

Tutorial:- 2

Data Set Analysis

Data analysis is defined as a process of cleaning, transforming, and modeling data to discover useful information for business decision-making. The purpose of Data Analysis is to extract useful information from data and taking the decision based upon the data analysis.

Data collected from discharge cycles of Li-ion batteries cycled under various conditions are analyzed. The battery cycling data is sourced from a publically available repository; provided by the Prognostics Center of Excellence (PCoE) at Ames Research Center, NASA . The dataset referred consists of some different batteries used in this work, along with their respective operating parameters. The data repository contains capacity, voltage, current, temperature, current load and voltage load recorded for each discharge cycle of the batteries. Except the cell capacity, all other parameters are recorded over time during discharge; however these parameters are acquired with non-uniform sampling rate. It is observed that as battery ages there will be change in measured voltage, current and temperature. Hence it is paramount to extract the relevant features from these curves that are crucial in determining battery life. From each discharge cycle, a set of 8 parameters is extracted from voltage and temperature curves representing minimum and maximum values of each curve, and their respective times.

Capacity (Cap): The capacity of battery is computed by integrating discharge current over time.

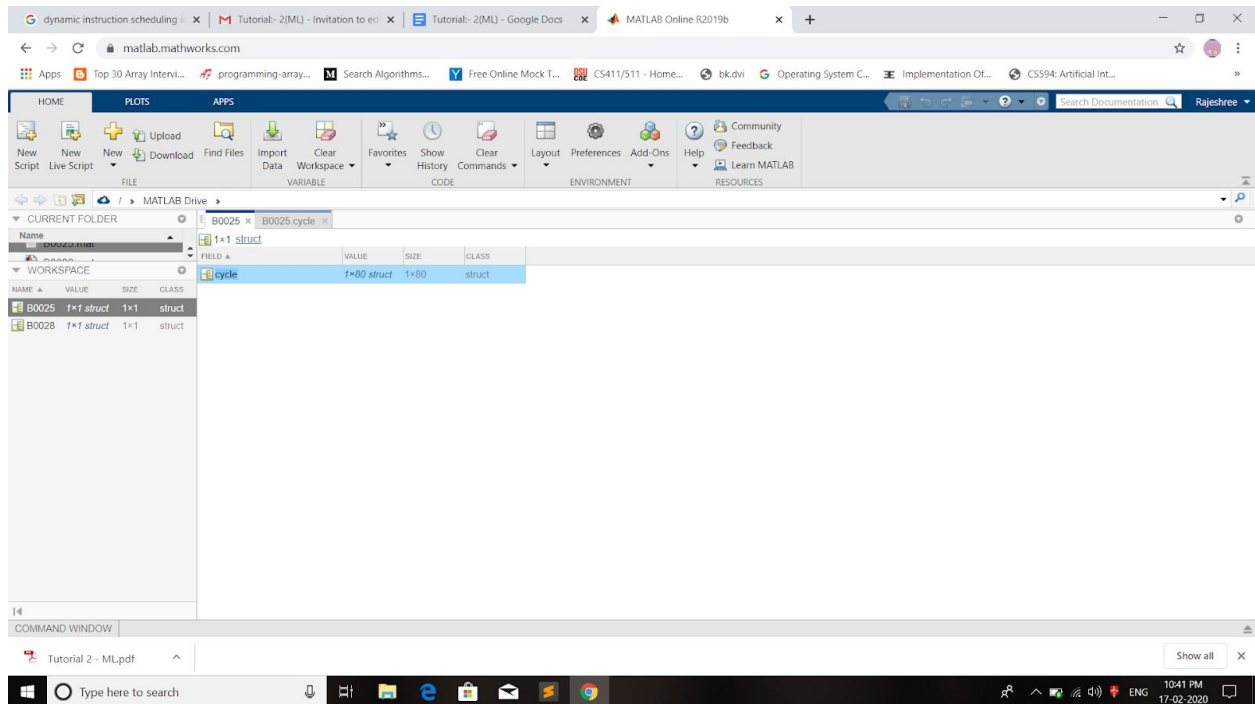
Voltage (V): Voltage is the pressure from an electrical circuit's power source that pushes charged electrons (current) through a conducting loop, enabling them to do work such as illuminating a light. It is a quantitative expression of the potential difference in charge between two points in an electrical field.
i.e Voltage measured at load (Volts) and Battery terminal voltage (Volts).

Current (I): Current is the flow of electrical charge carriers like electrons and flows from negative to positive points, i.e Battery output current (Amps) and Current measured at charger (Amps).

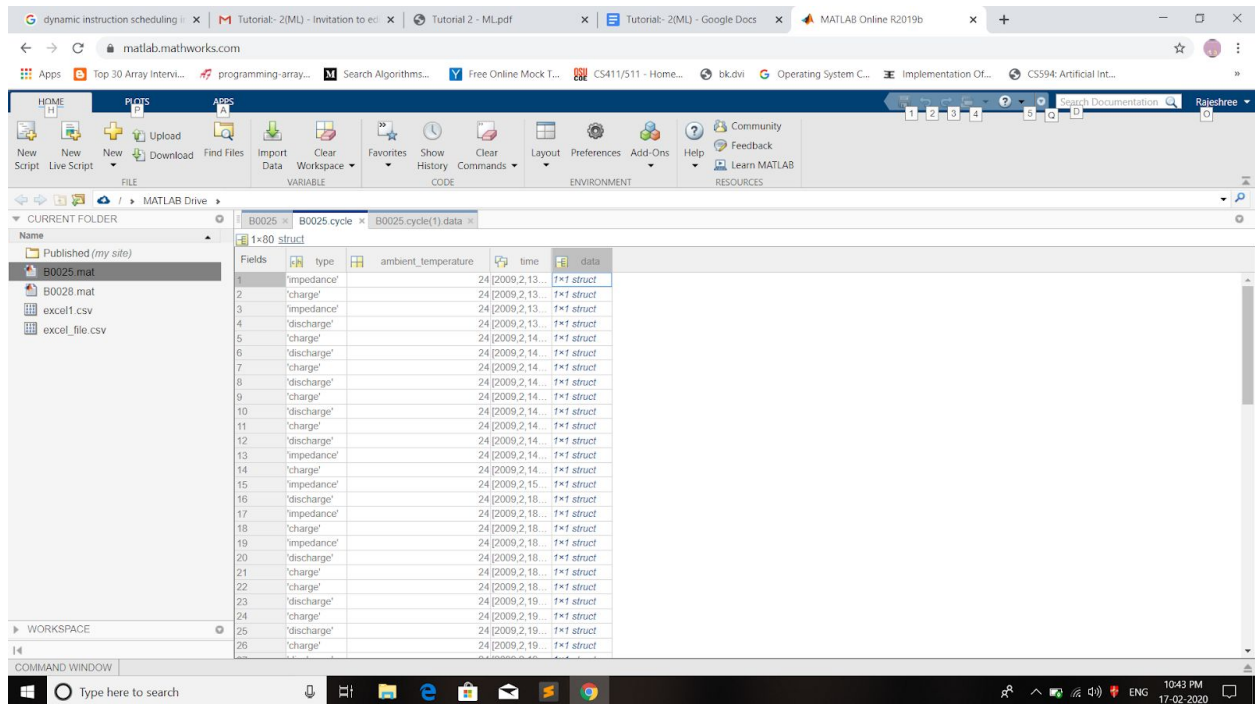
Temperature (T): Battery temperature (degree C).

Time measured: It is the time measured for the flow of voltage, current and temperature measured at each cycle. i.e.the date and time of the start of the cycle, in MATLAB date vector format.

Cycle:Top level structure array containing the charge, discharge and impedance operations



Type: operation type, can be charge, discharge or impedance



The screenshot displays the MATLAB Online R2019b interface. The browser tabs include 'dynamic instruction scheduling', 'Tutorial - 2(ML) - Invitation to ed...', 'Tutorial 2 - MLpdf', 'Tutorial - 2(ML) - Google Docs', and 'MATLAB Online R2019b'. The address bar shows 'matlab.mathworks.com'. The MATLAB interface features a top toolbar with options like 'New Script', 'Live Script', 'Download', 'Find Files', 'Import Data', 'Clear Workspace', 'Favorites', 'Show History', 'Clear Commands', 'Layout', 'Preferences', 'Add-Ons', 'Help', 'Community', 'Feedback', and 'Learn MATLAB'. The 'CURRENT FOLDER' pane on the left shows a folder named 'B0025' containing files 'B0025.mat', 'B0026.mat', 'excel1.csv', and 'excel_file.csv'. The main workspace displays a table with 26 rows and 5 columns: 'Fields', 'type', 'ambient_temperature', 'time', and 'data'. The 'type' column lists alternating 'impedance', 'charge', and 'discharge' operations. The 'time' column shows timestamps in the format '24[2009,2,13...'. The 'data' column indicates the data type as '1x1 struct'.

Fields	type	ambient_temperature	time	data
1	'impedance'		24[2009,2,13...	1x1 struct
2	'charge'		24[2009,2,13...	1x1 struct
3	'impedance'		24[2009,2,13...	1x1 struct
4	'discharge'		24[2009,2,13...	1x1 struct
5	'charge'		24[2009,2,14...	1x1 struct
6	'discharge'		24[2009,2,14...	1x1 struct
7	'charge'		24[2009,2,14...	1x1 struct
8	'discharge'		24[2009,2,14...	1x1 struct
9	'charge'		24[2009,2,14...	1x1 struct
10	'discharge'		24[2009,2,14...	1x1 struct
11	'charge'		24[2009,2,14...	1x1 struct
12	'discharge'		24[2009,2,14...	1x1 struct
13	'impedance'		24[2009,2,14...	1x1 struct
14	'charge'		24[2009,2,14...	1x1 struct
15	'impedance'		24[2009,2,15...	1x1 struct
16	'discharge'		24[2009,2,18...	1x1 struct
17	'impedance'		24[2009,2,18...	1x1 struct
18	'charge'		24[2009,2,18...	1x1 struct
19	'impedance'		24[2009,2,18...	1x1 struct
20	'discharge'		24[2009,2,18...	1x1 struct
21	'charge'		24[2009,2,18...	1x1 struct
22	'charge'		24[2009,2,18...	1x1 struct
23	'discharge'		24[2009,2,19...	1x1 struct
24	'charge'		24[2009,2,19...	1x1 struct
25	'discharge'		24[2009,2,19...	1x1 struct
26	'charge'		24[2009,2,19...	1x1 struct

For charge the fields are:

Voltage_measured: Battery terminal voltage (Volts)

Current_measured: Battery output current (Amps)

Temperature_measured: Battery temperature (degree C)

Time: Time vector for the cycle (secs)

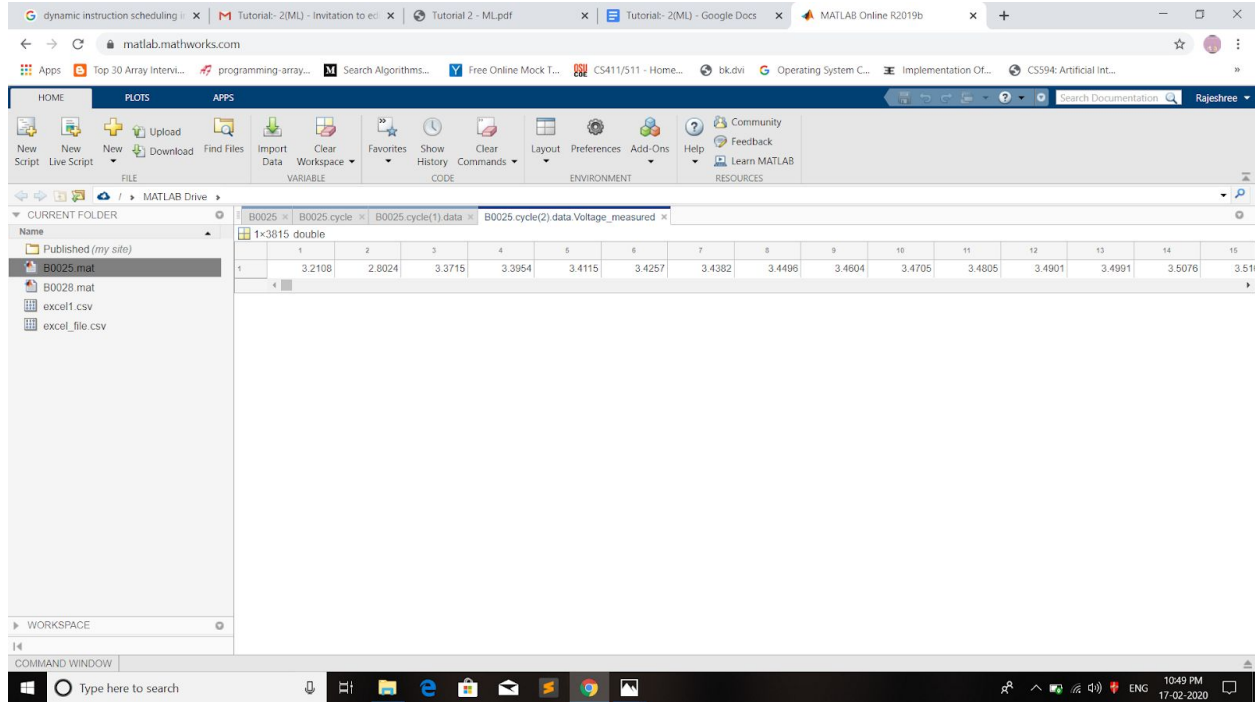
Capacity: Battery capacity (Ahr)

The screenshot displays the MATLAB Online R2019b web interface. The browser tabs include 'dynamic instruction scheduling', 'Tutorial- 2(ML) - Invitation to ed...', 'Tutorial 2 - ML.pdf', 'Tutorial- 2(ML) - Google Docs', and 'MATLAB Online R2019b'. The address bar shows 'matlab.mathworks.com'. The MATLAB interface features a top toolbar with options like 'New Live Script', 'New Script', 'Download', 'Find Files', 'Import Data', 'Clear Workspace', 'Favorites', 'Show History', 'Clear Commands', 'Layout', 'Preferences', 'Add-Ons', 'Help', 'Community', 'Feedback', and 'Learn MATLAB'. The left sidebar shows the 'CURRENT FOLDER' with files 'B0025.mat', 'B0028.mat', 'excel1.csv', and 'excel_file.csv'. The main workspace displays a '1x1 struct' with the following fields:

FIELD	VALUE	SIZE	CLASS
Voltage_measured	1x3815 do...	1x3815	double
Current_measured	1x3815 do...	1x3815	double
Temperature_measured	1x3815 do...	1x3815	double
Current_charge	1x3815 do...	1x3815	double
Voltage_charge	1x3815 do...	1x3815	double
Time	1x3815 do...	1x3815	double

The bottom of the interface shows a Windows taskbar with the search bar and system tray icons, including the date and time '10:46 PM 17-02-2020'.

Parameters and Values(Datatype)



For discharge the fields are:

Voltage_measured: Battery terminal voltage (Volts)

Current_measured: Battery output current (Amps)

Temperature_measured: Battery temperature (degree C)

Time: Time vector for the cycle (secs)

Capacity: Battery capacity (Ahr) for discharge till 2.7V

The screenshot displays the MATLAB Online R2019b interface. The top navigation bar includes tabs for 'HOME', 'PLOTS', and 'APPS'. Below this is a toolbar with icons for 'New Script', 'New Live Script', 'Upload', 'Download', 'Find Files', 'Import Data', 'Clear Workspace', 'Favorites', 'Show History', 'Clear Commands', 'Layout', 'Preferences', 'Add-Ons', 'Help', 'Feedback', 'Community', 'Learn MATLAB', and 'Resources'. The main workspace area shows a 'CURRENT FOLDER' on the left with a file list including 'B0025.mat', 'B0028.mat', 'excel1.csv', and 'excel_file.csv'. The 'WORKSPACE' pane on the right shows a '1x1 struct' with the following fields:

FIELD	VALUE	SIZE	CLASS
Sense_current	1x48 comp...	1x48	double (co...
Battery_current	1x48 comp...	1x48	double (co...
Current_ratio	1x48 comp...	1x48	double (co...
Battery_impedance	48x1 comp...	48x1	double (co...
Rectified_impedance	39x1 comp...	39x1	double (co...
Re	0.0505	1x1	double
Rct	0.0774	1x1	double

The 'COMMAND WINDOW' at the bottom shows the command '14'. The Windows taskbar at the very bottom includes a search bar and various application icons.

Parameters and Values(Datatype)

The screenshot displays the MATLAB Online R2019b web interface. The browser tabs include 'dynamic instruction scheduling', 'Tutorial- 2(ML) - Invitation to e...', 'Tutorial 2 - MLpdf', 'Tutorial- 2(ML) - Google Docs', and 'MATLAB Online R2019b'. The address bar shows 'matlab.mathworks.com'. The interface features a top navigation bar with 'HOME', 'PLOTS', and 'APPS' tabs. Below this is a toolbar with icons for 'New Script', 'New Live Script', 'Upload', 'Download', 'Find files', 'Import Data', 'Clear Workspace', 'Favorites', 'Show History', 'Clear Commands', 'Layout', 'Preferences', 'Add-Ons', 'Help', 'Community', 'Feedback', 'Learn MATLAB', and 'Rajeshree'. The main workspace is divided into two panes. The left pane, titled 'CURRENT FOLDER', shows a file tree with 'Published (my site)', 'B0025.mat', 'B0028.mat', 'excel1.csv', and 'excel_file.csv'. The right pane, titled 'WORKSPACE', shows a variable 'B0025' of type '1x641 double'. Below the workspace is a 'COMMAND WINDOW' with the prompt '14'. The Windows taskbar at the bottom shows the search bar, task view button, and several application icons. The system tray on the right indicates the time as 10:50 PM on 17-02-2020.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	4.1968	4.1970	3.7285	4.1961	3.7009	4.1475	3.6799	4.1328	3.6637	4.1210	3.6500	4.1103	3.6389	4.1008	3.62

For impedance the fields are:

Sense_current: Current in sense branch (Amps)

Battery_current: Current in battery branch (Amps)

Current_ratio: Ratio of the above currents

Battery_impedance: Battery impedance (Ohms) computed from raw data

Rectified_impedance: Calibrated and smoothed battery impedance (Ohms)

Re: Estimated electrolyte resistance (Ohms)

Rct: Estimated charge transfer resistance (Ohms)

The screenshot displays the MATLAB Online R2019b interface. The browser tabs at the top include 'dynamic instruction scheduling', 'Tutorial- 2(ML) - Invitation to e...', 'Tutorial 2 - ML.pdf', 'Tutorial- 2(ML) - Google Docs', and 'MATLAB Online R2019b'. The MATLAB interface shows the 'HOME' tab with various toolbars. The 'CURRENT FOLDER' pane on the left shows a file named 'B0025.mat'. The 'WORKSPACE' pane at the bottom shows a 1x1 struct named 'B0025.cycle(1).data'. The struct fields are listed in a table:

FIELD #	VALUE	SIZE	CLASS
1	Sense_current	1x48 comp... 1x48	double (co...
2	Battery_current	1x48 comp... 1x48	double (co...
3	Current_ratio	1x48 comp... 1x48	double (co...
4	Battery_impedance	48x1 comp... 48x1	double (co...
5	Rectified_impedance	39x1 comp... 39x1	double (co...
6	Re	0.0506 1x1	double
7	Rct	0.1059 1x1	double

The Windows taskbar at the bottom shows the time as 10:43 PM on 17-02-2020.

Parameters and Values(Datatype)

The screenshot displays the MATLAB Online R2019b web interface. The browser tabs include 'dynamic instruction scheduling', 'Tutorial- 2(ML) - Invitation to e...', 'Tutorial 2 - ML.pdf', 'Tutorial- 2(ML) - Google Docs', and 'MATLAB Online R2019b'. The address bar shows 'matlab.mathworks.com'. The interface features a top navigation bar with 'HOME', 'PLOTS', and 'APPS' tabs. Below this is a toolbar with icons for 'New Script', 'New Live Script', 'Upload', 'Download', 'Find Files', 'Import Data', 'Clear Workspace', 'Favorites', 'Show History', 'Clear Commands', 'Layout', 'Preferences', 'Add-Ons', 'Help', 'Community', 'Feedback', 'Learn MATLAB', and 'Resources'. The main workspace is divided into two panes. The left pane, titled 'CURRENT FOLDER', shows a file tree with 'Published (my site)', 'B0025.mat', 'B0028.mat', 'excel1.csv', and 'excel_file.csv'. The right pane, titled 'WORKSPACE', displays a variable 'B0025' of type '1x48 complex double'. The variable is expanded, showing a table of values. The table has 48 columns and 1 row. The values are complex numbers in scientific notation, ranging from 8.4110e+02 to 8.3070e+02. The bottom status bar shows the Windows taskbar with the search bar, taskbar icons, and system clock (10:50 PM, 17-02-2020).

	1	2	3	4	5	6	7	8	9	10	
1	8.4110e+02 - 3.10...	8.3678e+02 - 4.39...	8.3624e+02 - 5.41...	8.3673e+02 - 5.90...	8.3246e+02 - 5.75...	8.3499e+02 - 6.13...	8.3291e+02 - 6.22...	8.3106e+02 - 6.68...	8.3094e+02 - 6.80...	8.3070e+02 - 6.80...	8...