ELEC-E8101 Group project:
Lab B report
Group #21

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Reporting 5.1

We used the following PID parameters - Kp = -60.4437 Ki = -337.9116 Kd = -0.1257
The plot of x_w, θ_b and u was obtained from the serial data from the robot. These plots are shown in Figure 1.

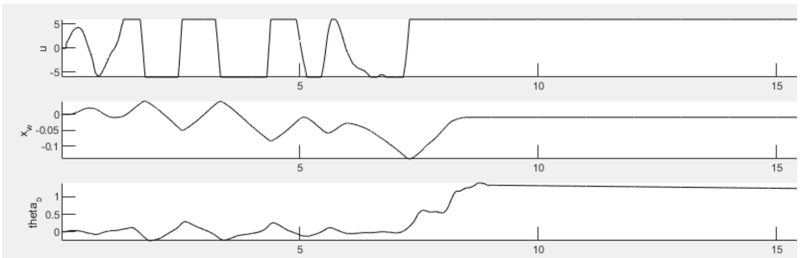

Figure 1: Plot of x_w, θ_b and u

The duration of time for which we were able to make the robot stand was varying in each attempt as we were not exactly releasing the robot from at equilibrium position. The maximum duration we got the robot to stand before falling was around 5 seconds.

Reporting 5.2

Observability and controllability can be determined using Matlab functions of $ctrb(A, B)$, $obsv(A, C)$. the controllability and observability of the system can be assessed by obtaining rank of the matrices returned by these functions. For Example, this system is observable if the controllability matrix has a rank of four.

$$\text{Controllability matrix} = \begin{bmatrix} 0 & 0.0000 & -0.0000 & 0.0046 \\ 0.0000 & -0.0000 & 0.0046 & -2.2058 \\ 0 & -0.0000 & 0 & -0.0203 \\ -0.0000 & 0.0000 & -0.0203 & 9.6527 \end{bmatrix} * 10^9$$

The rank of the matrix is four. Therefore, it is controllable.

$$\text{Observability matrix} = \begin{bmatrix} 0 & 0 & 0.0000 & 0 \\ 0 & 0 & 0 & 0.0000 \\ 0 & 0.0190 & 0 & -0.0004 \\ 0 & -9.0415 & -0.1409 & 0.1905 \end{bmatrix} * 10^5$$

The rank of matrix is 3. Therefore,it is not observable.

This system is not observable because there are no appropriate instruments to measure the state variable, or the state-variable might be measured in units for which there does not exist any measurement device. By utilizing observer, we can estimate state variables. In transfer function, one of the poles is eliminated by one of the zeros. As a result, the order of characteristic function is reduced to three.

$$\text{Transfer function} = \frac{-90.028s}{(s+475.1)(s+5.657)(s-5.72)}$$

Reporting 5.3

The systems poles are located at $p = -475.1, -5.657, 5.72, 0$ so one of the poles is unstable and the other pole is at 0. We replace that pole in left hand side of s plane to make our system stable without affecting the dynamics of our system. Hence we need to choose poles which are near our dominant pole. We chose $p = -475.1, -5.6571, -5.6572, -5.6570$. The pole which is in origin makes the system marginally stable and we are not allow to locate that in the left of -5.657 as the closest pole to the origin. We can derive gain matrix with aid of "place" function in MATLAB.

$$K = \begin{bmatrix} -118.3024 & -84.1284 & -118.3500 & -19.4169 \end{bmatrix}$$

The plot of θ_b and v_m is shown in Figure 2.

Reporting 5.4

The values of L (the gain of the full order estimator):$L = \begin{bmatrix} 28.2994 & 0.5872 \\ -0.1642 & 16.7632 \\ 0.6042 & 56.9316 \\ 19.5392 & 844.9284 \end{bmatrix}$

For the reduced order observer gains M1 to M7 are as follows -

$$M1 = \begin{bmatrix} -458.0668 & -47.7569 & 9.1357 \\ -47.8216 & -33.9131 & 1.0000 \\ 549.7949 & 61.0935 & -39.9722 \end{bmatrix}$$

$$M2 = \begin{bmatrix} 20.5759 \\ 0 \\ -90.0275 \end{bmatrix}$$

$$M3 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

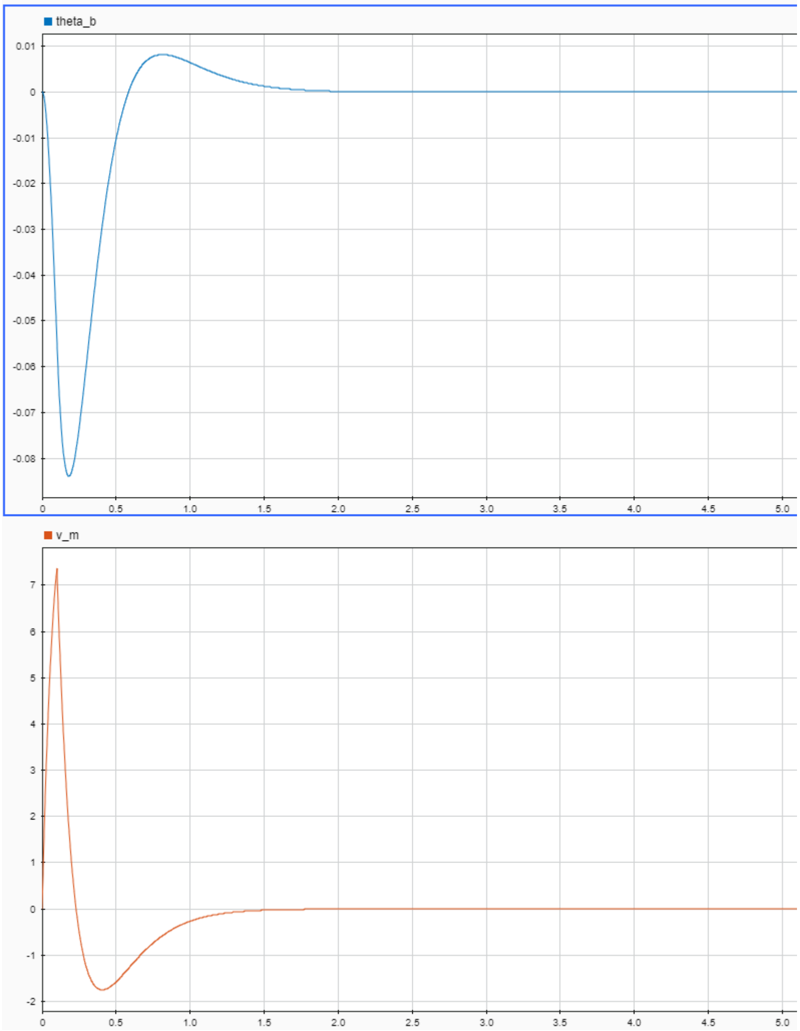

Figure 2: Plot for reporting 5.3

$$M4 = \begin{bmatrix} 41.6578 \\ 33.9131 \\ 0.9258 \end{bmatrix}$$

$$M5 = \begin{bmatrix} 0.02230 \\ 0.0478 \\ 1.3536 \end{bmatrix} * 10^3$$

$$M6 = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$M7 = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The simulation for the continuous time observer and controller was run and the values for θ_b and x_w was compared with the estimated value for the full order and the reduced order observer as shown in Figure 3.

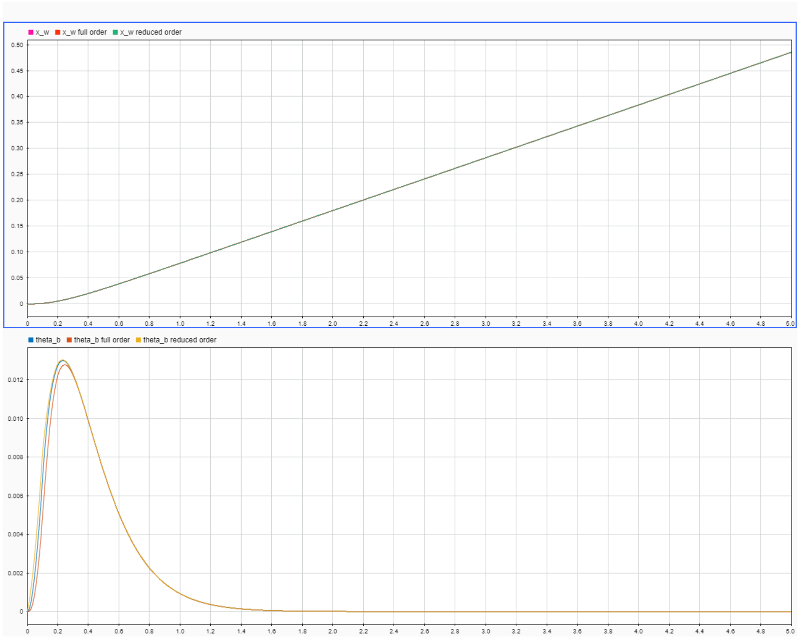

Figure 3: Plot of x_w, θ_b plotted against the estimated values

The maximum error committed in estimating the θ_b and x_w is shown in the table below

	x_w	θ_b
Full order observer	0.002	0.002
Reduced order observer	0	0.0013

Reporting 5.5

5.5.1

We took the continuous time transfer function of the system (G) and converted it to a discrete time transfer function by using the *c2d* function. Then, we found the state space representation variables of the discrete system A_d, B_d, C_d, and D_d.

$$A_d = \begin{bmatrix} 1 & 0.0028 & -0.0001 & 0.0002 \\ 0 & 0.0918 & -0.0074 & 0.0190 \\ 0 & 0.0317 & 1.0021 & 0.0093 \\ 0 & 3.9783 & 0.3858 & 0.9186 \end{bmatrix}$$

$$B_d = \begin{bmatrix} 0.0003 \\ 0.0430 \\ -0.0015 \\ -0.1882 \end{bmatrix}$$

$$C_d = \begin{bmatrix} 0 & 0 & 1 & 0 \end{bmatrix}$$

$$D_d = 0$$

5.5.2

Using the discrete time $A_d, B_d, C_d,$ and D_d, we can calculate the values of K_d and L_d easily by using the place command -

Kd = place(Ad,Bd,p_control_disc)

C_fullcontrol_dis = [1 0 0 0;0 0 1 0]

Ld = place(Ad',C_fullcontrol_dis',p_observe_disc)'

$$K_d = \begin{bmatrix} -108.6576 & -79.5522 & -111.9984 & -18.3624 \end{bmatrix}$$

$$L_d = \begin{bmatrix} 0.2465 & 0.0051 \\ 0.0074 & 0.1309 \\ 0.0054 & 0.4989 \\ 0.1131 & 6.5517 \end{bmatrix}$$

To calculate $M_{\mathrm{d1}} \mathinner{..} M_{\mathrm{d7}}$, we followed the same steps as in the continuous case. We used the equations given in the lab book to derive their values.

$$M_{\mathrm{d1}} = \begin{bmatrix} 0.0390 & -0.1046 & 0.0161 \\ -0.0993 & 0.7367 & 0.0021 \\ 0.7026 & 0.1029 & 0.7378 \end{bmatrix}$$

$$M_{\mathrm{d2}} = \begin{bmatrix} 0.0364 \\ -0.0178 \\ -0.5962 \end{bmatrix}$$

$$M_{\mathrm{d3}} = \begin{bmatrix} -0.0192 \\ -0.0476 \\ -1.1903 \end{bmatrix}$$

$$M_{\mathrm{d4}} = \begin{bmatrix} 0.0987 \\ 0.2692 \\ 0.3770 \end{bmatrix}$$

$$M_{\mathrm{d5}} = \begin{bmatrix} 0.0192 \\ 0.0476 \\ 1.1903 \end{bmatrix}$$

$$M_{\mathrm{d6}} = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$M_{\mathrm{d7}} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Reporting 5.6

Various control strategies were tested on the real robot, such as numerical, full-order and reduced-order observer. The best results were observed when the numerical observer was used. The plots of x_w, u and θ_b are shown in Figure 4

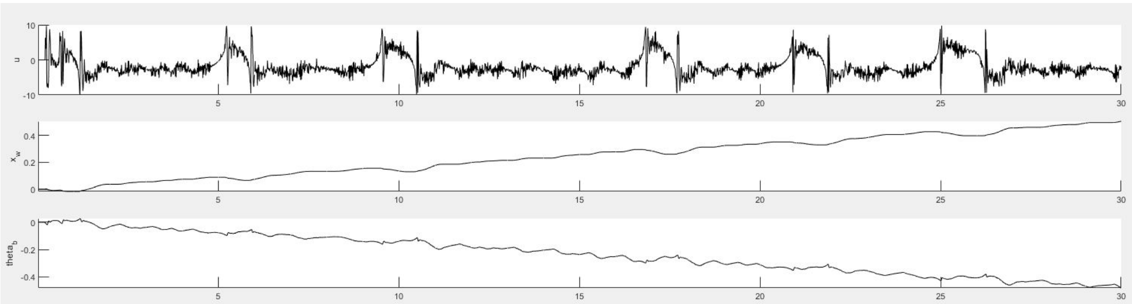

Figure 4: Plot of x_w, θ_b and u for numerical observer implemented on the robot.