Advanced Energy Storage Systems
(Battery Management)

Individual Project

EV Range Estimation

Submitted by

Vijayarangan Pandurengadurai Raju 110128279

Submitted to:

Dr. Balakumar Balasingam

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1. Compute and plot the duty cycles $P(t)$, pack current $I(t)$, and SOC $s(t)$ for the UDDS and US06 drive cycles using the two EV battery packs specified in Table 1 and the vehicle dynamics provided in Table 2.

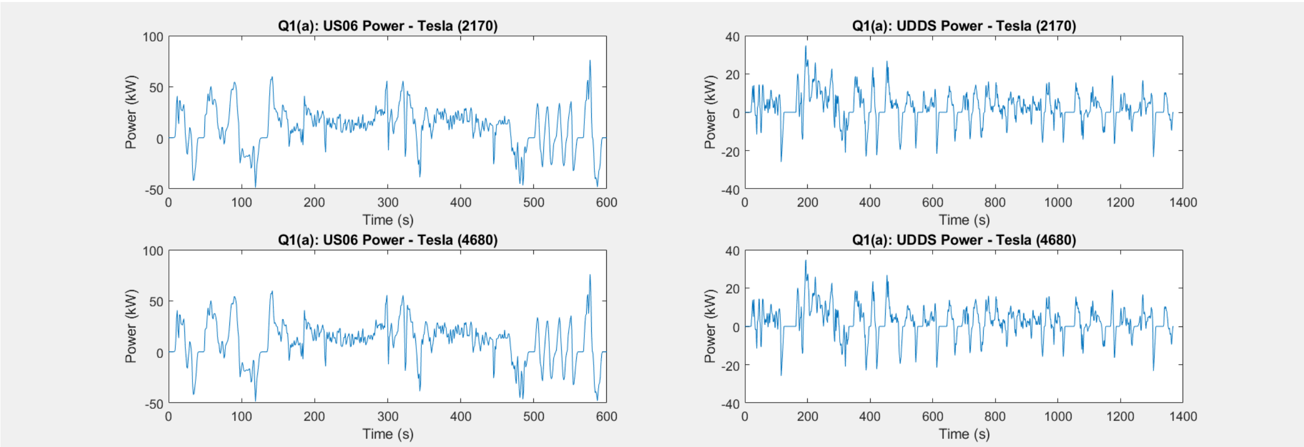
Table 1: EV battery packs.

Vehicle	xSyP configuration	V_{cell}	Q_{cell}	Cell weight
Tesla (2170)	96S46P	3.65 V	4.60 Ah	68.6 g
Tesla (4680)	92S9P	3.6 V	22 Ah	358 g

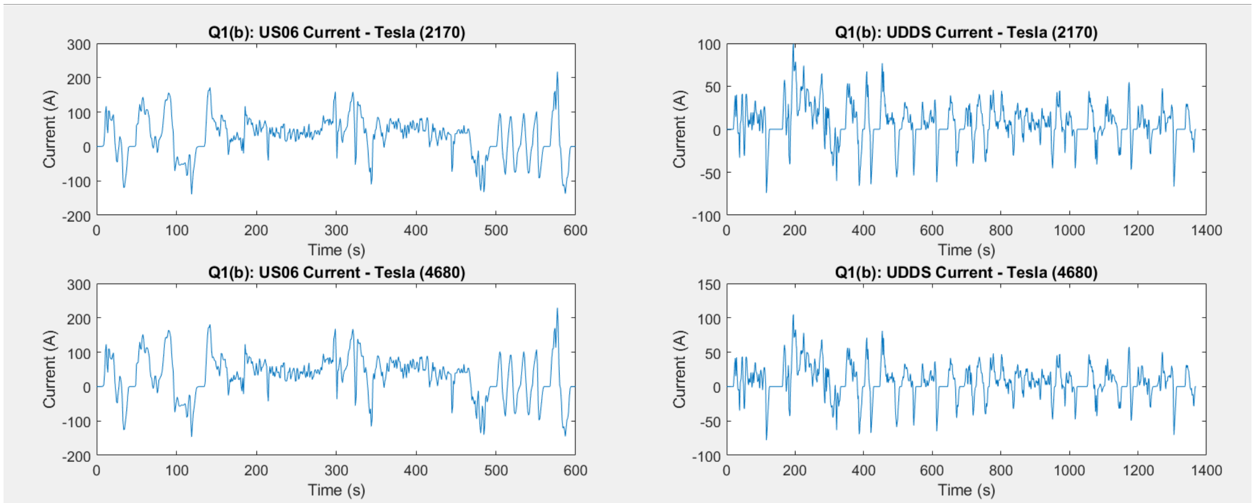
Table 2: Vehicle dynamics of a typical EV.

Vehicle mass (excluding battery pack)	m	1300 kg
Gravity acceleration	g	9.81 m/s^2
Slope	θ	0 deg
Rolling resistance coefficient	c_r	0.013
Frontal area	A_f	2.65 m^2
Air density	ρ_{air}	1.2 kg/m^3
Drag coefficient	c_d	0.23

(a) **Duty cycle** ($P(t)$ vs. t). Compute the duty cycles using the power equation in (4) and the vehicle dynamics provided in Table 2. Calculate the battery pack weights based on Table 1 and include them in the total vehicle mass for your calculations.



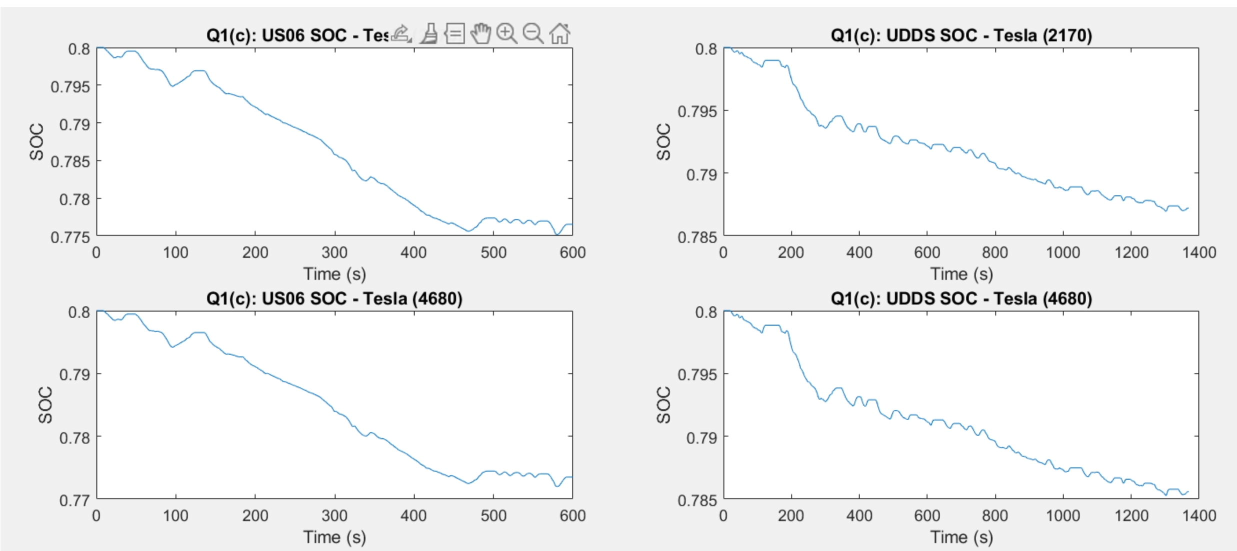
(b) **Pack current** ($I(t)$ vs. t). Compute the pack current by assuming $P(t) = I(t)V_{\text{pack}}$, where $V_{\text{pack}} = x \times V_{\text{cell}}$, and x is the number of cells in series.



(c) **Pack SOC** ($s(t)$ vs. t). Compute the pack SOC using the Coulomb counting equation:

$$s(t) = s(t_0) + \frac{1}{Q_{\text{pack}}} \int_{t_0}^{t} I(\tau)\, d\tau, \tag{9}$$

where the initial pack SOC, $s(t_0)$, is assumed to be 80%. The pack capacity is given by $Q_{\text{pack}} = y \times Q_{\text{cell}}$, where y is the number of cells in parallel. Note that, in the above SOC equation negative values of current correspond to battery discharge and positive current values correspond to charge.



2. Estimate the UDDS and US06 drive cycle ranges using (3) for the two battery packs specified in Table 1 and the vehicle dynamics provided in Table 2.

   - Similar to Question 1, calculate the battery pack weights based on Table 1 and include them in the total vehicle mass for your calculations.
   - Assume the powertrain efficiency and auxiliary coefficient are $\eta = 0.8$ and $c_a = 0.12$, respectively, to compute the vehicle energy consumption.

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Q2: Range Estimations
--- Tesla (2170) Results ---
US06 Range: 439.0814 km
UDDS Range: 690.8169 km
--- Tesla (4680) Results ---
US06 Range: 389.1595 km
UDDS Range: 612.9516 km
```

MATLAB Code:

```
clear; clc; close all;

%% Load US06 Data
us06_data = readtable('us06col.txt', 'Delimiter', '\t', 'HeaderLines', 2);
time_US06 = us06_data{:, 1}; % Time (s)
speed_mph_US06 = us06_data{:, 2}; % Speed (mph)
v_US06 = speed_mph_US06 * 0.44704; % Convert mph to m/s

%% Load UDDS Data
udds_data = readtable('uddscol.txt', 'Delimiter', '\t', 'HeaderLines', 2);
time_UDDS = udds_data{:, 1}; % Time (s)
speed_mph_UDDS = udds_data{:, 2}; % Speed (mph)
v_UDDS = speed_mph_UDDS * 0.44704; % Convert mph to m/s

%% Compute Acceleration
a_US06 = gradient(v_US06, mean(diff(time_US06)));
a_UDDS = gradient(v_UDDS, mean(diff(time_UDDS)));

%% Vehicle and Battery Parameters (From Table 2 and Table 1)
g = 9.81;       % Gravity (m/s^2)
theta = 0;      % Slope (deg)
cr = 0.013;     % Rolling resistance coeff
Af = 2.65;      % Frontal area (m^2)
rho_air = 1.2;  % Air density (kg/m^3)
cd = 0.23;      % Drag coefficient
eta = 0.8;      % Powertrain efficiency
ca = 0.12;      % Auxiliary consumption factor
m_vehicle = 1300; % Vehicle mass excluding battery (kg)

% Tesla (2170) Battery Pack: 96S46P configuration
x_2170 = 96;
y_2170 = 46;
Vcell_2170 = 3.65;   % V
Qcell_2170 = 4.60;   % Ah
num_cells_2170 = x_2170 * y_2170;
battery_mass_2170 = num_cells_2170 * 68.6e-3;  % cell mass * number of cells
m_total_2170 = m_vehicle + battery_mass_2170;
Vpack_2170 = x_2170 * Vcell_2170;
Qpack_2170 = y_2170 * Qcell_2170; % Ah
Epack_2170 = x_2170 * y_2170 * Vcell_2170 * Qcell_2170; % Wh

% Tesla (4680) Battery Pack: 92S9P configuration
x_4680 = 92;
y_4680 = 9;
Vcell_4680 = 3.6;  % V
Qcell_4680 = 22;   % Ah
num_cells_4680 = x_4680 * y_4680;
battery_mass_4680 = num_cells_4680 * 358e-3; % kg
m_total_4680 = m_vehicle + battery_mass_4680;
Vpack_4680 = x_4680 * Vcell_4680;
Qpack_4680 = y_4680 * Qcell_4680; % Ah
Epack_4680 = x_4680 * y_4680 * Vcell_4680 * Qcell_4680; % Wh
```

```matlab
%% Function to Analyze Cycle
function [P, I, s, E_vehicle, E_con, range] = analyze_cycle(time, v, a, m_total,
Vpack, Qpack, Epack, eta, ca, g, theta, cr, rho_air, cd, Af)
    dt = mean(diff(time));
    Qpack_As = Qpack * 3600; % Convert Ah to As

    % Compute Power P(t)
    P = (m_total*g*sind(theta) + cr*m_total*g*cosd(theta) + ...
         0.5*rho_air*cd*Af.*v.^2 + m_total.*a).*v;

    % Compute Current I(t)
    I = P / Vpack;

    % Compute SOC s(t) using Coulomb counting (Corrected sign)
    s = zeros(size(time));
    s(1) = 0.8; % Initial SOC = 80%
    for k = 2:length(time)
        s(k) = s(k-1) - (I(k)*dt)/Qpack_As;  % Use minus sign for discharge
    end

    % Compute Energy Used and Range
    Ed = sum(P(P > 0))*dt/3600; % Discharge energy in Wh
    Ec = sum(P(P < 0))*dt/3600; % Regen energy in Wh
    E_vehicle = (eta*Ec + Ed/eta)*(1 - ca); % Net vehicle energy considering
efficiency and auxiliaries

    % Distance traveled
    D = sum(v)*dt;    % meters
    D_km = D/1000;    % km

    % Energy consumption (Wh/km)
    E_con = E_vehicle/D_km;

    % Range (km)
    range = Epack / E_con;
end

%% Analyze Both Cycles for Tesla (2170)
[P_US06_2170, I_US06_2170, s_US06_2170, E_vehicle_US06_2170, E_con_US06_2170,
range_US06_2170] = ...
    analyze_cycle(time_US06, v_US06, a_US06, m_total_2170, Vpack_2170, Qpack_2170,
Epack_2170, eta, ca, g, theta, cr, rho_air, cd, Af);

[P_UDDS_2170, I_UDDS_2170, s_UDDS_2170, E_vehicle_UDDS_2170, E_con_UDDS_2170,
range_UDDS_2170] = ...
    analyze_cycle(time_UDDS, v_UDDS, a_UDDS, m_total_2170, Vpack_2170, Qpack_2170,
Epack_2170, eta, ca, g, theta, cr, rho_air, cd, Af);

%% Analyze Both Cycles for Tesla (4680)
[P_US06_4680, I_US06_4680, s_US06_4680, E_vehicle_US06_4680, E_con_US06_4680,
range_US06_4680] = ...
    analyze_cycle(time_US06, v_US06, a_US06, m_total_4680, Vpack_4680, Qpack_4680,
Epack_4680, eta, ca, g, theta, cr, rho_air, cd, Af);
```

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[P_UDDS_4680, I_UDDS_4680, s_UDDS_4680, E_vehicle_UDDS_4680, E_con_UDDS_4680,
range_UDDS_4680] = ...
    analyze_cycle(time_UDDS, v_UDDS, a_UDDS, m_total_4680, Vpack_4680, Qpack_4680,
Epack_4680, eta, ca, g, theta, cr, rho_air, cd, Af);

%% Presenting Results According to Questions

% Q1(a): Compute and Plot P(t) for Both Packs
figure('Name','Q1(a): P(t) Plots for Both Packs');
subplot(2,2,1);
plot(time_US06, P_US06_2170/1000);
xlabel('Time (s)'); ylabel('Power (kW)');
title('Q1(a): US06 Power - Tesla (2170)');

subplot(2,2,2);
plot(time_UDDS, P_UDDS_2170/1000);
xlabel('Time (s)'); ylabel('Power (kW)');
title('Q1(a): UDDS Power - Tesla (2170)');

subplot(2,2,3);
plot(time_US06, P_US06_4680/1000);
xlabel('Time (s)'); ylabel('Power (kW)');
title('Q1(a): US06 Power - Tesla (4680)');

subplot(2,2,4);
plot(time_UDDS, P_UDDS_4680/1000);
xlabel('Time (s)'); ylabel('Power (kW)');
title('Q1(a): UDDS Power - Tesla (4680)');

% Q1(b): Compute and Plot I(t) for Both Packs
figure('Name','Q1(b): I(t) Plots for Both Packs');
subplot(2,2,1);
plot(time_US06, I_US06_2170);
xlabel('Time (s)'); ylabel('Current (A)');
title('Q1(b): US06 Current - Tesla (2170)');

subplot(2,2,2);
plot(time_UDDS, I_UDDS_2170);
xlabel('Time (s)'); ylabel('Current (A)');
title('Q1(b): UDDS Current - Tesla (2170)');

subplot(2,2,3);
plot(time_US06, I_US06_4680);
xlabel('Time (s)'); ylabel('Current (A)');
title('Q1(b): US06 Current - Tesla (4680)');

subplot(2,2,4);
plot(time_UDDS, I_UDDS_4680);
xlabel('Time (s)'); ylabel('Current (A)');
title('Q1(b): UDDS Current - Tesla (4680)');

% Q1(c): Compute and Plot s(t) for Both Packs
figure('Name','Q1(c): s(t) Plots for Both Packs');
subplot(2,2,1);
plot(time_US06, s_US06_2170);
```

```
xlabel('Time (s)'); ylabel('SOC');
title('Q1(c): US06 SOC - Tesla (2170)');

subplot(2,2,2);
plot(time_UDDS, s_UDDS_2170);
xlabel('Time (s)'); ylabel('SOC');
title('Q1(c): UDDS SOC - Tesla (2170)');

subplot(2,2,3);
plot(time_US06, s_US06_4680);
xlabel('Time (s)'); ylabel('SOC');
title('Q1(c): US06 SOC - Tesla (4680)');

subplot(2,2,4);
plot(time_UDDS, s_UDDS_4680);
xlabel('Time (s)'); ylabel('SOC');
title('Q1(c): UDDS SOC - Tesla (4680)');

% Q2: Range for Both Packs and Cycles
disp('Q2: Range Estimations');
disp('--- Tesla (2170) Results ---');
disp(['US06 Range: ', num2str(range_US06_2170), ' km']);
disp(['UDDS Range: ', num2str(range_UDDS_2170), ' km']);

disp('--- Tesla (4680) Results ---');
disp(['US06 Range: ', num2str(range_US06_4680), ' km']);
disp(['UDDS Range: ', num2str(range_UDDS_4680), ' km']);
```