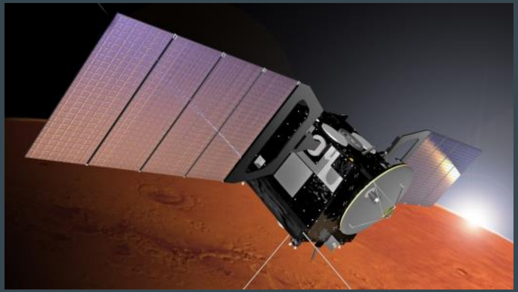
Mars Express Power Challenge

Group 6 BAE Systems

About Mars Express Orbiter (MEX)

- A spacecraft launched by the European Space Agency (ESA) in 2003.
- Provides invaluable scientific data.
- Contains an autonomous thermal system for regulating temperature.
- Uses electric power from solar panels (or batteries during eclipses)
    - **Science Power = Produced Power - Platform Power - Thermal Power**
- Predicting power consumption is crucial for optimising space operations and ensuring the longevity of MEX.



About the Mars Express Challenge

- MEX Flight Control Team from ESA collected three Martian years' (2061 Earth days, from 22/08/2008 to 14/04/2014) worth of MEX's telemetry data.
- Data was then released as part of a machine learning challenge in 2016.
- Develop predictive models that could predict the average electric current of 33 power lines per hour for the fourth Martian year (687 Earth days, from 14/04/2014 to 01/03/2016).

Objectives

- Develop a machine learning model to predict the average hourly electric current for each of the 33 thermal power lines on MEX.

- Evaluate the model's performance using Root Mean Squared Error (RMSE).

- Present our findings to Mr Gordon and the UoM team.

About the Data

- Dataset included four Martian years of data, categorised into two main parts:
  - Context data (independent variables):
    - SAAF
    - FTL
    - DMOP
    - EVTF
    - LTDATA
  - Observation data (dependent variable):
    - Hourly electric current measurements for each of the 33 power lines over the first three Martian years.
- The observation data for the fourth Martian year was never released.
  - Our project uses 20% of Year 1-3 data as unseen test data.

Project Timeline

Task	12 Feb - 18 Feb	19 Feb - 25 Feb	26 Feb - 3 Mar	4 Mar - 10 Mar	11 Mar - 17 Mar	8 Apr - 14 Apr	15 Apr - 21 Apr	22 Apr - 28 Apr	29 Apr - 5 May	6 May - End
Background research										
Reading accompanying literature										
Reading existing solution papers										
Sharing and collaborating research										
EDA and pre-processing										
Data cleaning										
EDA										
Feature engineering										
Resampling, interpolation and merging										
Model development and testing										
Discussion on approach										
Identifying important features										
Building model 1 (extra trees)										
Building model 2 (XGBoost)										
Hyperparameter tuning										
Model ensembling										
Writing the report										
Planning										
Creating visualisations										
Introduction										
Pre-processing section										
Machine learning section										
Results section										
Conclusion										
Creating the presentation										
Creating slides										
Script writing and rehearsal										

SAAF (Solar Aspect Angles) Files

- Provide information about the spacecraft's orientation with respect to the Sun:
  - ut_ms: Unix timestamp in milliseconds
  - sa: Solar aspect angle (angle between the spacecraft's solar panels and the Sun-MEX line)
  - sx, sy, sz: Solar angles of the X, Y, and Z axes of the satellite, respectively

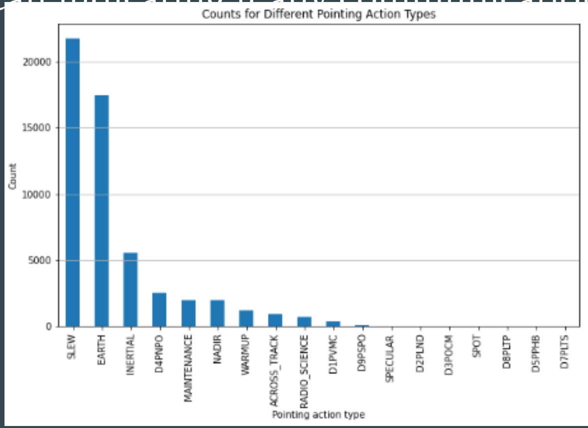
DMOP (Detailed Mission Operations Plan) Files

- Contain commands sent to various subsystems of the spacecraft:
    - ut_ms: Unix timestamp in milliseconds
    - subsystem: Name of the operated subsystem command

ut_ms	subsystem
1.21936E+12	AXXX301A
1.21936E+12	AAAAF20C1
1.21936E+12	AAAAF57A1
1.21936E+12	AAAAF23G1
1.21936E+12	AAAAF60A1
1.21937E+12	AXXX305A
1.21937E+12	AXXX380A
1.21937E+12	ASEQ4200
1.21937E+12	ATTTF301E
1.21937E+12	ATTTF310A
1.21937E+12	APSF01A2
1.21937E+12	APSF02A1
1.21937E+12	APSF89A1

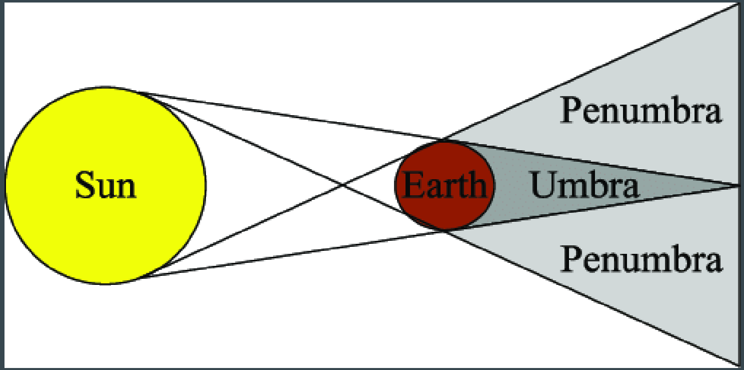
FTL (Flight Dynamics Timeline) Files

- Contain spacecraft pointing events:
  - utb_ms: Unix timestamp in milliseconds of the beginning of the pointing period
  - ute_ms: Unix timestamp in milliseconds of the end of the pointing period
  - type: Type of pointing or action
  - flagcomms: Boolean indicating if any communication device was used



EVTF (Event Files)

- (Event) files, which contain descriptions of other events such as umbras, penumbras, or changes in altitude:
    - ut_ms: Unix timestamp in milliseconds
    - description: Short description of the event



ut_ms	description
1.21936E+12	MLG_LOS_05_/_RTLT_02373
1.21936E+12	NNO_AOS_00_/_RTLT_02373
1.21937E+12	MLG_LOS_02_/_RTLT_02373
1.21937E+12	NNO_AOS_05_/_RTLT_02373
1.21937E+12	NNO_AOS_10_/_RTLT_02374
1.21937E+12	4000_KM_DESCEND
1.21937E+12	MRB_/_RANGE_06000KM_START
1.21937E+12	OCC_MARS_200KM_START_/_RA_181.68_/_DE_-00.08_/_OMP_(296.35,-46.48)_/_SZA_077
1.21937E+12	OCC_MARS_START_/_RA_181.69_/_DE_-00.08_/_OMP_(299.32,-43.44)_/_SZA_076
1.21937E+12	2000_KM_DESCEND
1.21937E+12	MRB_AOS_00
1.21937E+12	1200_KM_DESCEND

LTDATA (Long-Term Data) Files

- Provide daily measurements of various parameters related to the spacecraft's environment:
    - ut_ms: Unix timestamp in milliseconds (one sample per day)
    - sunmars_km: Distance between the Sun and Mars in kilometers
    - earthmars_km: Distance between Earth and Mars in kilometers
    - sunmarsearthangle_deg: Sun-Mars-Earth angle in degrees
    - solarconstantmars: Solar constant at Mars in W/m^2
    - eclipseduration_min: Total duration of all eclipses in the day, in minutes
    - occultationduration_min: Total duration of all occultations in the day, in minutes

Feature Engineering

Context File	Features Selected	Comment
SAAF	sa, sx, sy, sz	No additional feature engineering was necessary.
DMOP	command, ON/OFF pairs, no_of_subsystem_commands	Various engineering attempts made. Referred to an existing solution on Github for ON/OFF pairs.
FTL	flagcomms, pointing action types	Dummy variables created for different pointing action type.
EVTF	altitude, direction, umbra, penumbra, time_since_last_pericentre_ms	Converting strings into various binary and integer features.
LTDATA	earthmars_km, sunmarsearthangle_deg, solarconstantmars, eclipseduration_min, occultationduration_min	No additional feature engineering was necessary.

Data Resampling and Merging

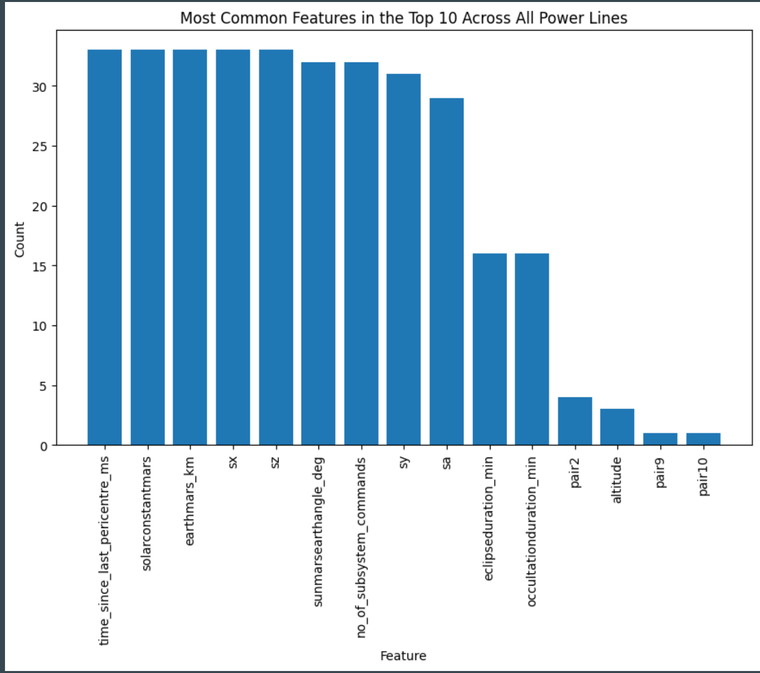
- Context files initially contained varying time granularities and date ranges.
- Solution: Resampling all files to a consistent hourly time granularity.
    - Initially considered a time granularity of 30 seconds, but found it infeasible.
    - Techniques used:
        - Linear interpolation and mean imputation for numerical features.
        - Forward or backward filling for binary features.
- The resampled files were then merged into a single dataset.

Feature Selection

- Built 33 simple Extra Trees models for each power line.

- Extracted feature importances.

- Picked the top 20 for each power line.



Predicting the Thermal Power Consumption

- Models:
  - Extra Trees:
    - Well-suited for large, high-dimensional datasets.
    - Effective for feature importance identification.
    - Reduces overfitting through random thresholds.
  - XGBoost:
    - Handles large datasets efficiently.
    - Delivers high predictive performance.
    - Tackles complex relationships within the data.
- Performed hyperparameter tuning using a random search and cross-validation.
- Used ensembling to leverage the strengths of both, creating a third model.

Results

- Extra Trees Mean RMSE: 0.0981
- XGBoost Mean RMSE: 0.0978
- Ensemble Mean RMSE: 0.0976

Challenges and Improvements

- Lack of official documentation

- Incorporation of lag features

- Sheer size of the dataset

References

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