Transformers and Deep Learning for Satellite Manoeuvre Detection

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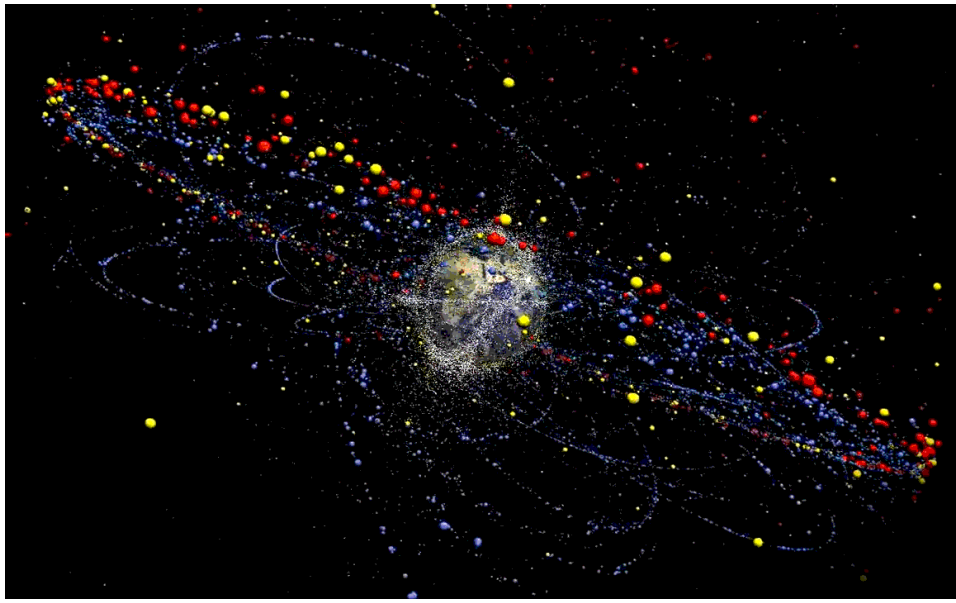
Geostationary Environment

The Geostationary Belt (Courtesy of Roberts 2020)



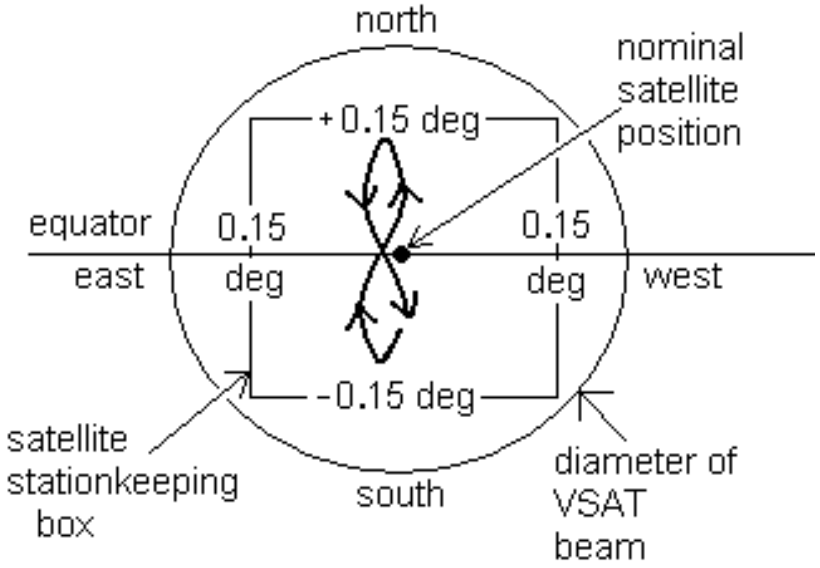
Space Environment (Courtesy of TUB)

Orbital Characteristics

- Circular orbit at an altitude of approximately 35,786 km.
- Zero inclination, meaning the satellite stays above the equator.
- The satellite appears stationary relative to a fixed point on Earth.

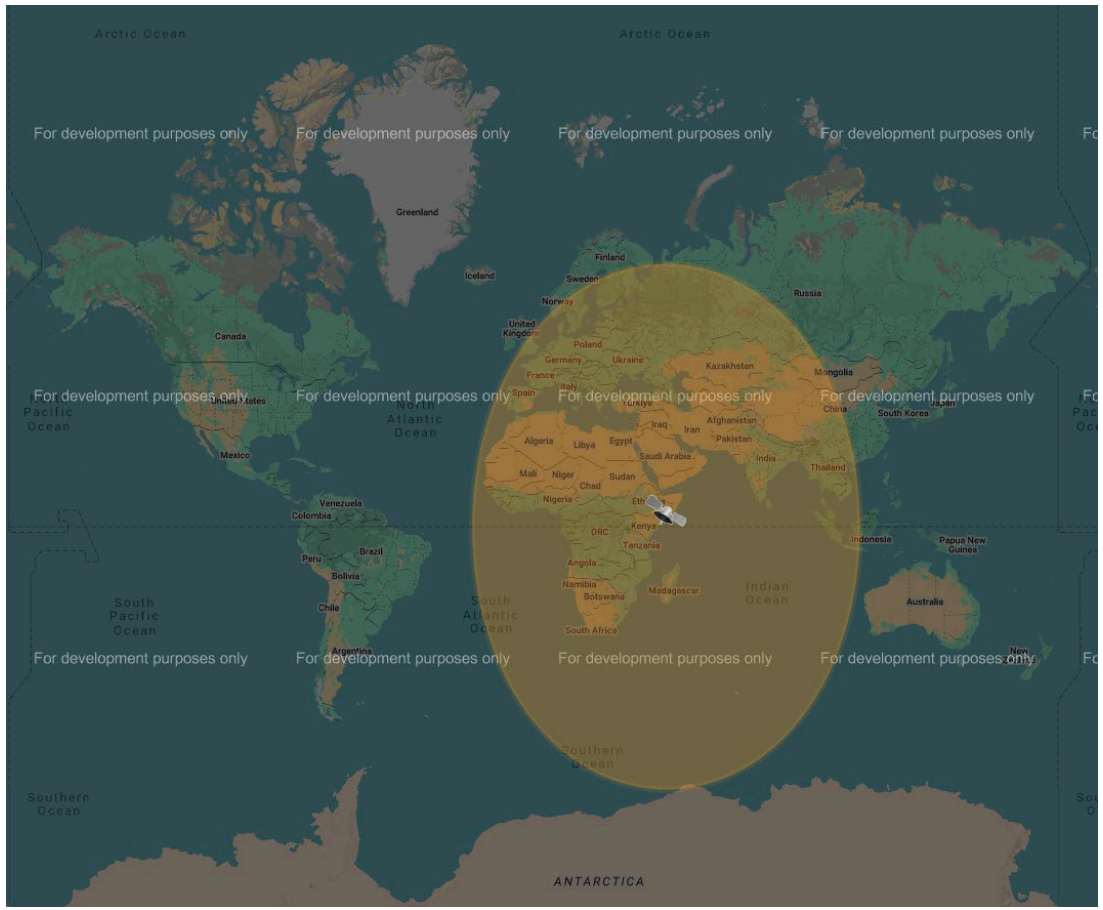
Applications

- Telecommunications, weather monitoring, navigation and timing, etc.

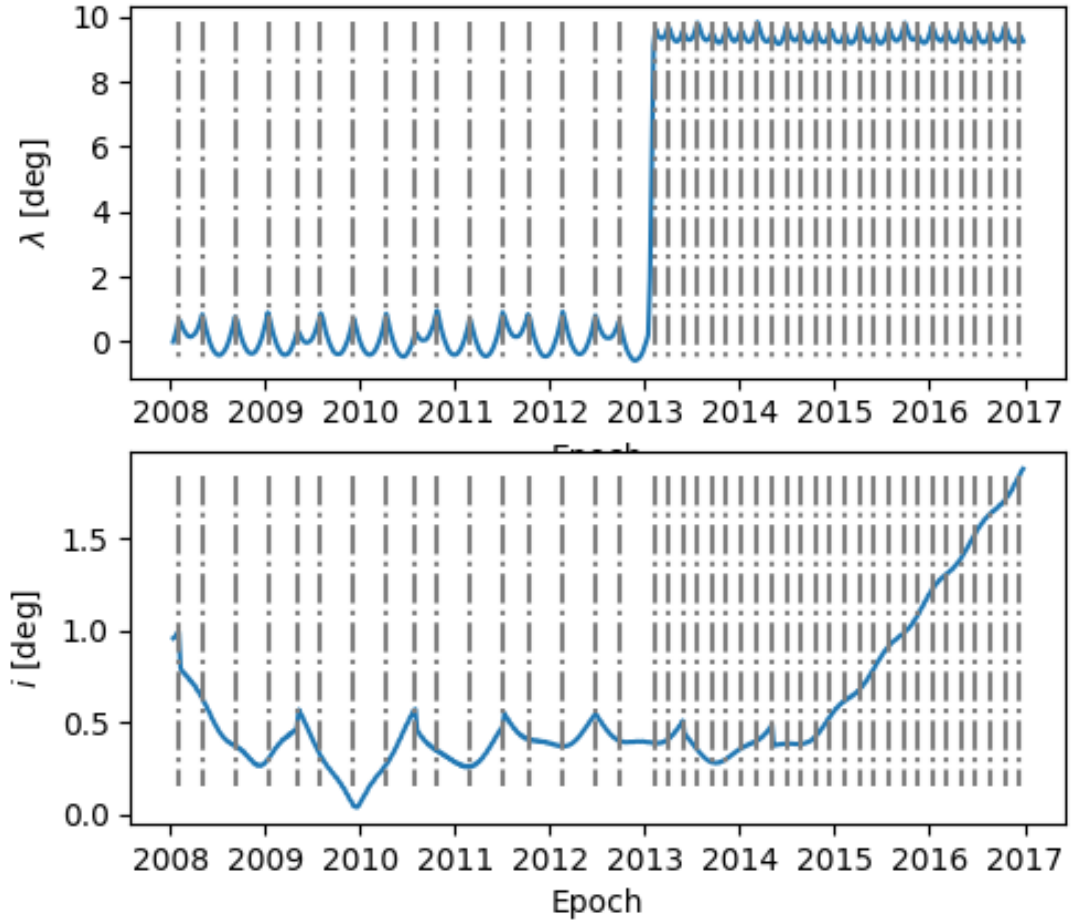


Station-Keeping of GEO Satellites (Courtesy of Satellite Signals)

Time Series of MeteoSat9 Manoeuvres



MeteoSat9 Location and Field of View (Courtesy of OSCAR)



MeteoSat9 Orbital Elements (Retrieved from Two-line Elements)

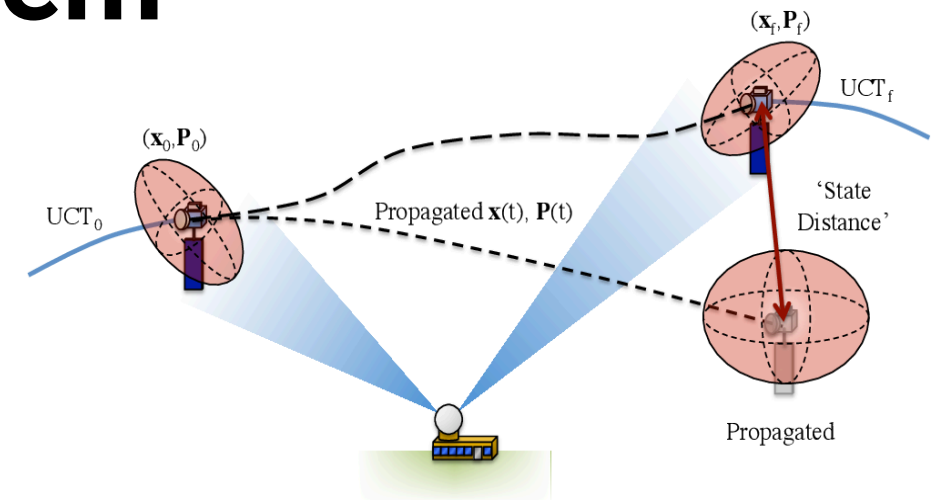
Research Problem

Motivation - Space Sustainability

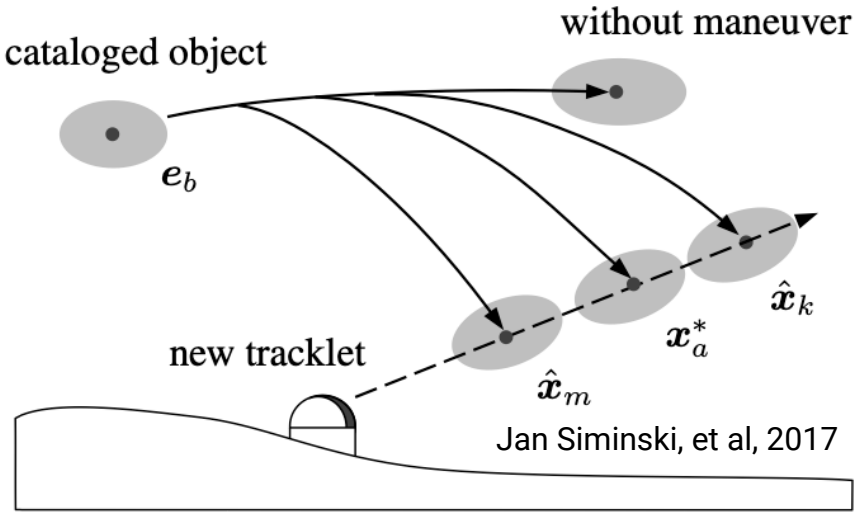
- Catalogue Maintenance
- IADC Space Debris Mitigation Guidelines

Challenges - Sporadic Satellite Tracking Data

- Irregular Observations: Optical tracking data is collected at uneven intervals.
- Rare Manoeuvres: Manoeuvres are infrequent compared to the prevalence of non-manoeuvre events.
- Missed Manoeuvre Periods: Manoeuvres may occur during gaps when sensors are not observing.

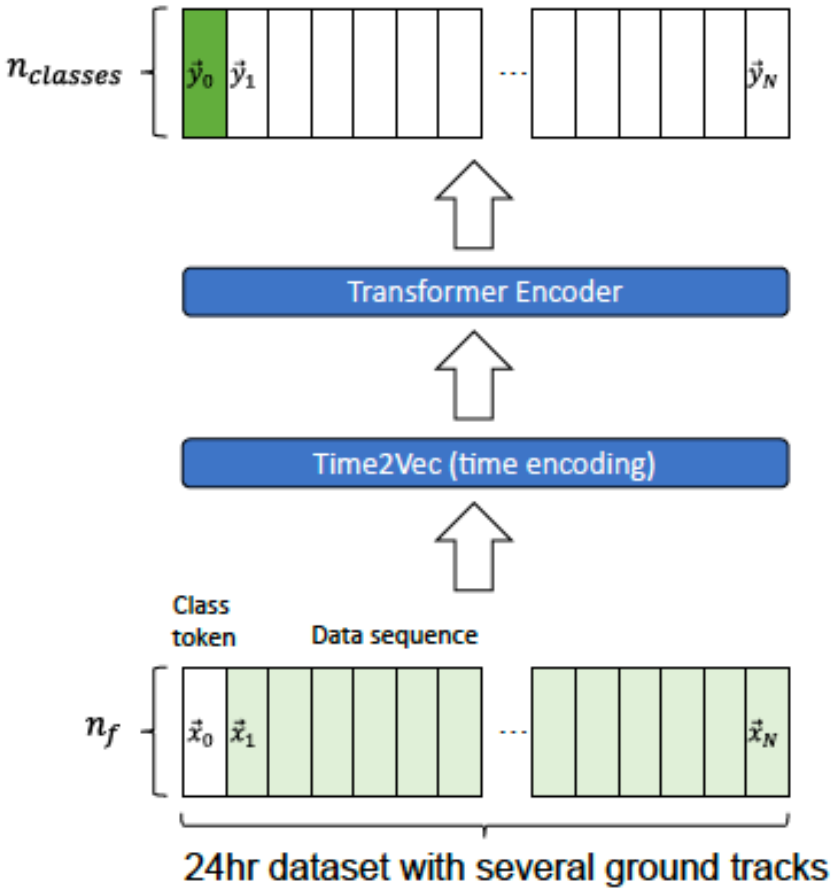


M. Holzinger and D. Scheeres, 2010



Jan Siminski, et al, 2017

Transformers and LSTM for Satellite Manoeuvre Detection



Measurement Transformer Architecture
(Courtesy of Popplewell & Re 2024)

Transformers: Excel at capturing long-range dependencies in sporadic tracking data.

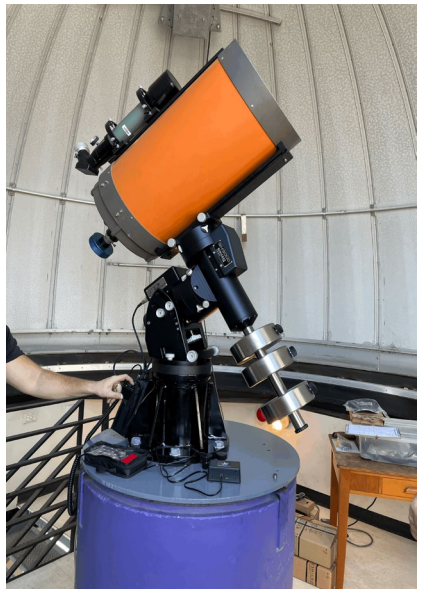
LSTM (Long Short-Term Memory): Effective for sequential data, modelling temporal dynamics.

Hybrid Approach: Combining LSTM and Transformers leverages both temporal and contextual features for enhanced manoeuvre detection accuracy.

Data Source

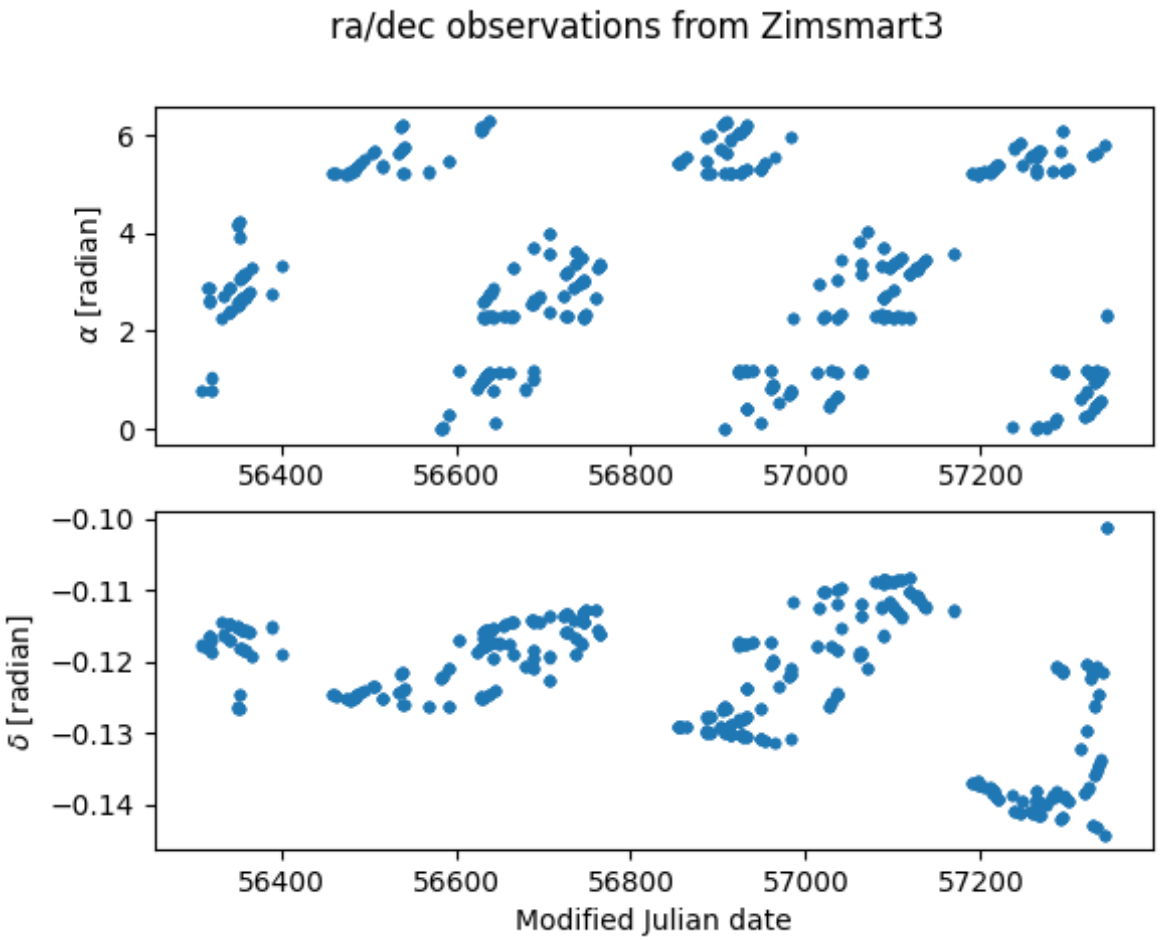
- Real-life datasets
  - Optical tracking data for our telescopes
- Simulated datasets
  - Synthetic datasets generated by our astrodynamics tools
- Existing datasets
  - E.g., MIT The Satellite Pattern-of-Life Identification Dataset (SPLID)

UNSW Observatory



UNSW C14 Telescope

MeteoSat9 - Optical Data



- Optical data from Zimmerwald observatory of AIUB (Courtesy of **Dr Jan Siminski** (ESA/ESOC) and **Prof Thomas Schildknecht** (AIUB))

Table 1: Maneuver epochs and observation epochs.

#	*Type*	*Maneuver*	*Observation*
1	EWSK	2014-01-08 07:13	2014-01-08 21:50
2	EWSK	2014-03-11 08:43	2014-03-12 03:49
3	SLEW	2014-04-08 10:58	2014-04-10 03:13
4	EWSK	2014-08-27 05:48	2014-09-01 20:45
5	EWSK	2014-10-22 07:13	2014-10-23 17:55
6	EWSK	2014-12-17 22:58	2014-12-18 23:09
7	EWSK	2015-02-09 06:58	2015-02-10 02:11
8	EWSK	2015-09-29 05:28	2015-09-30 18:47

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Any questions?

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