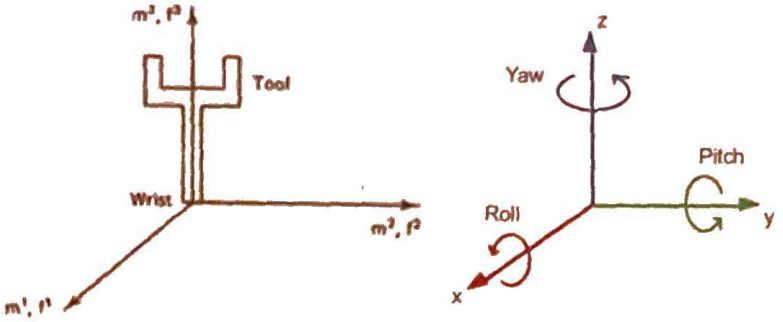
Robot Engineering - 20161

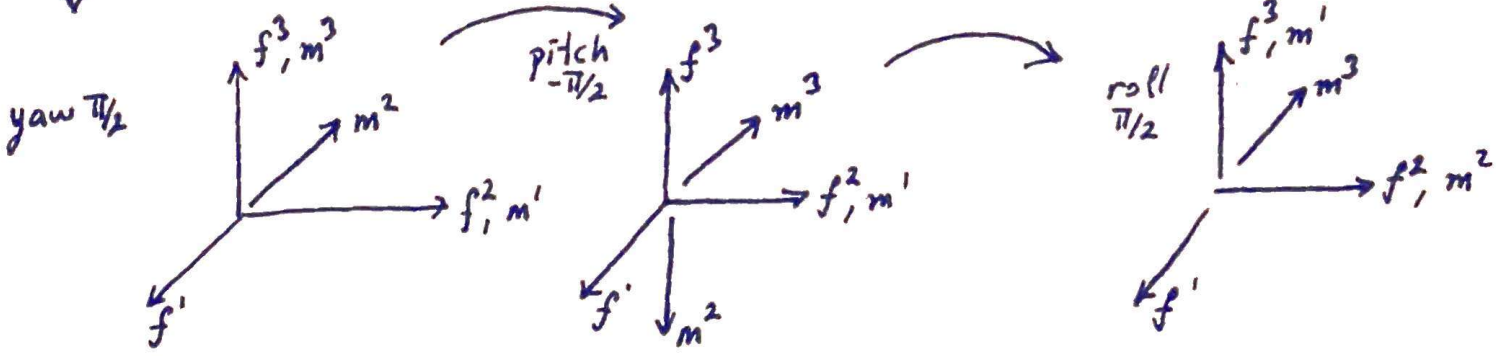
2nd Midterm

Name: **Last name:** **#:**

1. Consider the following robotic tool attached to a mobile coordinate frame, $M\{m^1,m^2,m^3\}$ in the picture. Sketch the tool position after each intermediate position of the following YPR operation with respect to fixed coordinate frame, $F\{f^1,f^2,f^3\}$: yaw $\pi/2$, pitch $-\pi/2$ and roll $\pi/2$ (5 points). Find corresponding composite rotation matrix. (5 points)



(Hareketli koordinat takımına bağlı şekilde robot uç işlemcisi verilmiştir. Hareketli koordinat takımı, sabit koordinat takımına göre sapma $\pi/2$, yunuslama $-\pi/2$ and dönme $\pi/2$ hareketlerini sırasıyla yaptığı takdirde eksen takımlarının birbirine göre konumunu her bir aşamada ve son aşamada gösteriniz ve bu harekete karşılık geldiği bileşik rotasyon matrisini bulunuz.)



$$R_{YPR} = R(x,\pi/2)\cdot R(y,-\pi/2)\cdot R(z,\pi/2)$$

$$R_{YPR} = \begin{bmatrix}1&0&0\\0&0&-1\\0&1&0\end{bmatrix}\begin{bmatrix}0&0&-1\\0&1&0\\+1&0&0\end{bmatrix}\begin{bmatrix}0&-1&0\\1&0&0\\0&0&1\end{bmatrix} = \begin{bmatrix}0&0&-1\\-1&0&0\\0&1&0\end{bmatrix}\begin{bmatrix}0&-1&0\\1&0&0\\0&0&1\end{bmatrix}$$

$$\boxed{R_{YPR} = \begin{bmatrix}0&0&-1\\0&+1&0\\1&0&0\end{bmatrix}}$$

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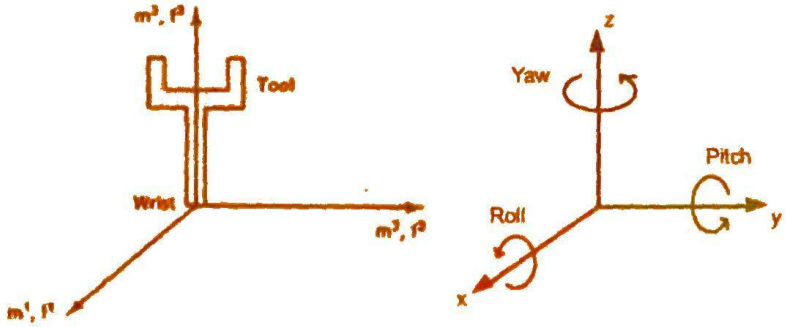
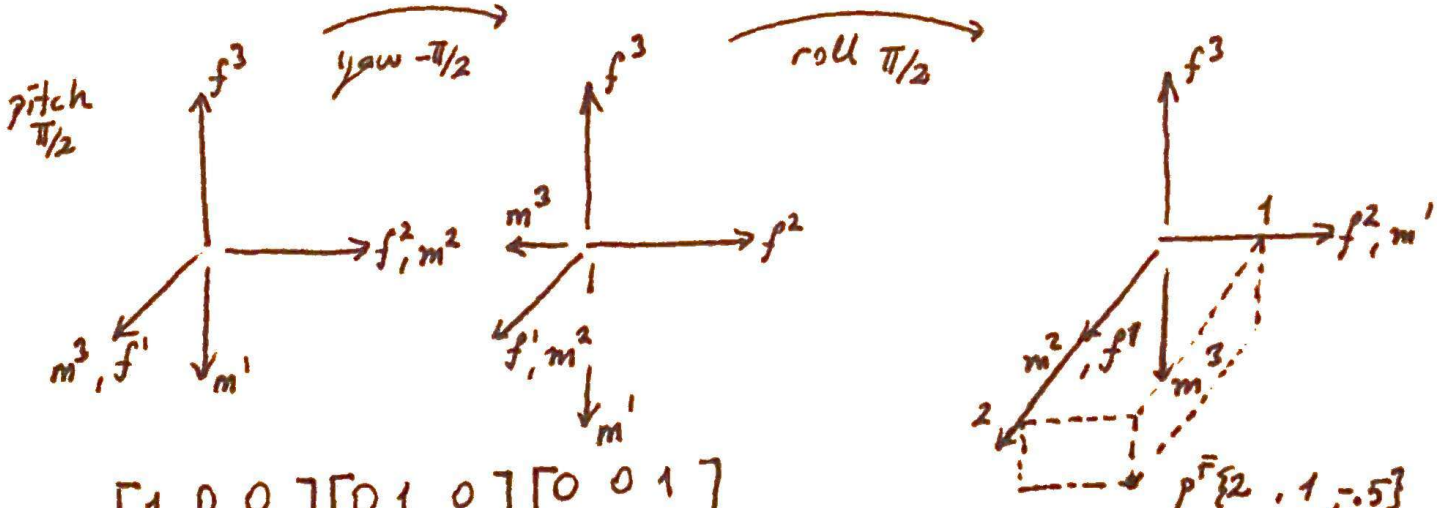
2. Consider the following mobile coordinate frame, $M\{m^1,m^2,m^3\}$ in the picture. Find $p^M\{1,2,0.5\}$ point position with respect to $F\{f^1,f^2,f^3\}$ after rotating mobile platform with respect to fixed coordinate frame by pitch $\pi/2$, yaw $-\pi/2$ and roll $\pi/2$ by sketching (5 points) and by rotation matrix (5 points)



(Şekildeki hareketli koordinat takımında tanımlı $p^M\{1,2,0.5\}$ noktasının konumunu, hareketli koordinat takımı sabit koordinat takımına göre sırasıyla yunuslama $\pi/2$, sapma $-\pi/2$ and dönme $\pi/2$ hareketlerini yaptıktan sonra çizerek ve rotasyon matrisi kullanarak bulunuz)



$p^F\{2, 1, -.5\}$

$$R_{PYR} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix}\begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & -1 \\ -1 & 0 & 0 \end{bmatrix}\begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix} \Rightarrow$$

$$p^F = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & -1 \end{bmatrix}\begin{bmatrix} 1 \\ 2 \\ 0.5 \end{bmatrix} = \begin{bmatrix} 2 \\ 1 \\ -0.5 \end{bmatrix}$$

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3. **For the given rotation matrix, EXPLAIN a. which axis of rotation this rotation matrix represents (5 points) and b. what is the meaning of last column? (5 points)**

$$R=\begin{bmatrix} C_1 & S_1 & 0 \\ S_1 & -C_1 & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

(Yukarıda verilmiş olan rotasyon matrisinde, hangi eksen etrafında dönüşü temsil ettiğini ve son kolonun anlamını açıklayınız.)

axis of rotation : z
m^3 is in the reverse direction of f^3

Please look at the seventh question base and elbow coordinate frames and corresponding rotation matrix!

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4. How much translation and rotation below homogenous transformation matrix is representing, (5 points). Which axis of rotation is it referring, (5 points)?

$$T_0^1 = \begin{bmatrix} 0.866 & -0.5 & 0 & 2 \\ 0.5 & 0.866 & 0 & 4 \\ 0 & 0 & 1 & 5.5 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(Yukarıda verilmiş olan homojen dönüşüm matrisinde, hangi eksen etrafında dönüş temsil ediliyor ve ne kadar dönme ve öteleme mevcut, açıklayınız.)

Translation : $\sqrt{2^2+4^2+5.5^2} = 7.08$

Rotation around z axis : $\begin{bmatrix} c\theta & -s\theta & 0 \\ s\theta & c\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.866 & -0.5 & 0 \\ 0.5 & 0.866 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

$\theta = 30^\circ$

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5. Translate mobile coordinate frame, *M*, along f^1 by 3 units and rotate *M* about f^2 by π. Find corresponding homogenous transformation matrix. (Hareketli koordinat takımının, f^1 boyunca 3 birim hareketi, ve f^2 etrafında pi kadar dönmesine karşılık gelen homojen dönüşüm matrisini bulunuz) (10 points)

$$T = \left[\begin{array}{ccc:c} -1 & 0 & 0 & 3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \hdashline 0 & 0 & 0 & 1 \end{array}\right]$$

6. Find inverse homogenous transformation matrix of previous question? (Önceki sorudaki sistemin ters homojen dönüşüm matrisini bulunuz.) (10 points)

$$T^{-1} = \left[\begin{array}{ccc:c} -1 & 0 & 0 & 3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \hdashline 0 & 0 & 0 & 1 \end{array}\right]$$

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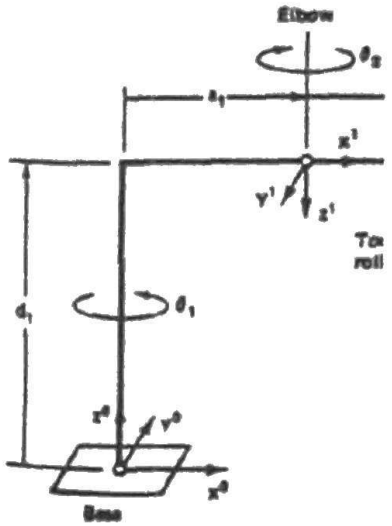
7. Consider two adjacent coordinates frames of below SCARA robotic system. Base and elbow coordinate frames are given. Between these two coordinate frames, there is rotation around x^0 by pi, along x^0 by a_1, along z^0 by d_1 and about z^0 by θ_1. Find corresponding screw transformation matrices around/along x^0 and z^0 axis (10 points) and find homogeneous transformation matrix, T_0^1 (10 points).



(Yukarıda bir SCARA robotunun taban ve dirsek koordinat takımları verilmiştir. İki koordinat takımı arasında x0 etrafında pi kadar dönme, x0 boyunca a1 kadar öteleme, z0 boyunca d1 kadar öteleme ve z0 etrafında θ1 kadar dönme olduysa, ilgili vida dönüşüm matrislerini ve sonuç homojen dönüşüm matrisini bulunuz)

$$T_0^1 = \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & a_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$\underbrace{\qquad\qquad}_{screw(z,\theta_1,d_1)}$ $\underbrace{\qquad\qquad}_{screw(x,\pi,a_1)}$

$$\begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 1 & 0 & 0 & a_1 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_0^1 = \begin{bmatrix} C_1 & S_1 & 0 & a_1 C_1 \\ S_1 & -C_1 & 0 & a_1 S_1 \\ 0 & 0 & -1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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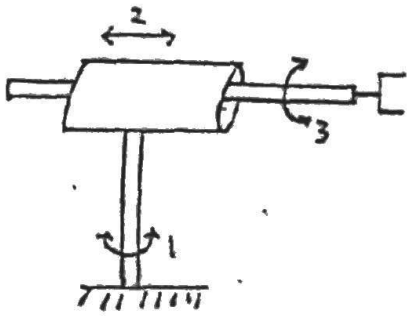
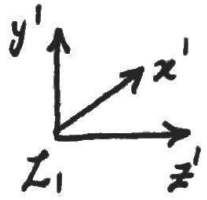
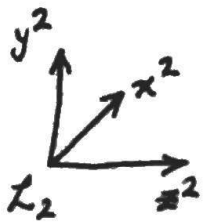
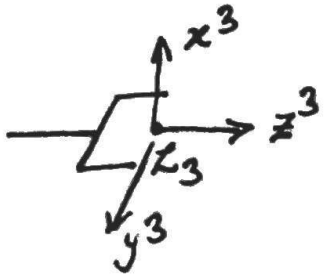
8. Below, 3 dof robotic system is given. Robotic system can rotate around its base, then another translating axis is present. Then, there exists a rotary joint that rotates the end effector. Assign coordinate frames to this robotic system. (20 points).

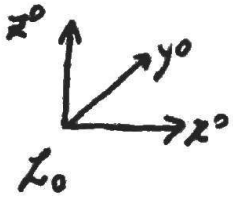


(3 serbestlik dereceli bir robot sistemi yukarıda gösterilmiştir. Tabanı etrafında dönebilen bu sistemde bir sonraki hareket öteleme ve üçüncü olarak da dönmedir. Bu sistemin koordinat takımlarını belirleyiniz.)









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