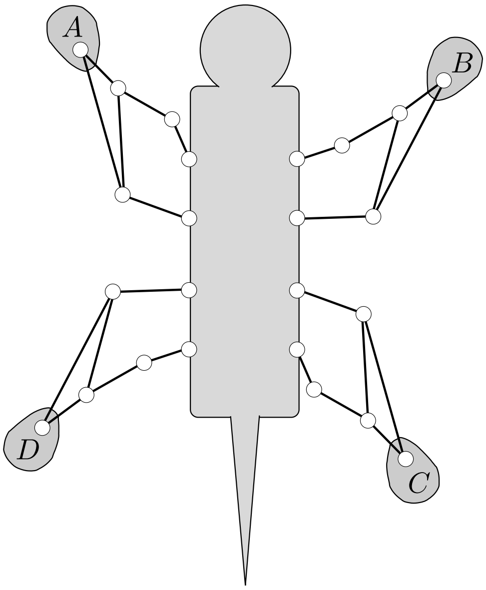
Final Exam

June 11th, 2012

Test questions (10/20 points)

Mark the correct answer in the attached answer sheet. Each question has only one correct answer. Failed answers do not substract points.

1. **(1 point)** The robot shown in the figure is climbing a wall. At the instant depicted in the figure, points A, B, C, and D maintain their position fixed at the wall. Which is the minimum number of joint angles that have to be blocked to maintain this configuration fixed?

Stickybot_III_Stanford

(a) 0 (b) 3 (c) 12 (d) 24 (e) 27

2. **(1 point)** Consider a 3RPR parallel robot. If j is the Jacobian which transforms joint forces $\vec{\lambda}$ into wrenches $\hat{w}$ on the end effector, which one of the following statements is true when the robot goes from a singular to a non-singular configuration:

   (a) Dim(Ker j) increases, Dim(Im j) decreases, Dim(Ker $j^\top$) increases, Dim (Im $j^\top$) decreases.

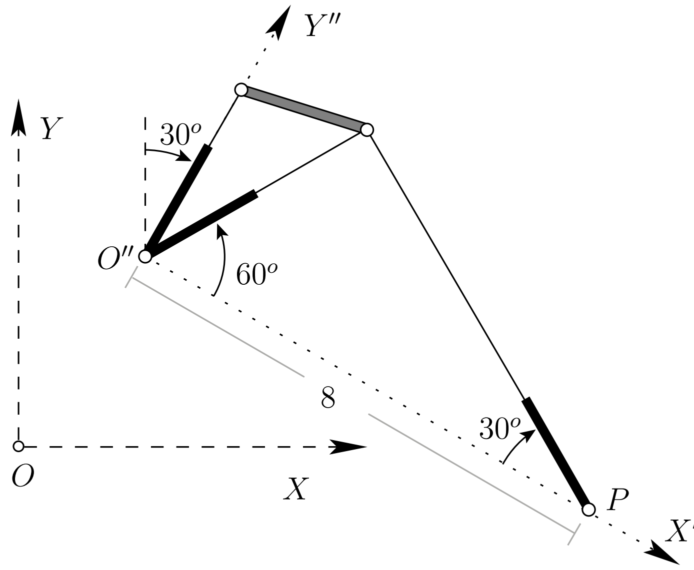
   (b) Dim(Ker j) decreases, Dim(Im j) increases, Dim(Ker $j^\top$) decreases, Dim (Im $j^\top$) increases.

   (c) Dim(Ker j) increases, Dim(Im j) increases, Dim(Ker $j^\top$) decreases, Dim (Im $j^\top$) decreases.

   (d) Dim(Ker j) decreases, Dim(Im j) decreases, Dim(Ker $j^\top$) increases, Dim (Im $j^\top$) increases.

   (e) All four spaces Ker j, Im j, Ker $j^\top$, and Im $j^\top$ decrease their dimension.

3. **(1 point)** Consider the following 3-RPR planar mechanism, wheres points O'' and P are fixed on the ground, and the coordinates of point O'' expressed in the OXY reference frame are $O'' = (2, 3)$. The figure is drawn to scale.



If j and j'' stand for the static Jacobian of the manipulator in references OXY and $O''X''Y''$, respectively, mark the correct statement:

(a)
$$j = \begin{bmatrix} \frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{-1}{2} \\ \frac{\sqrt{3}}{2} & \frac{1}{2} & \frac{\sqrt{3}}{2} \\ 0 & 0 & 4 \end{bmatrix}, \quad j'' = \begin{bmatrix} 0 & \frac{1}{2} & \frac{-\sqrt{3}}{2} \\ 1 & \frac{\sqrt{3}}{2} & \frac{1}{2} \\ 0 & 0 & 1 \end{bmatrix}.$$

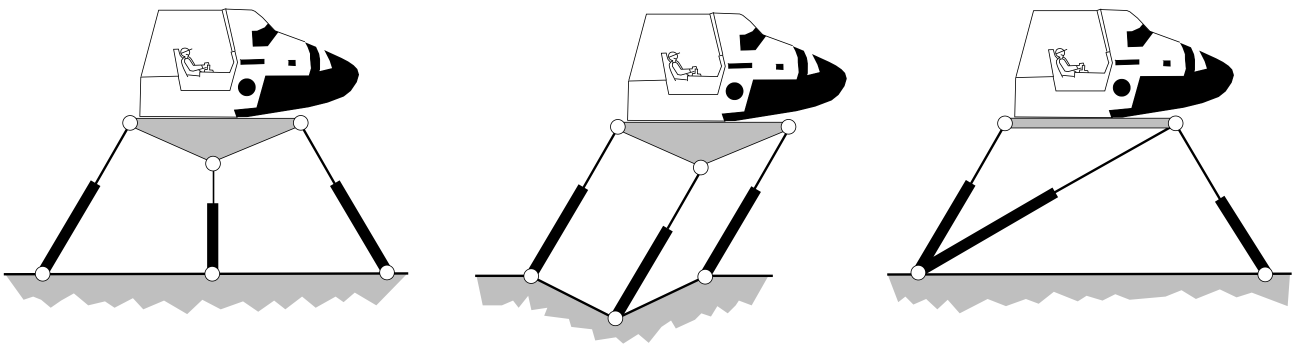
(b)
$$j = \begin{bmatrix} \frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{-1}{2} \\ \frac{\sqrt{3}}{2} & \frac{1}{2} & \frac{\sqrt{3}}{2} \\ \sqrt{3} - \frac{3}{2} & 1 - \frac{3\sqrt{3}}{2} & \sqrt{3} + \frac{11}{2} \end{bmatrix}, \quad j'' = \begin{bmatrix} 0 & \frac{1}{2} & \frac{-\sqrt{3}}{2} \\ 1 & \frac{\sqrt{3}}{2} & \frac{1}{2} \\ 0 & 0 & 4 \end{bmatrix}.$$

(c)
$$j = \begin{bmatrix} \frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{-1}{2} \\ \frac{\sqrt{3}}{2} & \frac{1}{2} & \frac{\sqrt{3}}{2} \\ 0 & 0 & \sqrt{3} + \frac{11}{2} \end{bmatrix}, \quad j'' = \begin{bmatrix} 0 & \frac{1}{2} & \frac{-\sqrt{3}}{2} \\ 1 & \frac{\sqrt{3}}{2} & \frac{1}{2} \\ 0 & 0 & 4 \end{bmatrix}.$$

(d)
$$j = \begin{bmatrix} \frac{1}{2} & \frac{\sqrt{3}}{2} & \frac{-1}{2} \\ \frac{\sqrt{3}}{2} & \frac{1}{2} & \frac{\sqrt{3}}{2} \\ 2 - 3 & 2 + 3 & \sqrt{3} + \frac{11}{2} \end{bmatrix}, \quad j'' = \begin{bmatrix} 0 & \frac{1}{2} & \frac{-\sqrt{3}}{2} \\ 1 & \frac{\sqrt{3}}{2} & \frac{1}{2} \\ 0 & 0 & 1 \end{bmatrix}.$$

(e)
$$j = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -3 & 2 & 1 \end{bmatrix}, \quad j'' = \begin{bmatrix} \frac{\sqrt{3}}{2} & \frac{-1}{2} & 0 \\ \frac{1}{2} & \frac{\sqrt{3}}{2} & 0 \\ 0 & 0 & 1 \end{bmatrix}.$$

4. **(1 point)** We want to build up a simplified flight simulator using the 3RPR plataform, and operating only the joints P. Three designs with the following configurations are considered, and the simulator will work close to them.



(A) (B) (C)

Mark the correct statement:

(a) From all three designs, the ideal one is B, as in the shown configuration the platform presents no non-controllable twists, while gaining a degree of freedom that allows to simulate more complex flights.

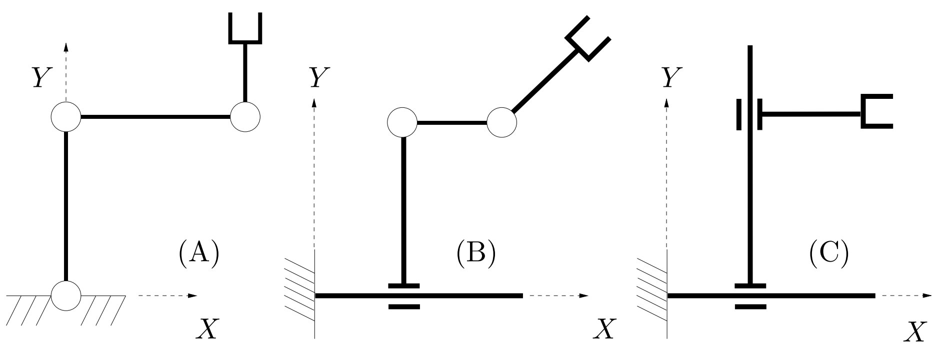
(b) From all three designs, the ideal one is A, as in the shown configuration, and also close to it, all the twists of the platform will be controllable.

(c) From all three designs, the ideal one is C, as in the shown configuration, and also close to it, the legs can equilibrate any externally applied wrench, in particular the one related to the weight of the cockpit plus the forces of inertia.

(d) In configuration A the kernel of Jacobian j has dimension 0.

(e) In configuration C the rank of Jacobian j is 2.

5. **(1 point)** Consider the three serial robots in the figure:



Mark the correct answer:

(a) The instant center of rotation of the end effector of robot A can never lie at infinity.

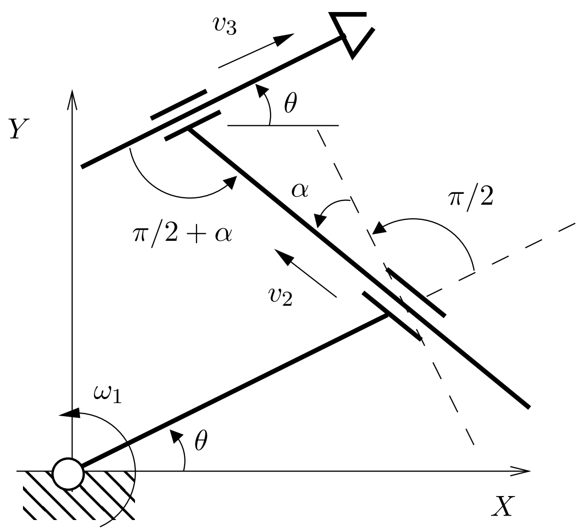
(b) The instant center of rotation of the end effector of robot B has to lie necessarily at infinity, in direction of axis Y.

(c) The instant center of rotation of the end effector of robot C lies at infinity, always in direction of axis X or in direction of axis Y.

(d) The instant center of rotation of the end effector of robot C lies always at infinity, but it can be in any direction.

(e) If we block the two last joints of robot A, the instant center of rotation of the end effector may lie on any point of the plane.

6. **(1 point)** Consider the serial robot of the figure, where α is a building parameter (it is not a variable):



Mark the incorrect answer:

(a) With the sign criterium given by the joint velocities, $det(J) = -\cos\alpha$.

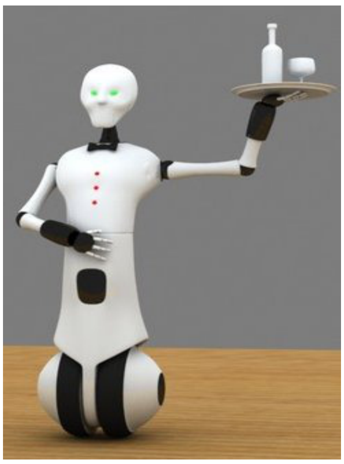
(b) For $\alpha \notin \{\pi/2, 3\pi/2\}$ the manipulator never can be in a singular configuration.

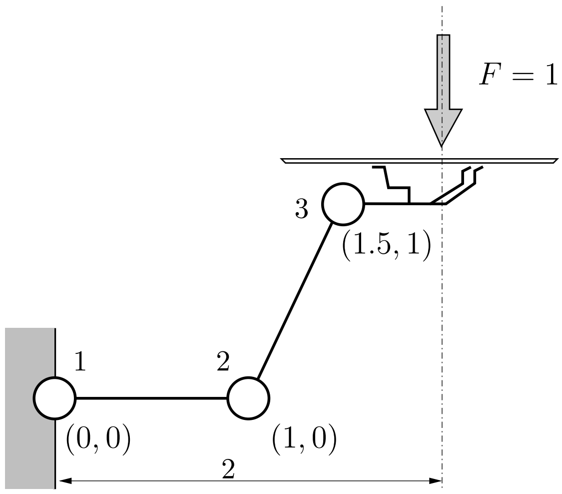
(c) For $\alpha = \pi/4$ and $\theta = 0$, there appear internal velocities in the manipulator.

(d) For $\alpha = 0$, any twist at the end effector can be achieved, regardless of angle θ.

(e) Be $\alpha = 0$, the joint velocities $\omega_1 = 0$, $v_2 = -v \cdot \sin\theta$, and $v_3 = v \cdot \cos\theta$ achieve a twist at the end efector which is purely linear, in direction of axis X.

7. **(1 point)** Let's define τ_i as the equilibrant joint torqueat joint i which each one of the arm actuators has to apply in the waiter robot of the figure, in the schematically shown configuration, to hold the indicated load (SI units):





Mark the correct answer:

(a) $\tau_1 = -2$, $\tau_2 = 4$, and $\tau_3 = -3$

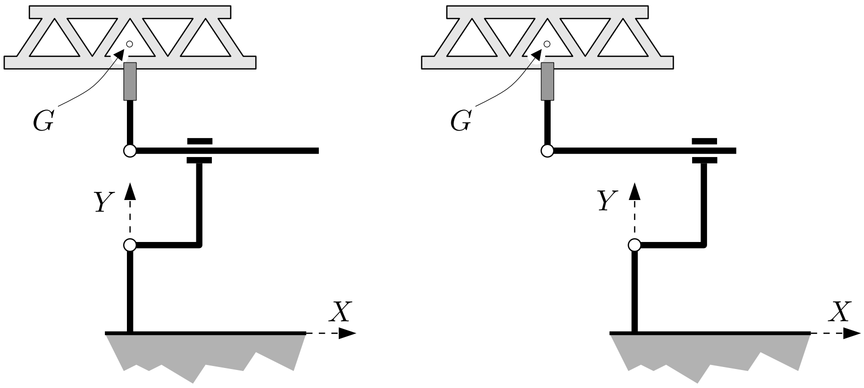
(b) $\tau_1 = 2$, $\tau_2 = -4$, and $\tau_3 = 3$

(c) $\tau_1 = 0$, $\tau_2 = -1$, and $\tau_3 = -1.5$

(d) $\tau_1 = -2$, $\tau_2 = -1$, and $\tau_3 = -0.5$

(e) $\tau_1 = 2$, $\tau_2 = 1$, and $\tau_3 = 0.5$

8. **(1 point)** An RPR arm is holding a little beam with its gripper. The center of mass of the beam lies in point G. In configuration A the two joints R lie on the same vertical line, while in B, one is displaced with respect to the other one:

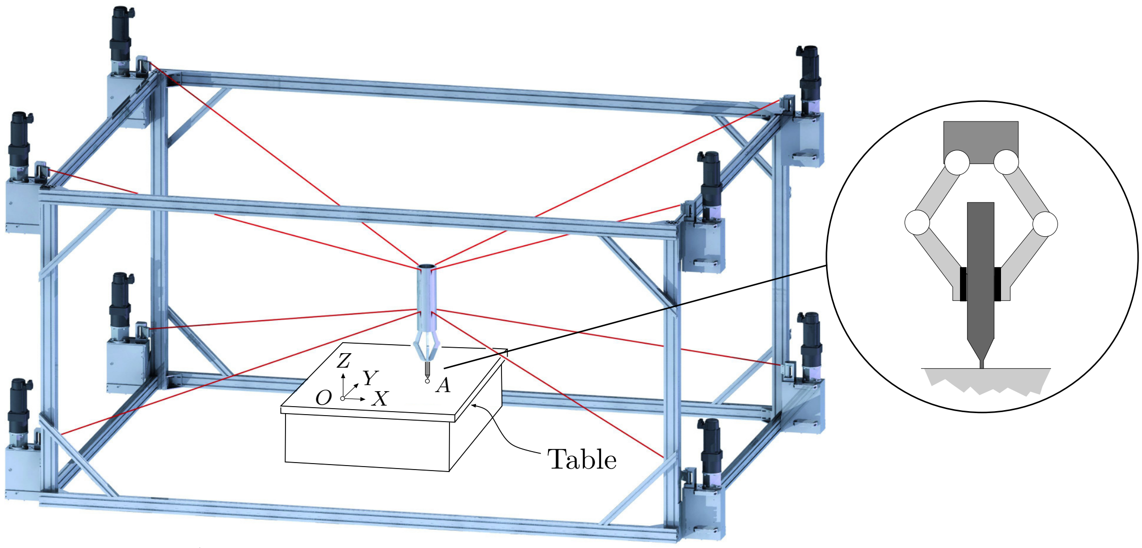


(A) (B)

Mark the incorrect statement with respect to these configurations:

(a) In A the arm lies in a singularity.
(b) In A the arm can support the weight of the beam without having to actuate any joint.
(c) In A the point G may displace with horizontal velocities, but no vertical ones.
(d) In B we have total dexterity, as the arm is able to move the beam under any twist.
(e) In B there are internal velocities of the arm that produce a null twist at the end effector.

9. **(1 point)** The figure shows a robotic gripper hold by eight cables, used in a "demo" to draw on a table with a marker.



Robot IPAnema of Fraunhofer Institute for Manufacturing

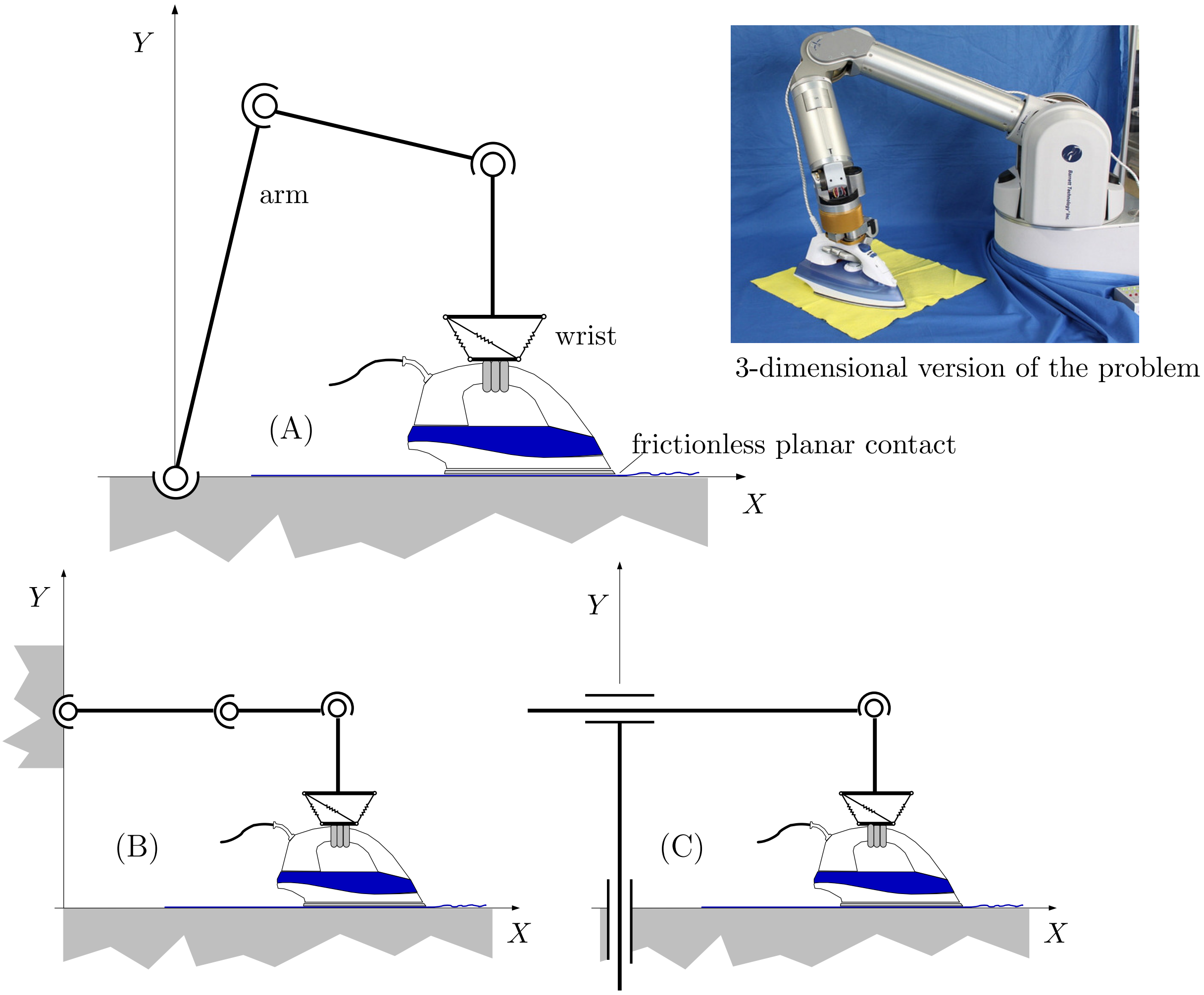
At the instant depicted in the figure the marker is in equilibrium, and having a point contact with the table at point A. Meassuring the tension at the cables, and using the Jacobian of the manipulator, one can find out that the wrench that the marker applies on the table is, in the reference frame $OXYZ$,

$$\hat{w} = [0, 0, -2, -6, 6, 0]^{\mathsf{T}} \quad \text{(SI units)}. \tag{1}$$

Assuming that the plane OXY coincides with the plane of the table, mark the incorrect statement:

(a) The coordinates of point A in the reference frame $OXYZ$ are $(3, 3, 0)$ m.
(b) The pitch of wrench $\hat{w}$ is $h = 0$.
(c) The gripper applies a force vector $[0, 0, -2]$ N on the table, plus a torque vector $[-6, 6, 0]$ Nm.
(d) The central axis of the wrench is a line aligned with axis Z, which passes through A.
(e) Reducing the wrench $\hat{w}$ to its central axis, we note that $\hat{w}$ encodes a pure force.

10. **(1 point)** Consider an ironing robot working on the plane XY as shown in the figure:



Mark the correct answer (the first three refer to the set shown in (A)):

(a) The instant center of rotation of the iron with respect to the ground lies at infinity, in the direction of axis X.

(b) In the reference frame OXY, the space of contact wrenches which makes sense to control is

$$\left\langle \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix} \right\rangle$$

(c) The arm-wrist set can only correct position errors of the iron.

(d) At the configuration of the 3R shown at (B) not all of the allowed displacement errors of the iron can be corrected.

(e) The arm shown at (C) does not allow to perform a hibrid force and position control on the iron.