The University of Texas Rio Grande Valley
Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (MECIS)

Drone Position and Attitude Estimation with Neural Networks

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Abstract

Drones have wide usage, but do not always have GPS signal available for navigation. This project will attempt to train a neural network model for position and attitude estimation from IMU measurements in GPS denied environments.

Introduction & Background

Drones typically attempt to follow a pre-planned set of [x y z] coordinates over time, or the desired trajectory. The drone needs to be able to estimate how close it is to the desired [x y z] position at each timestep to determine how well the trajectory is followed. The orientation of the drone, or the attitude, also needs to be known so the drone can correctly calculate the thrust and torque needed to continue following the trajectory. The following equations of motion depict why the attitude of the drone needs to be known.

Equations:

Position = $p = [x\ y\ z]^{\mathrm{T}}$ Acc = $\ddot{p} = \frac{d^2p}{dt^2}$

Angular velocity = Ω Angular acc = $\dot{\Omega} = \frac{d\Omega}{dt}$

Acc of gravity = g Mass = m

Thrust = T Rotation Matrix = R

Torque = τ Inertia Matrix = I

Ext Forces = F_{ext} Ext Moments = M_{ext}

Vertical Earth Vector = $\hat{z}_e$

Euler Angles (attitude) = $\Theta = [\phi\ \theta\ \psi]^{\mathrm{T}}$

Forces: $m\ddot{p} = mg\hat{z}_e - TR(\Theta)\hat{z}_e + F_{ext}$

Moments: $I\dot{\Omega} = -\Omega \times I\Omega + \tau + M_{ext}$

Kinematics: $\dot{\Theta} = W(\Theta)\Omega$

The position and Euler angles can be calculated based on data from an inertial measurement unit (IMU) which captures acceleration and angular velocity readings from an accelerometer and gyroscope. Estimations using IMU data, however, is susceptible to drift, meaning the estimate will become less reliable over long periods of time. To combat drift, a neural network model will be created which attempts to recognize drift patterns and correct the errors.

Methodology

The neural network models attempted use Long Short-Term Memory (LSTM) layers as the foundation. The change in position and Euler angles between timesteps is used as the desired output of the models rather than the total position and Euler angles. This helps normalize the data and improves the training process. The dataset used is the Mid-Air dataset which contains hours of simulated drone flight. The Mid-Air IMU and groundtruth data was used for input and desired output. The data was adjusted to have the same sample rate as camera data from the dataset for future vision integration.

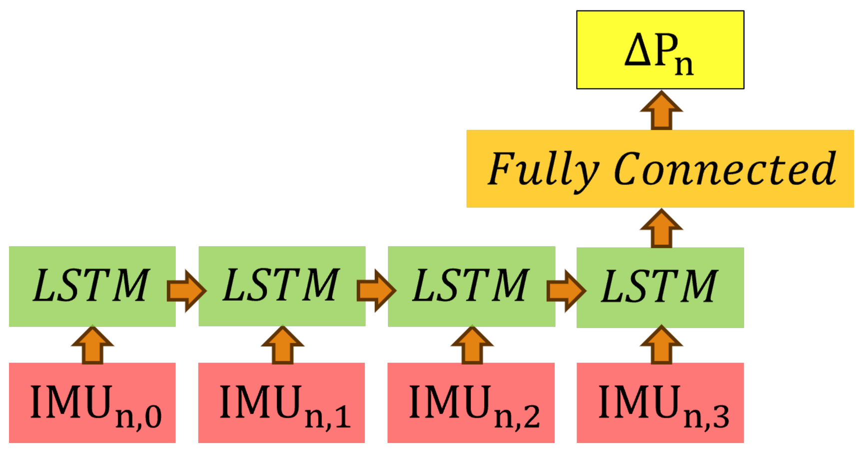

Figure 1: Model 1 Architecture

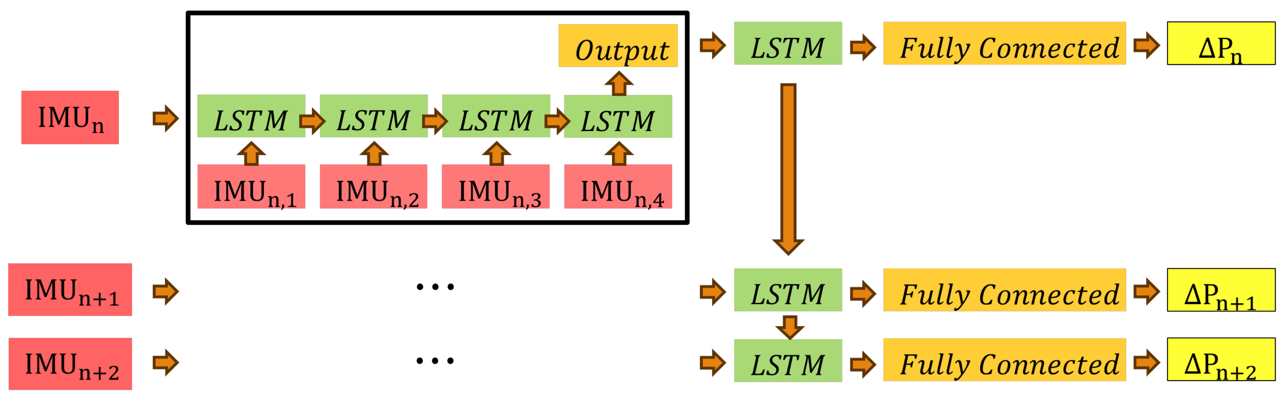

Figure 2: Model 2 Architecture

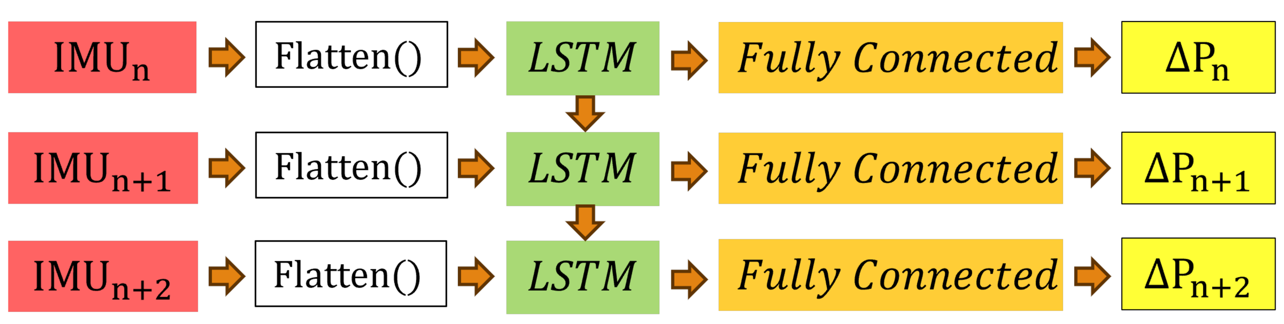

Figure 3: Model 3 Architecture

Data and Results

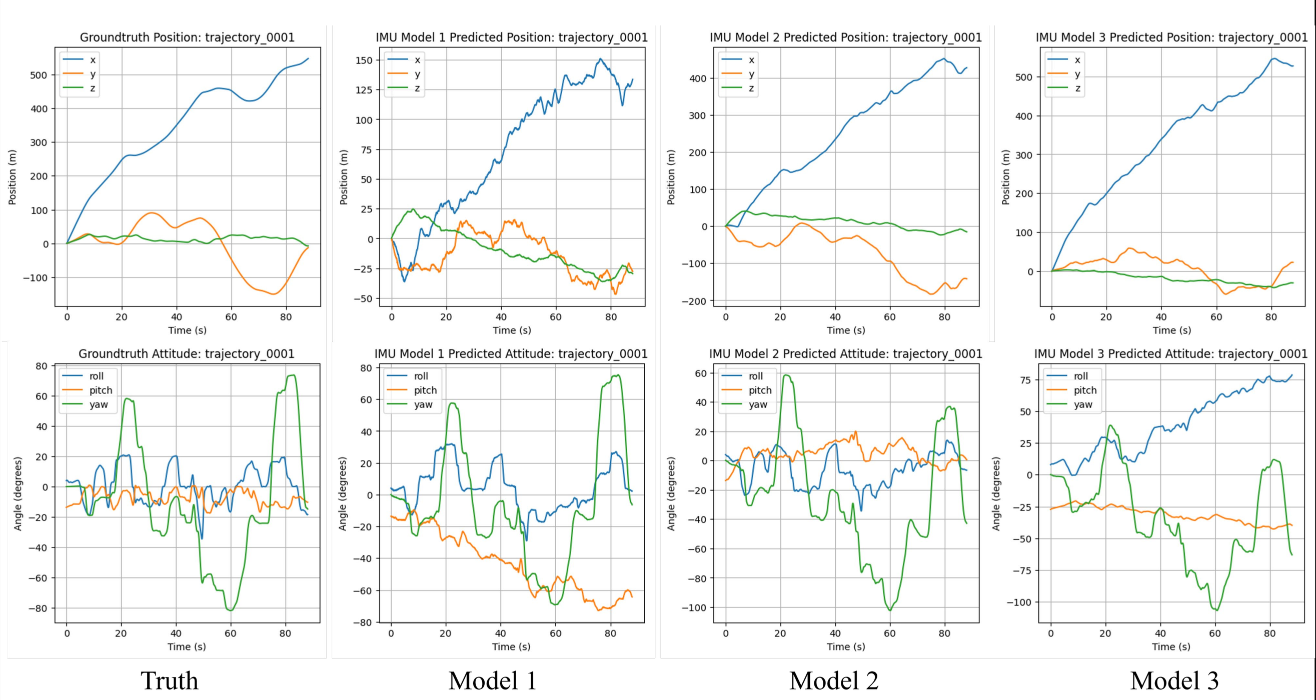

Figure 4: Model Predictions vs Groundtruth

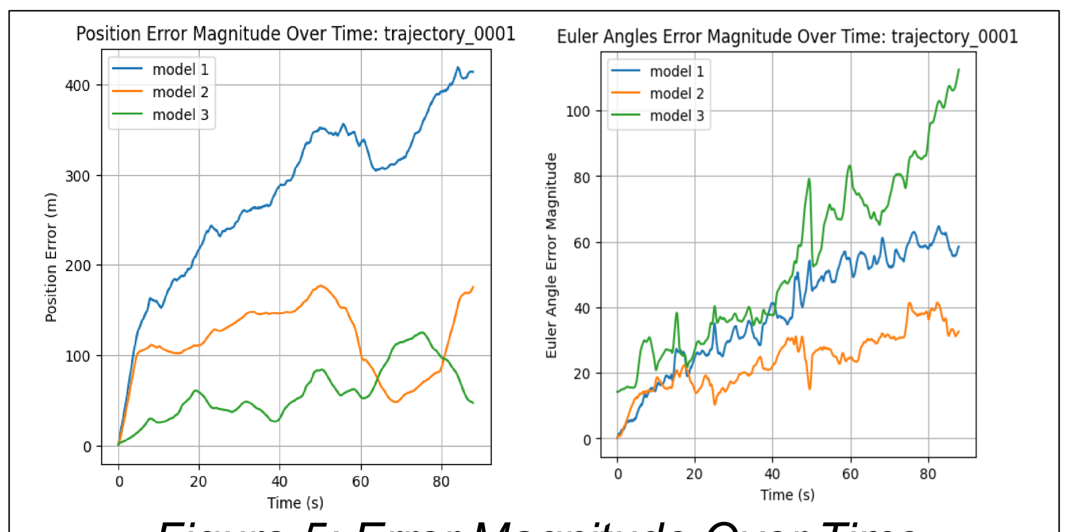

Figure 5: Error Magnitude Over Time

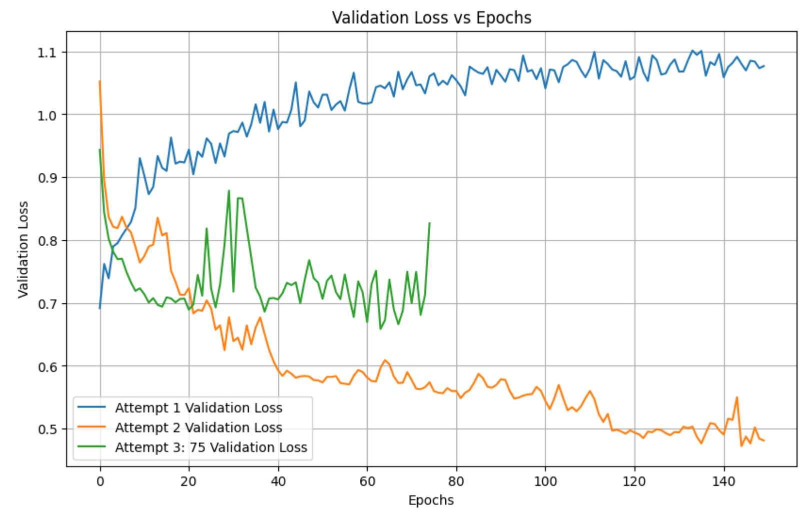

Figure 6: Validation Loss vs Epochs

Conclusions & Future Work

The model still experiences drift, and the validation loss vs epochs stagnates. The stagnation of the validation loss vs epochs indicates that the model cannot improve further, and the model architecture needs to have increased complexity to be able to better capture the patterns of the drone flight along with the noise/bias of the measurements. Future work can include attempting to merge the benefits of neural networks and physics-based models, increasing model complexity, and attempting transformer neural networks.

Acknowledgments

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[2] Fonder, Michael, and Marc Van Droogenbroeck. "Mid-Air: A Multi-Modal Dataset for Extremely Low Altitude Drone Flights." *2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, June 2019, 553–62. https://doi.org/10.1109/cvprw.2019.00081.