ISRO's Web-Based Automatic Identification of Solar Bursts in X-RAY Light Curves

Introduction

Problem Statement:
Build a stand-alone web-based application using open-source software(s) to identify and categorize X-ray bursts.

Data Source:
To train our data and get the mathematical foreground of the burst, data was taken from [ISRO's PRADAN website]() for Solar X-Ray data.

Setup and Installation:

- The dependencies are mentioned in requirements.txt.
- Then install them by "pip install -r requirements.txt"
- to run the web application, do "python3 main.py"

Requirements Satisfied:

- App will accept input file of light curve data encoded in FITS format.
- Upon uploading the input data file, logic returns a python dictionary with following parameters:
  - t_start: list of instances when our solar burst starts (sampled from x)
  - t_stop: list of instances when our solar burst ends (sampled from x)
    - above two features give us the regions of insterest.
  - category: list of categories of the solar bursts detected
  - peak count rate: list of peak count rates for all the solar bursts
  - peak instance: list of instances of maxima of burst rate count (sampled from y)
  - rise instance: list of instance corresponding to the **rise time of solar burst** (sampled from x)
  - decay instance: same as rise instance
  - i_start: same as t_start but rather stores the index of **x** instead of value
  - i_stop: same as t_stop but rather stores the index of **x** instead of value
  - i_peak: same as peak_instance but rather stores the index of **x** instead of value
  - i_rise: same as rise_instance but rather stores the index of **x** instead of value
  - i_decay: same as decay_instance but rather stores the index of **x** instead of value

For a given light curve, we can extract 2 columns, y(count rate) and x(corresponding time), and the length of these 2 columns is equivalent to the count of seconds in a day.

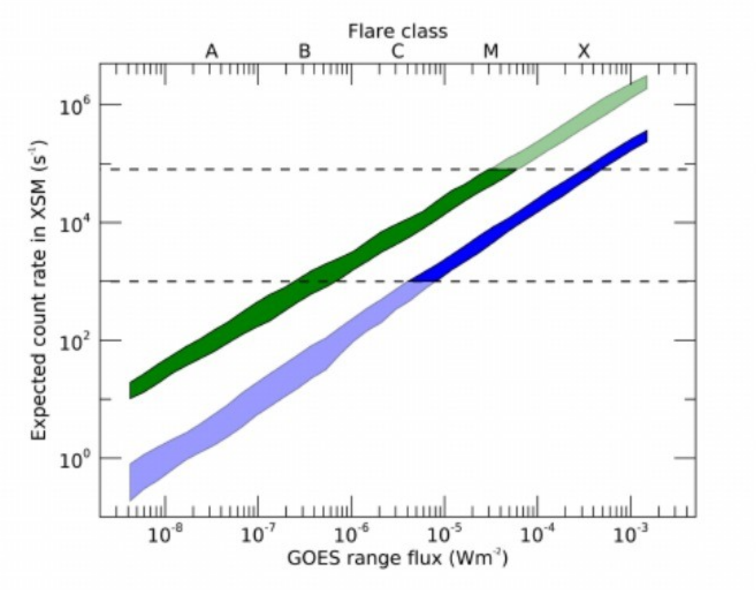
- This data is then taken by the app and presented in a 'JSON' format which can be saved and exported.
- Entire project developement uses open-source softwares and entire classification process is handled statistically.

Definitions and Assumptions:

- The flare end time is defined as the time when the flux reading recovers to one-half of its maximum, where the maximum is the flux value at the start of the event minus the flux value at the start of the event.
- We define flare length as the total time between the reported flare start time and the flare end time; rise time is the time between the flare start time and the time of maximum flare; and decay time is the time between the time of maximum flare and the flare end time.
- To determine the flare start time, we took the time of the peak as originally reported and searched back to discover the time when the SRS (soft X Ray) flux was either 5% of the peak flux or 5% of the peak flux.
- A figure of 5% was established to account for preflare heating and to guarantee that if another peak occurred before to the flare of interest, the start time would fall between the two flares.
- We calculated the flare termination time by looking ahead from the initially stated peak time to the time when the SXR flux reduced to 50% of the peak value.
- If flare end time of a sloar flare comes after flare start time of another solar burst (i.e two solar bursts happen simultaneously), then then it will be comsidered as a single burst.
- Classification criteria was taken as:

Classification	Approximate peak flux range at 0.1-0.8 nanometre (watts/square metre)
A	$< 10^{-7}$
B	$10^{-7} – 10^{-6}$
C	$10^{-6} – 10^{-5}$
M	$10^{-5} – 10^{-4}$
X	$> 10^{-4}$

- However the light curve data provided to us gives plot of count_rate(y) with respect to time(x) instead of flux w.r.t time. For our use case, we had to map count rate to flux, for classification according to above criteria.



- This was referenced from the paper titled: [Solar X-ray Monitor On Board the Chandrayaan-2 Orbiter: In-flight Performance and Science Prospects]

- From the above plot, count rate follows flux almost linearly and was approximated similarly:

Index	Count rate: lower bound	Count rate: upper bound	Class
1.	63.09	630.95	A
2.	630.95	5011.87	B
3.	5011.87	25118.86	C
4.	25118.86	251188.6	M
5.	251188.6	~	X

  - ***the above mapping is approximate and can have edge errors.**

- The XSM module is operational periodically through out the day (with time periods of 2 hours approximately) and therefore sometimes, it may start recording the flux of solar flare after it has peaked.

  - The Sun angle with regard to the instrument boresight varies with half the orbital period throughout observations (120 minutes). As a result, the effective area for Sun observations varies, which is rectified by the analysis programme. However, it is possible that minor residual impacts of these differences will remain in the light curves. As a result, any periodicities seen in the data that correspond to the orbital period of Chandrayaan-2 or its harmonics will be disregarded.

  - For the reasons indicated above, we will disregard such incomplete solar flares and treat them as residual noise.

- Additionally, a condition for mimimum flare duration was set to be 2 minutes.

Code Explanation:

- Entirety of classification was done using a statistical model as explained above.

- All of this was abstracted using a function **extractor(...).** Function takes the following parameters:

    - signal- numpy array of count rate
    - time- numpy array of time instances corresponding to the count rate

- extractor() returns a python dictionary with following keys:

    - t_start: list of instances when our solar burst starts (sampled from x)
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        - above two features give us the regions of insterest.

    - category: list of categories of the solar bursts detected
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- Due to limitations which will be discussed later, **stable()** which is called within the **extractor()** normalizes the signal to remove maximum possible noise to **reduce false predicitions.**

    - **Stable(...):** takes numpy array as input and returns normalized numpy array

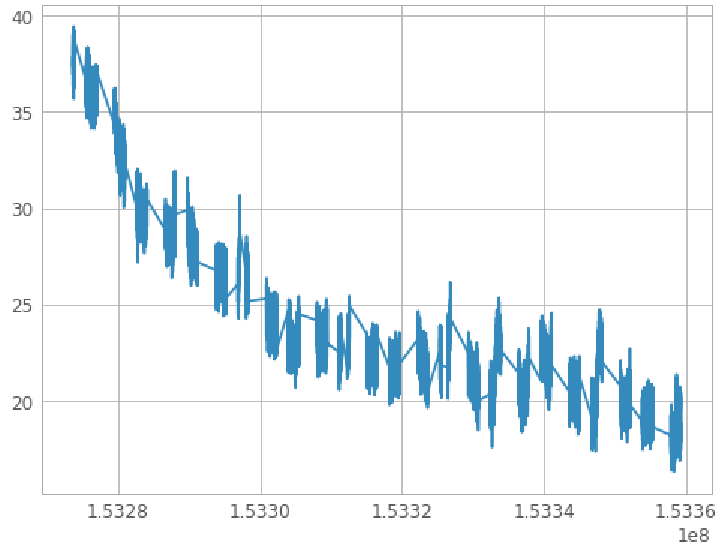
- Using this normalized array, we extract our regions of interest.

- Using above assumptions, definitions and helper functions; we calculated all the required parameters which were then passed to our app.

Limitations:

- **Limitation 1**:

Count rate of ‘A’ type solar burst varies from 63/s to 630/s second. This is the range where the noise of the XSM falls in as well.



- Also the bins of categorization are not equal. It is very narrow (merely 567/s approx.) for ‘A’ type and is very vast (more than 226K/s) for ‘M’ type. Since this all is done by a single instrument, it faces calliberation issues.

- Attempt to denoise the signal results in loss of information, especially for ‘A’ type. This leads to very poor prediction of type ‘A’. **To avoid false prediction, classification of type ‘A’ bursts were omitted.**

- **Limitation 2:**
  As the input data was not multi-spectral, two overlapping solar bursts cannot be differentiated, and therefore are being considered as same single burst.

References:

1. https://www.researchgate.net/publication/344334937_Solar_X-ray_Monitor_On_Board_the_Chandrayaan-2_Orbiter_In-flight_Performance_and_Science_Prospects
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