4/10/2025

Change #001: Utilize Delta Time
Deltas: in the context of a time series model are the change in value between successive time steps rather than the values themselves.

For our satellite data, each state is a position and velocity vector [rt, vt]

The delta is simply the difference from the previous state.

$$[\Delta rt, \Delta vt] \ = \ [r(t) \ - r(t - 1), \, v(t) \ - v(t - 1)]$$

Change in position and change in velocity. So instead of the model learning where the satellite is at time t, it is learning how the position and velocity vectors change each step.

As of up until now, we have been training the model on absolute state vectors. My hypothesis is that this is much harder to learn than observing local changes over time.

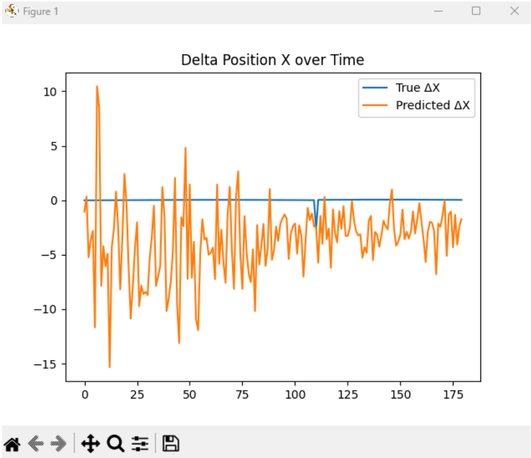
Change 1: normalized time step in OrbitDataset class,
Epoch: 30/50 | Train Loss: 0.017032 (Pos: 0.006106, Vel: 0.010926) | Val Loss: 0.010146 (Pos: 0.000922, Vel: 0.009224)

Change #002: Normalize Deltas Separately

Position and velocity values are currently being normalized independently but their delta values are not normalized. This could be leading to inconsistent training.

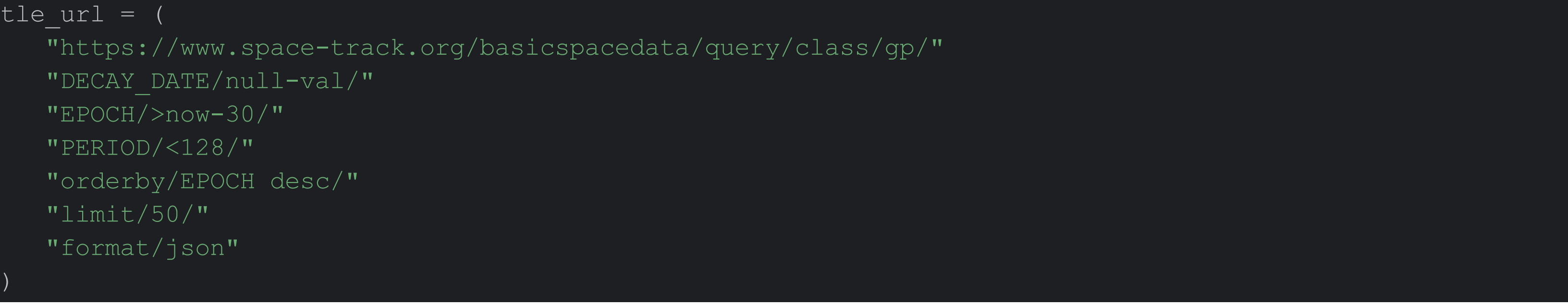
Change 2: normalized delta values separately in OrbitDataset class,
Epoch: 13/50 | Train Loss: 0.116235 (Pos: 0.005885, Vel: 0.110350) | Val Loss: 0.149951 (Pos: 0.000593, Vel: 0.149357)

Change #003: Improve data quality
I suspected that the TLE data we have may not all be pertinent to Low Earth Orbiting satellites. This would be due to an imperfect API query from Space-track.org. So I improved our API call, propagated the new TLE's with SGP4 and seemingly made an improvement to the model's learning.

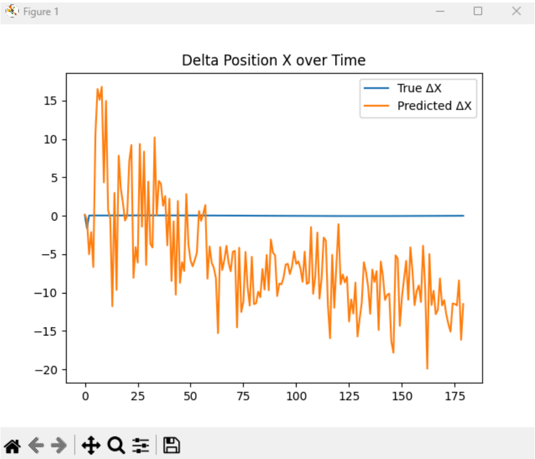


Here is the error over time. Unidentified behavior is happening on the ground truth plot, between 100-125 time steps. I will be investigating this.

Tweaked the API call further to improve it, here's the associated error over time graph.
Here is the latest API query



```
tle_url = (
    "https://www.space-track.org/basicspacedata/query/class/gp/"
    "DECAY_DATE/null-val/"
    "EPOCH/>now-30/"
    "PERIOD/<128/"
    "orderby/EPOCH desc/"
    "limit/50/"
    "format/json"
)
```



Delta Position X over Time

4/15/2025

Change #004: Tuned hyperparameters, reduced model size, seq_size, and pred_size increased from 2 to 180. Model training time was literally 8 hours for not even 1 epoch. Lowered from 180 to 60 and model training time became 30 minutes per epoch. Model training time used to be 30 seconds, so 60 times longer. However the model should be much more accurate when trained on more orbits than trying to predict. I stopped training after 8 epochs because clearly this was taking too long and the loss was still too high, especially on **velocity**.

Change #005: Velocity has always been hard for our model to learn how to accurately predict. So I am dropping velocity since we can always calculate it later using position. Position validation loss has been as low as 0.000037 at points whereas velocity loss would be ~0.03. Calculating velocity is $v = \frac{\Delta r}{\Delta t}$

4/16/2025 Change #006: Batching per satellite. This will prevent data leakage so that we don't mix training and validation from the same satellite nor inflate validation scores due to temporal leakage

4/17/2025 Change #007: Architecture swap from Transformer to GRU for the project’s minimum viable product.