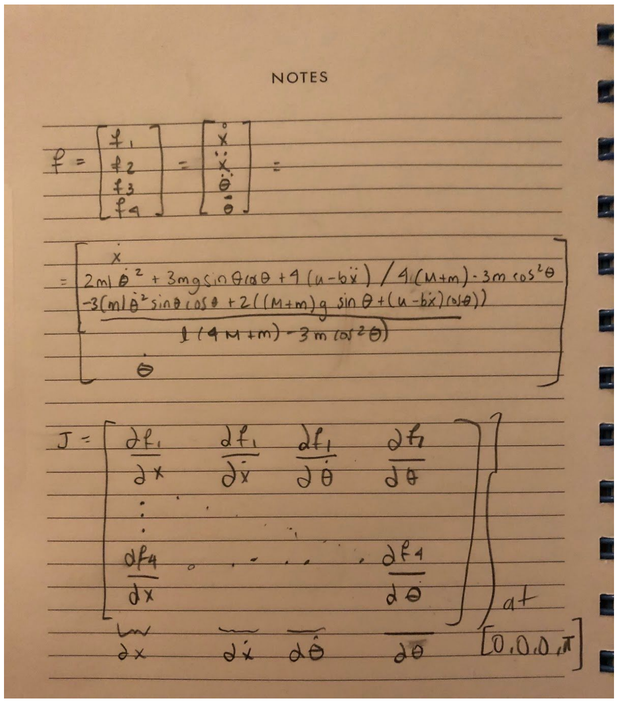
Parsa Yadollahi - 260869949
COMP 417 - Assignment 4

Question 1:
I had trouble implementing the from_laser_to_map_coordinates(). I was able to get the final solution of the image but was not able to get the green lasers to show the walls. Unfortunately, I didn't have much time to implement the function denoted above because I had other assignments due. I finished most of the assignment before the github code had been updated so that I may focus on my other work and didn't know I would have to implement the laser function.
I was able to learn to find the range and angle of the beam and I learned how to compute where the point is in the laser's frame given the range sensed at the angle that corresponds to each beam. By doing so, I was able to recreate the image provided in the pdf given.

As for question 2, here my report that describes my investigations and progress:

- I knew the biggest requirement for this cartpole to balance itself was the A and B matrices. Once these were properly calculated, tuning would be straightforward since they did not affect the end result by a lot. I was able to achieve balancing the cartpole with the ball above it. Also, Unfortunately, I was unable to try to tune the Q and R matrices to make the balancing perfect.
- The outcome I received for the following explanation is where the ball is stabilized above the block. The math to get the following A,B are as follows:

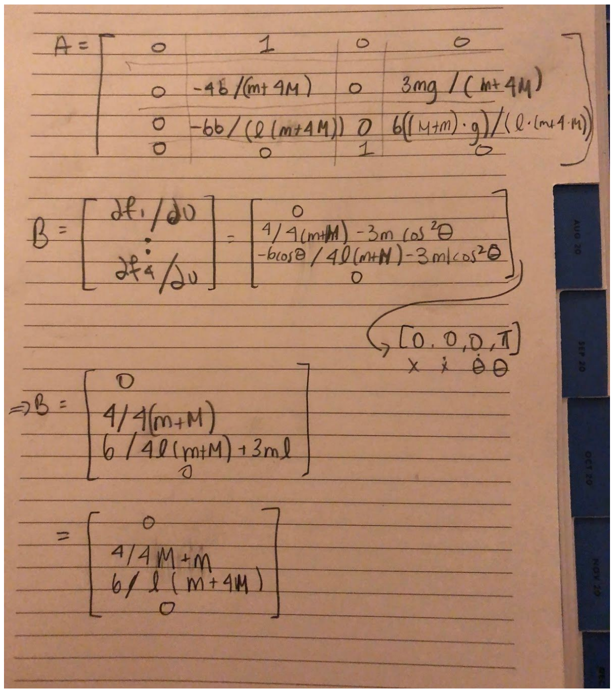

NOTES

$$f = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{bmatrix} = \begin{bmatrix} \dot{x} \\ \ddot{x} \\ \dot{\theta} \\ \ddot{\theta} \end{bmatrix} =$$

$$= \begin{bmatrix} \dot{x} \\ 2ml\dot{\theta}^2 + 3mg\sin\theta\cos\theta + 4(u-b\dot{x}) / 4(M+m) - 3m\cos^2\theta \\ \dfrac{-3(ml\dot{\theta}^2\sin\theta\cos\theta + 2((M+m)g\sin\theta + (u-b\dot{x})\cos\theta))}{l(4M+m) - 3m\cos^2\theta)} \\ \dot{\theta} \end{bmatrix}$$

$$J = \left[\begin{bmatrix} \frac{\partial f_1}{\partial x} & \frac{\partial f_1}{\partial \dot{x}} & \frac{\partial f_1}{\partial \theta} & \frac{\partial f_1}{\partial \theta} \\ \vdots & & \ddots & \\ \frac{\partial f_4}{\partial x} & \cdots & \cdots & \frac{\partial f_4}{\partial \dot{\theta}} \end{bmatrix} \right] \text{at } [0,0,0,\pi]$$

$$\partial x \quad \partial \dot{x} \quad \partial \dot{\theta} \quad \partial \theta$$


$$A = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & -4b/(m+4M) & 0 & 3mg/(m+4M) \\ 0 & -6b/(l(m+4M)) & 0 & 6((M+m)\cdot g)/(l\cdot(m+4\cdot M)) \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \partial f_1/\partial u \\ \vdots \\ \partial f_4/\partial u \end{bmatrix} = \begin{bmatrix} 0 \\ 4/4(m+M) - 3m\cos^2\theta \\ -6\cos\theta / 4l(m+M) - 3ml\cos^2\theta \\ 0 \end{bmatrix} \rightarrow \begin{array}{cccc} [0, & 0, & 0, & \pi] \\ x & \dot{x} & \dot{\theta} & \theta \end{array}$$

$$\Rightarrow B = \begin{bmatrix} 0 \\ 4/4(m+M) \\ 6/4l(m+M) + 3ml \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} 0 \\ 4/4M+m \\ 6/l(m+4M) \\ 0 \end{bmatrix}$$

Following these calculations, I went on to tune the R and Q matrices. I knew that the R and Q matrices had to be symmetric, so I started with the identity matrix for Q and R and the ball would stay above the block. To debug, I subtracted the state with the matrix [0,0,0,pi] and printed this result to follow the angle of the ball relative to the y axis. This would fluctuate a lot and would take a long time to stabilize. I then tried to modify Q by increasing the 1s in the diagonal to 10 then 100 then 1000 to notice that this would only increase the rate at which the ball would stabilize above the block (i.e. the block would move less and less in the x axis). But there was a limit to how high these numbers could go. For example, if I tuned the numbers on the diagonal of the Q matrix to 10000, then the block and ball would not stay at the top but move around the entire canvas rapidly in random order. Thus there was a limit to how high we could increase these numbers. Increasing the other numbers in that matrix (other than the diagonal) would not change the speed of stability. Afterwards, I tried to modify the R matrix, but increasing this would only lead to worse outcomes where the ball would take longer to stabilize.

- The bulk of the second question of the assignment was determining the matrix A and B since these required calculations and derivations. Once I calculated the A and B matrix, Q and R were simply tuning which did not take very long. Before tuning, I set the two matrices to the identity matrix and wrote the *policyfn()* function that would balance the cartpole. This did not take very long either since it was straight forward. All I had to do was substract the state by the angle wanted (i.e. [0,0,0,pi]) and then dot product that value with the *k* value calculated in the l*qr()* function.