ESD.33 Systems Engineering

Assignment 5
Error Budgeting

Due Date: 13 July, 8:30AM EST

Deliverable: Team written report (about five pages)

Time allotment: You should expect to spend 5 hours all together on this homework.

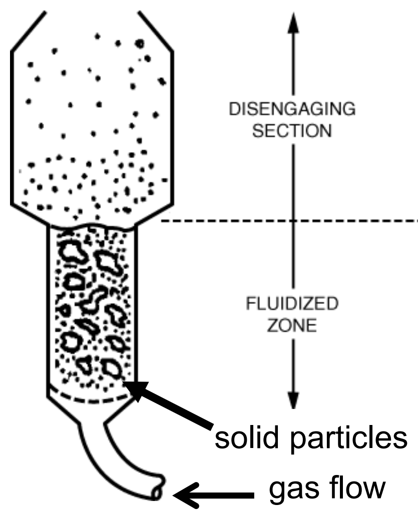
Grading: 5% of your final course grade. Every team member earns the same grade.

Assignment:
Self select into teams of 2 to 3 people. In this case, I think it is best to have a heterogeneous team.

1) Short answer questions

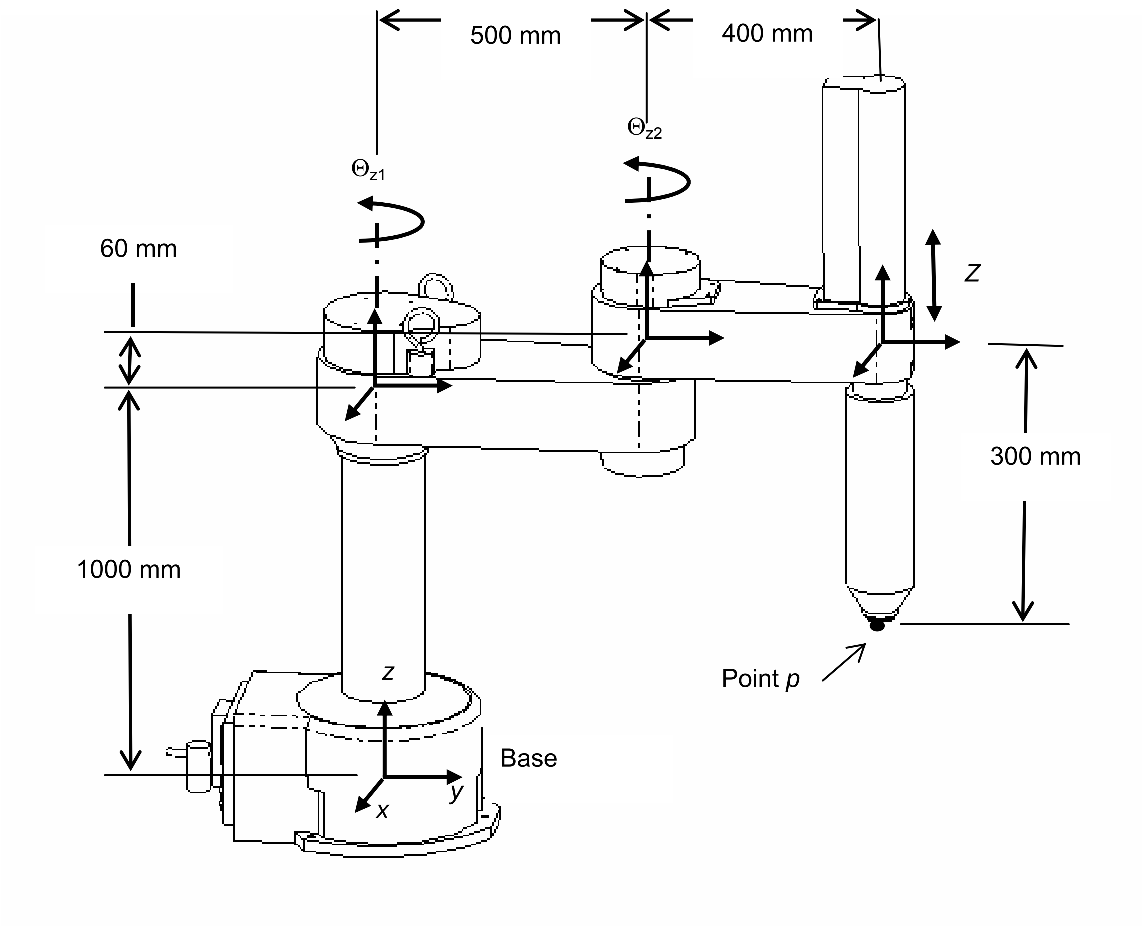
a. The collapsible umbrella is a solution to a practical problem. State the problem it solves as a contradiction (as is the suggested approach in TRIZ).

b. A fluidized bed (as depicted to the right) is composed of solid particles, but the ensemble of particles in the "fluidized zone" flows like a liquid. What type of resolution of a system conflict does this represent according to TRIZ?



c. You roll a set of three dice (the usual six sided kind). What is the expected value of the total value showing on the three dice? What is the probability of observing a total equal to the expected value?

d. You roll a set of three dice (the usual six sided kind). The standard deviation of any one die is 1.708. What is the standard deviation of the total value showing on the three dice?



$$
{}^{0}\mathbf{T}_3 = \begin{bmatrix} 1 & 0 & 0 & 0mm \\ 0 & 1 & 0 & 0mm \\ 0 & 0 & 1 & 1000mm \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\Theta_{z1}+\varepsilon_{z1}) & -\sin\Theta_{z1} & 0 & 0mm \\ \sin\Theta_{z1} & \cos(\Theta_{z1}+\varepsilon_{z1}) & 0 & 0mm \\ 0 & 0 & 1 & 0mm \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 & 500mm \\ 0 & 1 & -xp_2 & 0mm \\ 0 & xp_2 & 1 & 60mm \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
\cdot \begin{bmatrix} \cos(\Theta_{z2}+\varepsilon_{z2}) & -\sin\Theta_{z2} & 0 & 0mm \\ \sin\Theta_{z2} & \cos(\Theta_{z2}+\varepsilon_{z2}) & 0 & 0mm \\ 0 & 0 & 1 & 0mm \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 & 400mm \\ 0 & 1 & 0 & 0mm \\ 0 & 0 & 1 & 0mm \\ 0 & 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & \varepsilon_{y3} & 0mm \\ 0 & 1 & -\varepsilon_{x3} & 0mm \\ -\varepsilon_{y3} & \varepsilon_{x3} & 1 & -Z-\delta_{z3} \\ 0 & 0 & 0 & 1 \end{bmatrix}
$$

$$
\begin{Bmatrix} p'_x \\ p'_y \\ p'_z \\ 1 \end{Bmatrix} = {}^{0}\mathbf{T}_3 \begin{Bmatrix} 0 \\ 0 \\ -300 \\ 1 \end{Bmatrix}
$$

Error	Description	μ	σ
ε_{z1}	Drive error of joint #1	0 rad	0.0001 rad
ε_{z2}	Drive error of joint #2	0 rad	0.0001 rad
δ_{z3}	Drive error of joint #3	$Z \cdot 0.0001$	0.01mm
ε_{x3}	Pitch of joint #3	0 rad	0.00005 rad
ε_{y3}	Yaw of joint #3	0 rad	0.00005 rad
xp_2	Parallelism of joint 2 in the x direction	0.0002 rad	0.0001 rad

2) The document Frey_Error Budgeting.pdf describes an error budget for a SCARA robot. This series of questions is related to the machine including its kinematic model and the list of error sources (above).

a. The robot is used to apply thermally conductive adhesive to a printed wiring board. The board's surface is at z=100mm. The adhesive nozzle has to be placed above the surface by 1±0.1mm. Approximate the process capability (C_{pk}) for this task when joint 2 is rotated modestly ($\Theta_{z2} = -15 \text{ deg}$) and the adhesive nozzle has been lowered to the nominally correct height (Z=659mm). For part (a) you may assume the simplified model given in equation 21 of the assigned reading -- $p'_z = 760 - Z - \delta_{z3} + [400 \sin \Theta_{z2}] xp_2$ ..

b. The solution to the problem above should indicate there is a significant bias ($k \neq 0$). Suggest a procedure to reduce the bias in the process. Your procedure should not make turnover of the robot between different tasks more difficult. Your procedure should preferably work even if the adhesive must be applied at different points in the working volume of the robot.

c. The robot is to be used to locate a test probe at x=700±0.25mm and y=50±0.25mm. You should be able to verify that this will require, nominally, that the inputs to the robot are $\Theta_{z1} = -29.813 \text{ deg}$, $\Theta_{z2} = 78.097 \text{ deg}$, and Z=560mm. You can assume all the bias in the error has been eliminated by you process in part (b). Determine whether the x and y positions of the probe are correlated. Estimate the probability that the tolerance on x position is satisfied. Estimate the probability that the tolerance on y position is satisfied. Approximate the yield of this process (the fraction of the instances in which the probe will be placed simultaneously satisfying both x and y tolerances).

NOTE: The folder on Sloanspace has Matlab files that essentially solve this problem. They are named "tip.m" and "probsim.m". If you download them both to a folder, set your path to include the folder, and type "probsim" a graph will appear from which the answers should be clear. These files are there is case you get stuck. If you use them, say so in your homework and you will still get partial credit (most of the credit) as long as your discussion and analysis are strong.

d. Comment on the answers to part (c) from the perspective of Suh's theory of Axiomatic Design. Does the information content of the FRs sum? Is the design coupled? Would you suggest any changes to the design on the basis of these observations?