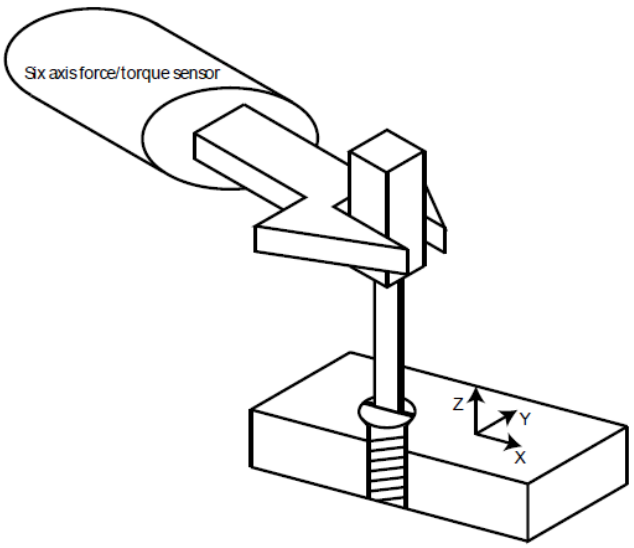
2. Suppose you want to design a hybrid position/force controller for the task illustrated below, where a 6-DOF robot is screwing a screw into a block using a flat-head screwdriver. For the purposes of control design, assume that the contact between the tool and the screw is frictionless.

2.1 Set up a table of natural and artificial constraints for hybrid control and find the selection matrix.

2.2 Sketch a block diagram for the hybrid control. Also write the control law.

2.3 Should the constraint frame be rotating with the tool? If the force/torque sensor is located in the wrist of the robot, what frame will the measured force/torque be in? Show how you handle these coordinate transformations in your controller.



2.1)

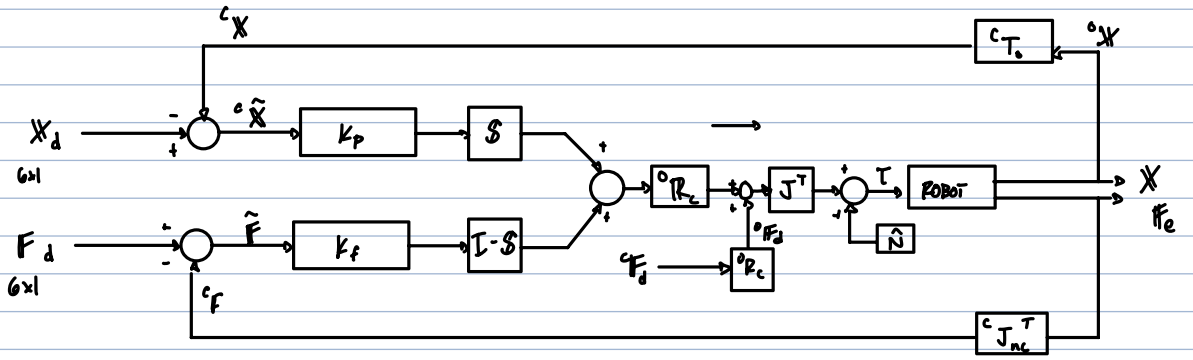
	KINEMATIC	STATIC
NATURAL	$\omega_x = 0$, $v_y = 0$, $\omega_y = 0$, $v_z = 0$	$f_x = 0$, $\tau_z = 0$
ARTIFICIAL	$v_z = v_{z,d} = 0$, $\omega_z = \omega_{z,d}$	$f_z = f_{z,d}$, $f_y = f_{y,d} = 0$, $\omega_x = \omega_{x,d} = 0$, $\omega_y = \omega_{y,d} = 0$

ASSUME: NO FRICTION IN SCREW

$$\sigma = [1\ 0\ 0\ 0\ 0\ 1]$$

$$S = \text{diag}(\sigma)$$

2.2)



$$u = K_{p,z}\,\tilde{v}_z + K_{p,\omega_z}\,\tilde{\omega}_z + K_{p,f_x}\,\tilde{f}_x + K_{p,f_y}\,\tilde{f}_y + K_{p,\tau_x}\,\tilde{\tau}_x + K_{p,\tau_y}\,\tilde{\tau}_y$$

$\omega_z = \omega_{z,d}$, $v_z = v_{z,d}$

$f_x = f_{x,d} = 0$, $f_y = f_{y,d} = 0$, $\omega_x = \omega_{x,d} = 0$, $\omega_y = \omega_{y,d} = 0$

2.3) THE ABOVE DIAGRAM SHOWS HOW TO DEAL WITH ROTATING THE END EFFECTOR. BELOW ARE EQUATIONS USED FOR ROTATIONS. IF A WRENCH IS FED BACK, USE THE JACOBIAN TRANSPOSE

$$^cX = {}^cR_o\ {}^oX$$

$$^cX = {}^cT_o\ {}^oX$$