Automotive Control Systems (EE 5812/ MEEM 5812)
Project #6
Hybrid Electric Vehicle Power Split Control Using Dynamic Programming

Optimal control of hybrid electric vehicles (and other systems) can be achieved using dynamic programming. Model predictive control of hybrid electric vehicles is achieved by using dynamic programming operating over a shortened horizon time interval. This project is designed to introduce the students to dynamic programming. A simplified plant model and limited control input range will be used to introduce the concept of dynamic programming without adding the complexity associated with HEV modelling.

Given the plant and the initial condition:

$$\dot{x}(t) = -\frac{P_{elec}}{36{,}000} \bullet 100\% \quad ;\ x(0) = 70\%$$

where x is the battery state of charge in percent, P_{elec} is the power (both positive and negative) in kW from the Battery. The control system must supply the driver's demanded power at each point in time. The driver's demanded power is:

$$P_D(t) = \eta_{eng} P_{eng} + \eta_{elec} P_{elec}$$

where P_{eng} is power of the engine in kW and the electrical motor efficiency η_{elec} is 0.90. The engine efficiency is a function of the net load provided by the engine. The Matlab code for computing the efficiency is:

```
etaeng=0.3-(Pengnet(m)-400).^2./(400^2/.3);
if etaeng<0.05
    etaeng=0.05;
end
```

Note that these efficiencies are both greatly over simplified. The driver's demanded power over the 10-minute (600 second) drive cycle is given in the file "PD" on Canvas. The state of charge of the battery is constrained to be between 30% and 80%. Use 51 quantization levels for the state: {30, 31, …, 80}. The power of the electric motor is constrained to be between -500 and 500. Use 201 quantization levels for the control: {-500, -495, …, 495, 500}. The power of the engine is constrained to be between 0 and 2000. Note that any control that results in violating one of these constraints will be inadmissible.

Using dynamic programming, generate and plot the optimal state trajectory and the optimal control trajectory that minimizes the cost:

$$J = \int_0^{600} P_{eng}(t)dt + 10^6 * \left(1 - \delta_{x(600),70}\right) = \int_0^{600} P_{eng}(t)dt + \begin{cases} 0 & x(600)=70 \\ 10^6 & else \end{cases}$$

where P_{eng} is the power supplied by the gasoline engine and $\delta_{i,j}$ is the Kronecker Delta function (defined above). The Kronecker Delta function term in the cost function is used to drive the final state of charge to the 70% initial state of charge. Round off the state of charge when evaluating this final term in the cost. Also, give the cost, J, associated with the optimal trajectory. Use a time quantization of one second.

When generating the optimal state trajectory, you should round off the state at every point in time. Your results may be a little odd. There will be times when there is some oscillations in the engine power and the electric power. Alas, this is the optimal solutions. I suspect that this will not happen with a more realistic model where the engine power can not change instantaneously. One good indication that your trajectory is correct is the final state of charge should be 70%. As always, feel free to show me your results and I will be happy to let you know if it looks correct.

Upload your <u>very brief</u> report in Canvas as a pdf file. Your report should include:

1. The optimal state of charge trajectory.
2. The optimal power of the electric motor trajectory.
3. The optimal power of the engine trajectory.
4. The cost associated with the optimal trajectory.
5. Brief comments you wish to make about the trajectories.
6. Upload the Matlab program that you used to generate the optimal trajectories as an m-file. We will run your code and compare it with the results.

Comments:

Each student should do this project individually and no student should share Simulink diagrams or code or results with other students. Note that I will be running your results through a similarity checker. If you have shared results and it is detected, you will fail this course! So, please don't share code. But, feel free to ask your instructor questions or check results with your instructor.