Model Predictive Control

Mini Project Report
Group 13

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1 Introduction

Model Predictive Control(MPC) is a control strategy that is computed using a plant model and solving a optimization problem. Formulation of control law in MPC can includes constraints on input and output thus overcoming the limitations of the PID loop.

In MPC, we predict the system future response using a model of a system. Then to determine the best control action we solve a optimization problem considering the various constraints on input and output of the system. We can tune few parameters of the controller to achieve the desired response.

2 Four Tank Problem

In previous projec of the four tank problem, we implemented Kalman Filter to estimate the heights of the lower tanks. In this project, we use MPC to reach setpoint for different cases of tank levels involving input and output constraints. We are provided with sampling time of 0.1s, initial states [12.4 12.7 1.8 1.4]^T.

Constraints for Part I includes: DUmin = 5*[-1 -1]^T DUmax = 5*[1 1]^T Umin = 0*[-1 -1]^T Umax = 20*[1 1]^T

3 Implementation and Analysis

A. Implement Constraint MPC to control

Case 1: h1, h2 when h3, h4 are measured

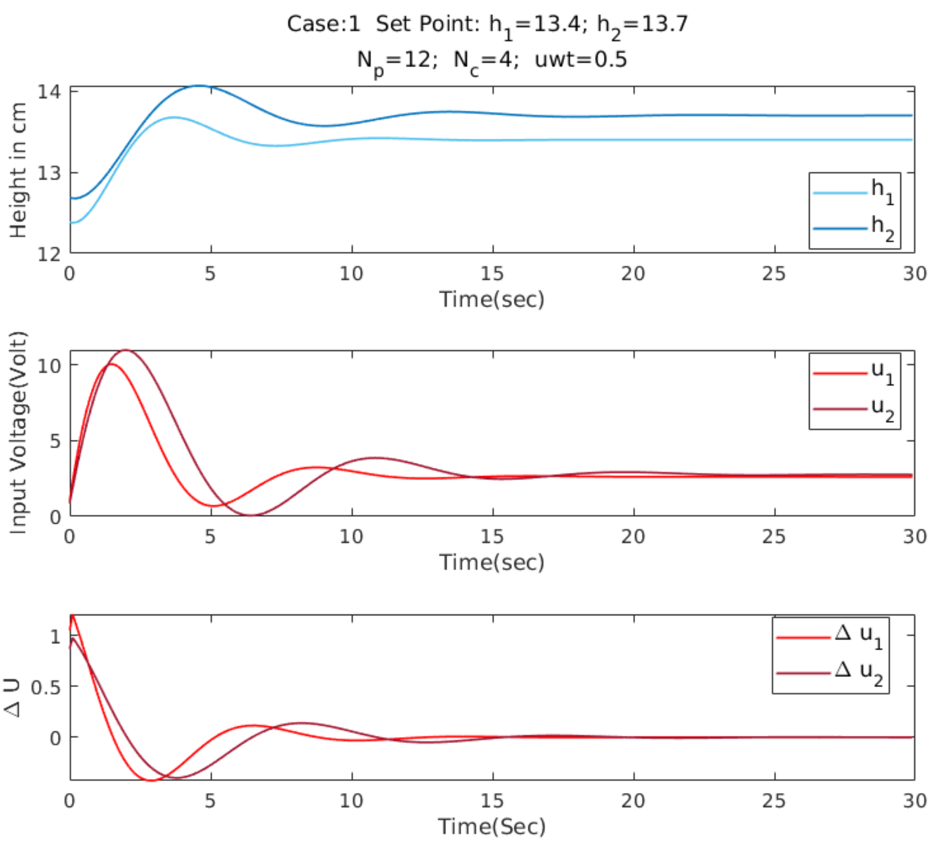


Figure 1: Case I

Case 2: h3, h4 when h1, h2 are measured

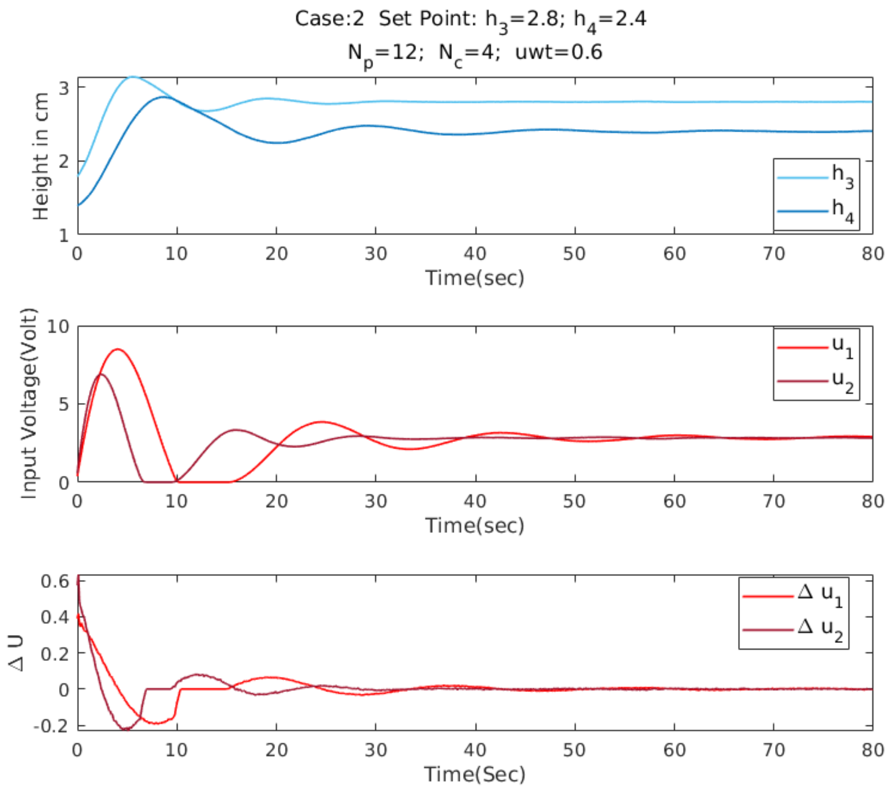


Figure 2: Case II

Case 3: h2, h3 when h1, h4 are measured

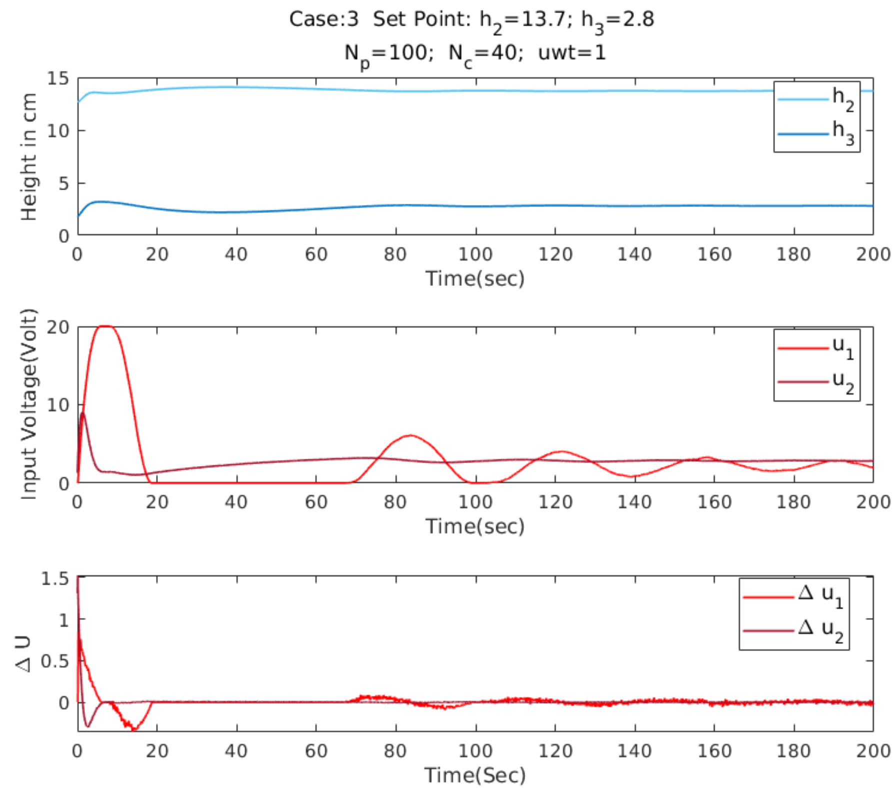


Figure 3: Case III

Case 4: h1, h3 when h2, h4 are measured

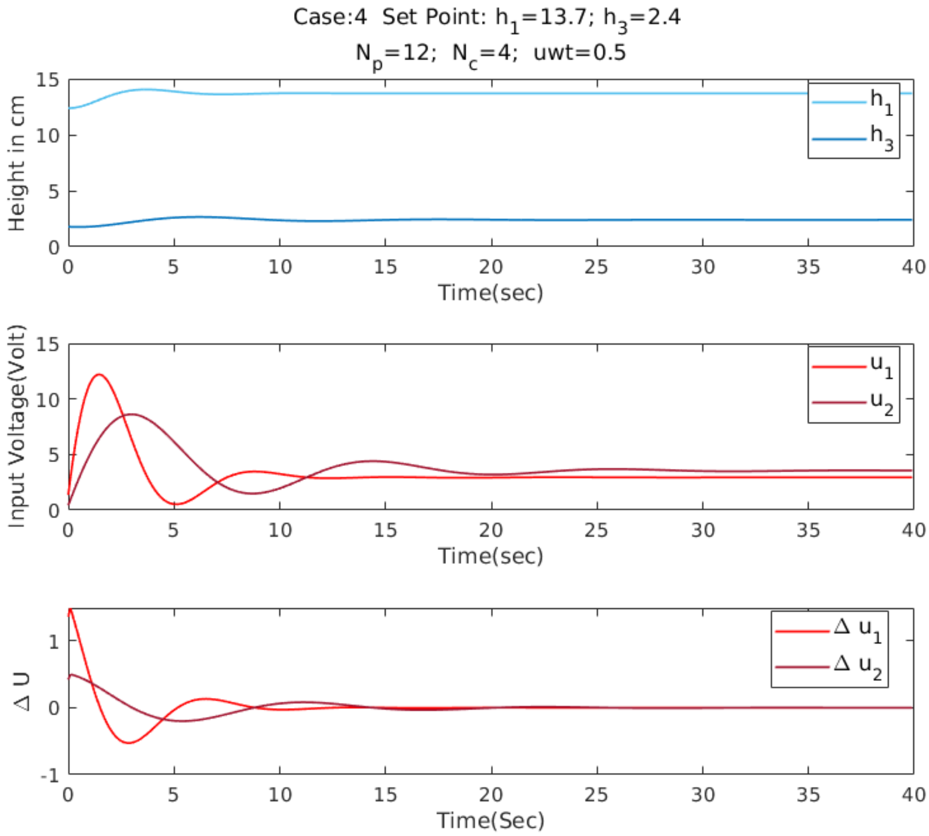


Figure 4: Case IV

Questions

1. Comment on the performance of MPC for cases 1-4 and whether the set point is achieved.

   Ans.. Set point was achieved for all the four cases. The input voltage was between 0 volt to 20 volt. For case 1,2 and 4 oscillation in the response was very less and the system reached the set point faster. But for case 3, because of oscillation it took little longer for the response to reach set point. The input voltages were controlled between 0 and 20. Different size of prediction horizon and control horizon were used to achieve better response.

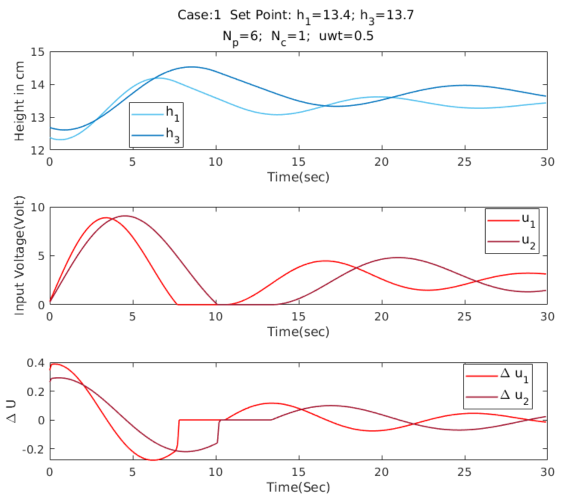
2. Do you see good control performance in all the cases? If there are any performance deterioration between cases, is it due to the Kalman filter or MPC performance?

   Ans.. Yes, we can see good control performance in all the cases. The measured heights, controlled heights are different in each case. Also, the control horizon, prediction horizon and input weights are different, resulting in difference in the values of the controller, which affects the performance of MPC. But, since the measurement noise and process noise parameters Q and R, in Kalman filter estimation is same for all cases, the performance deterioration observed between the cases is due to MPC and not due to Kalman Filter.

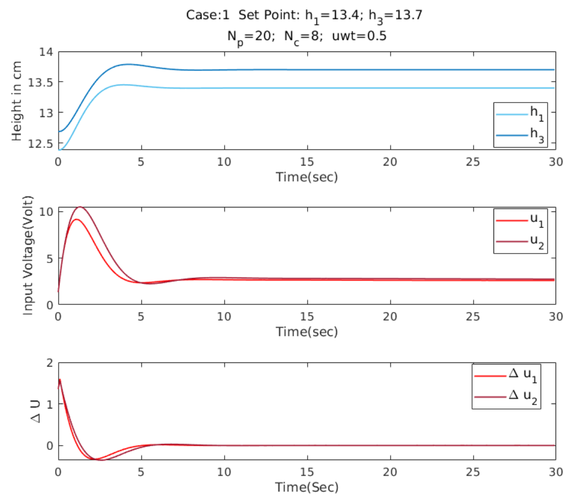
3. Experiment few ways to improve the overall performance and report the same.

   Ans.. The MPC performed better when the control horizon and prediction horizon were extended. Once the system achieved the set point, there was less overshoot and oscillation, and the system reached the set point significantly more quickly. The extra computational time needed as a result of expanding the control and prediction horizons, however, is a disadvantage. Therefore, the performance of the MPC and computational time can be traded off.

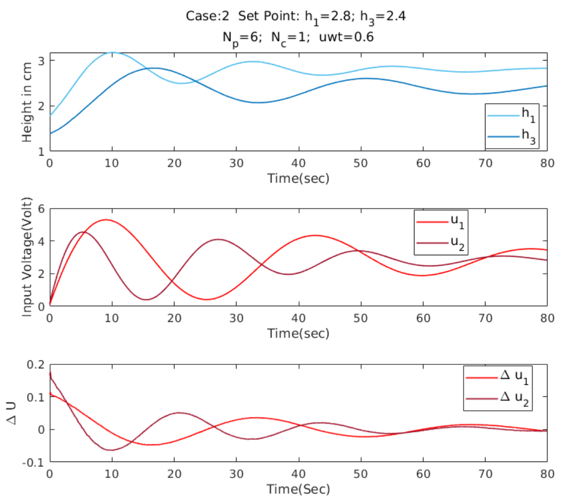
4. Report the effect of control and prediction horizon on MPC performance for cases 1 and 2



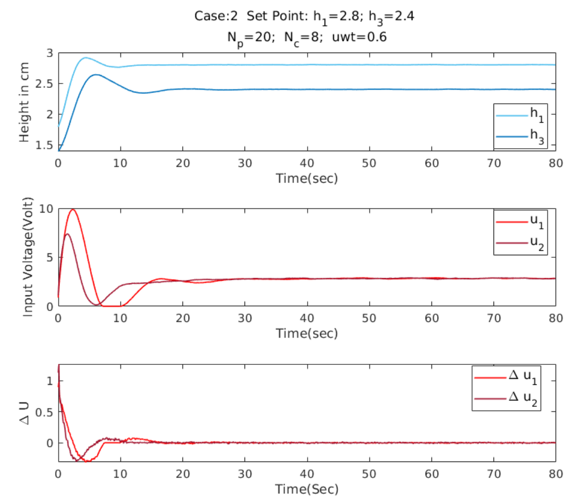
(a) Case-1: Np=6; Nc=1



(b) Case-1: Np=20; Nc=8



(c) Case-2: Np=6; Nc=1



(d) Case-2: Np=20; Nc=8

Figure 5: Effect of Change in Prediction and Control Horizon for Case-1 and Case-2

Ans.. On increasing the prediction horizon and control horizon, MPC reaches setpoint faster with less overshoot and less oscillations. But, the settling time increases as the number of steps to reach setpoint increased.

B. Implement constrain MPC to control Case 1 along with the output constraints

Ymin = $[12\ 12]^T$

Ymax = $[13.9\ 14]^T$

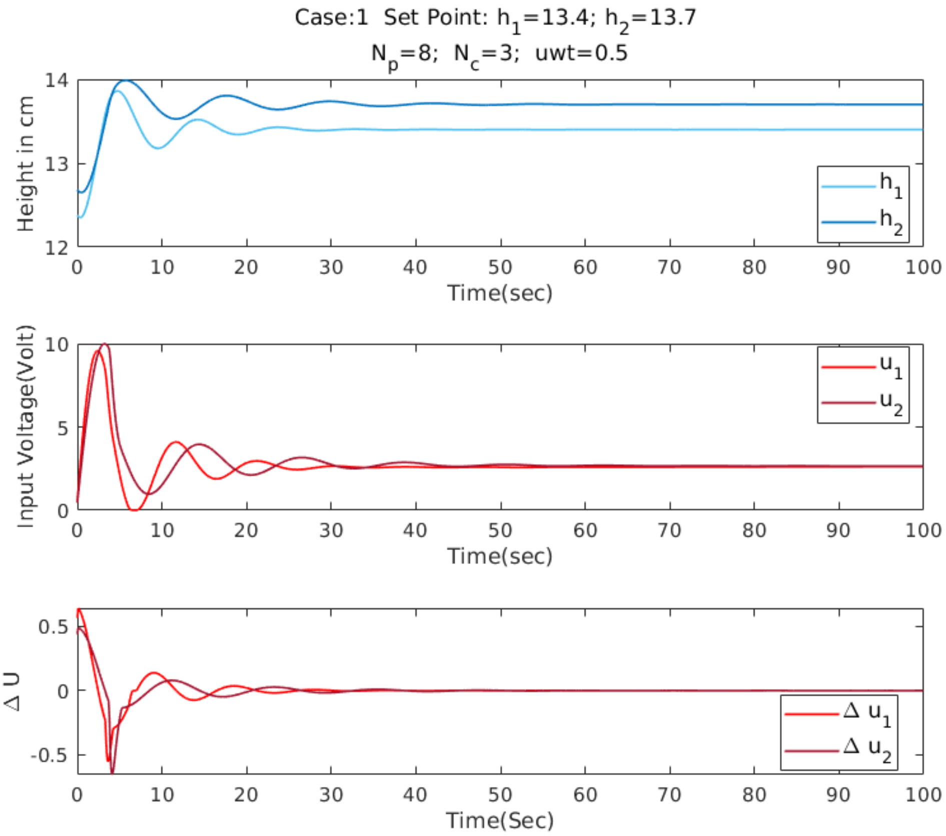


Figure 6: Response of System with Output Constraints

Questions

(a) Comment on the performance of MPC and whether the constraints are met.

Ans.. Our MPC easily achieved the set point even after applying output constraint. The settling time our MPC has taken is 35 sampling time unit with prediction horizon 8 and control horizon 3 and penalty 0.5. The settling time can be reduced just by increasing the prediction horizon or by reducing penalty.

(b) Report the overshoot observed in the response and reduce it by 10% by two different ways.

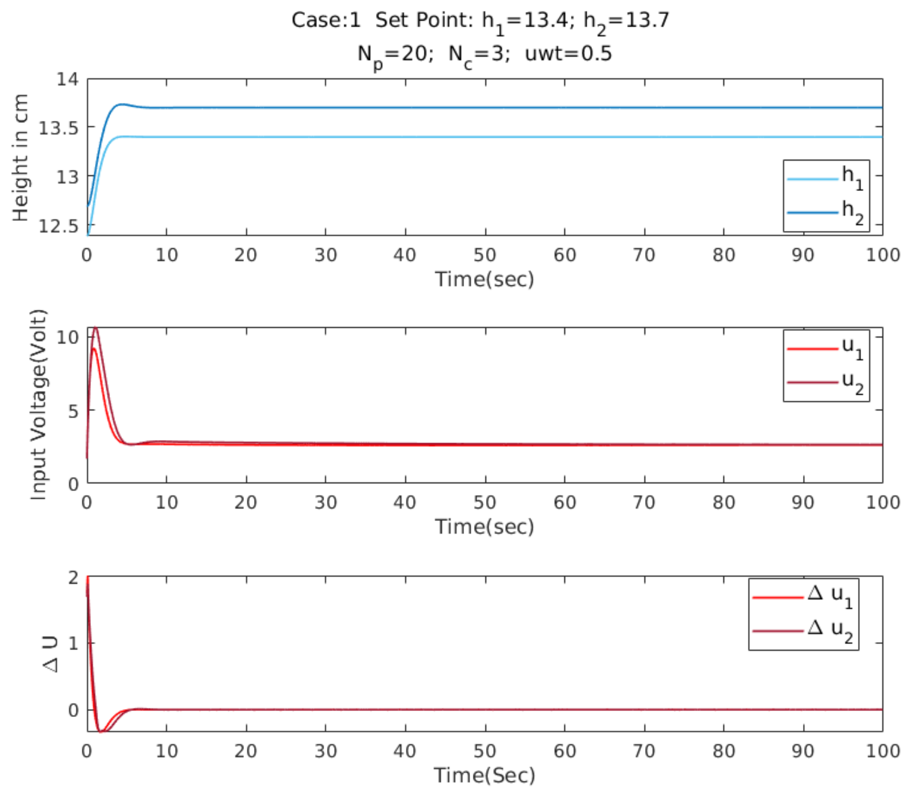


Figure 7: Increasing Prediction Horizon to reduce overshoot

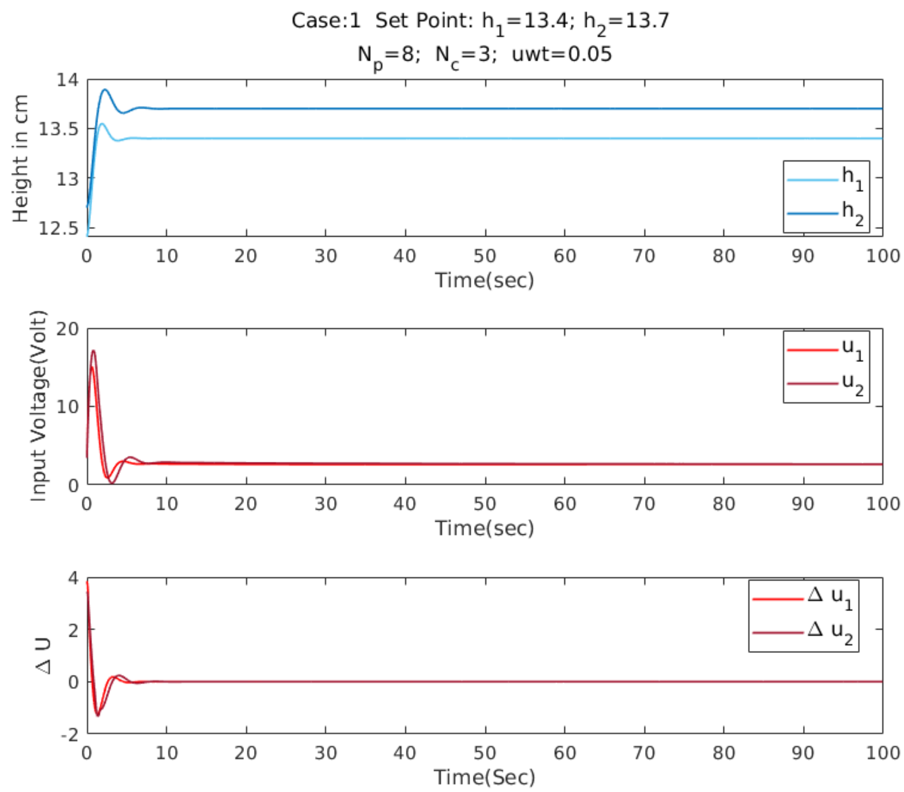


Figure 8: Decreasing Control Penalty to reduce overshoot

Ans.. Yes, there is little overshoot observed in the response when prediction horizon was 8 control horizon was 3 and penalty was 0.5. The overshoot can easily be reduced by increasing the number of prediction horizon or by reducing control horizon or by reducing penalty. Figure 7 shows the reduction in the overshoot when the prediction horizon is increased to 20 keeping the control horizon and input penalty constant. Figure 8 shows the reduction in the response overshoot by decreasing the input penalty to 0.05 while keeping the prediction and control horizon constant.

(c) Vary the Ymin values (Increase and decrease from the given values) and comment on the feasibility of the process.

Ans.. Since the initial value of the states (h1 and h2) is [12.4 12.7] we were able to increase the value of Ymin upto [12.4 12.69]. The least value of Ymin for h1 and h2 can be 12.4 and 12.7 respectively, beyond which we cannot solve the optimization problem. To increase the Ymin value beyond this we need to change the initial point for h1 and h2 accordingly. Not much changes were observed when the Ymin value was increased.

Since there are no severe undershoot in the system response as shown in figure 10, there is no restriction for decreasing Ymin.

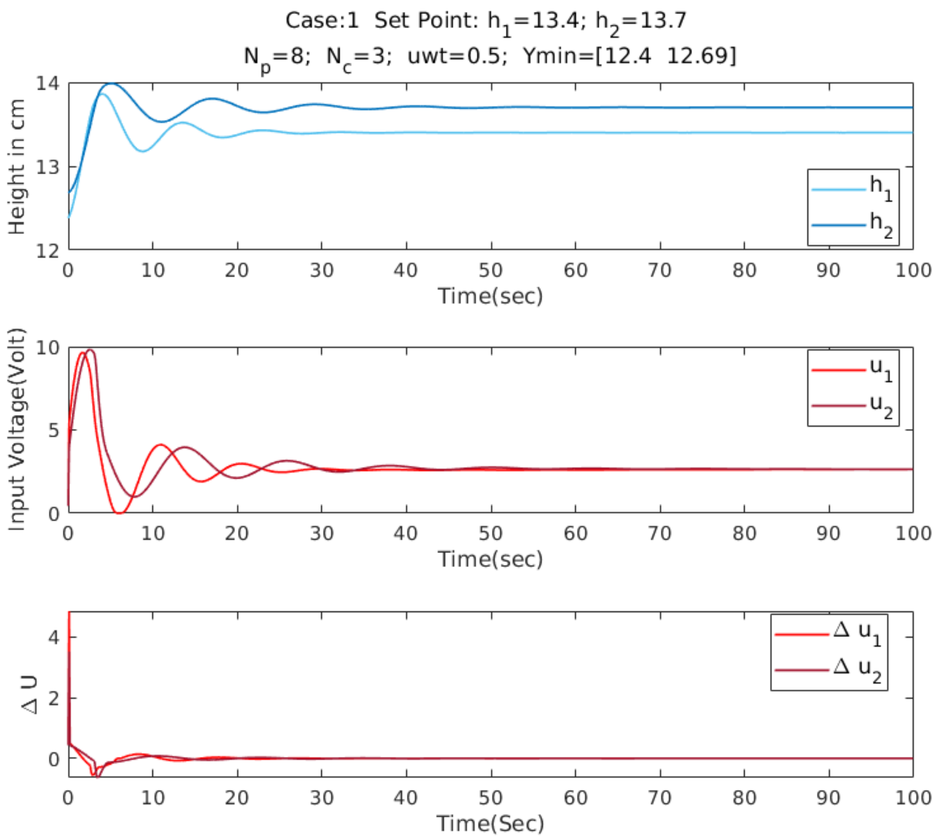


Figure 9: Effect of increasing Ymin

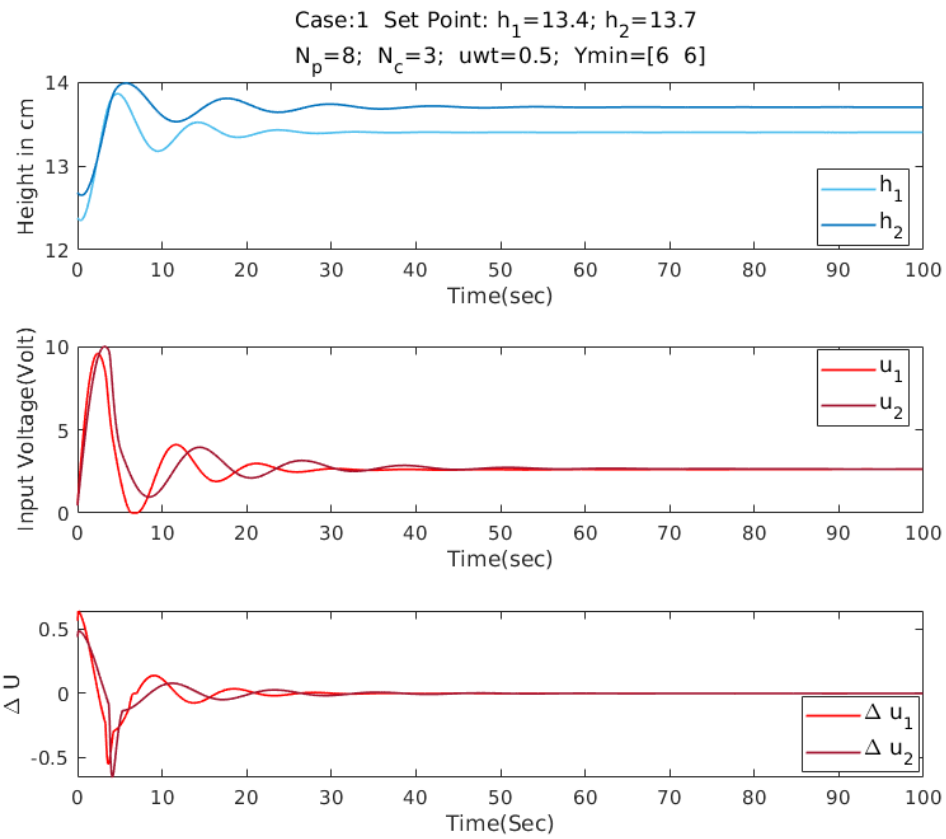


Figure 10: Effect of decreasing Ymin

4 Task Division

We first discussed all the cases to be clear about our objectives and wrote initial code that would be applicable for all cases. Then the task division was done in the following way.

1. Arjun Bhusal: Case I and Case II of Part A
2. Jasmin Karki: Case III and Case IV of Part A
3. Krishna Sah Teli: Part B

Explanation to the questions was done together by repeated edit by every group member to put the best answer.