Training Physics Informed Neural Networks with Rover Dynamics Data

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Introduction

Problem Statement

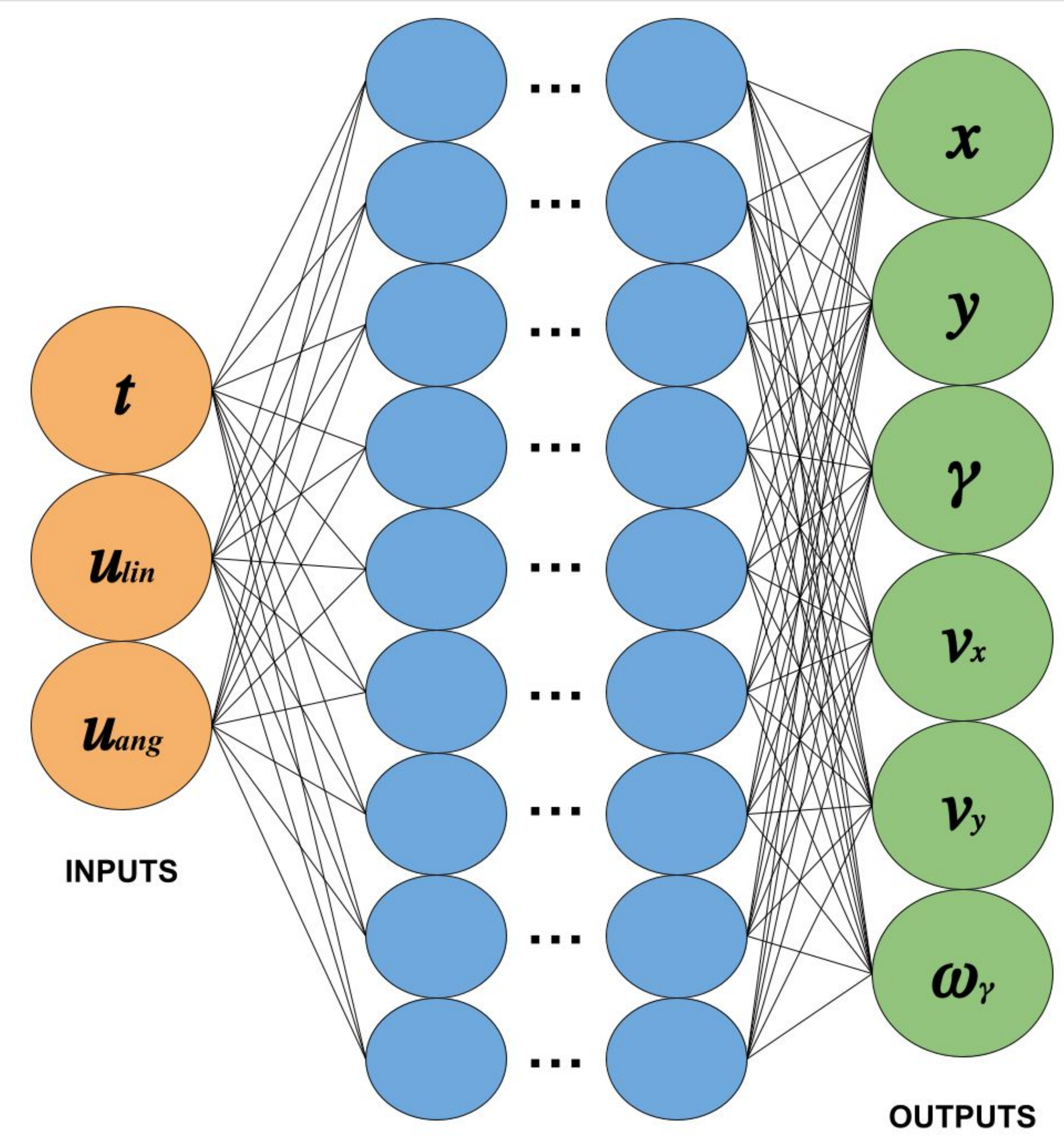
- The structure of rover dynamics is unknown when a rover is interacting with new terrain
- Predictions can be done by various methods, but it is mathematically intensive to do so
- A Physics Informed Neural Network(PINN) can be trained to learn the dynamics

Development Methodology

- Weekly meetings with sponsor to provide updates and receive feedback
- Tasks assigned and updated at meetings to ensure goals were able to be met

Acknowledgements

- Project idea and PINN framework provided by Hao Wang
- Simulated dataset of rover movements provided by Hans Mertens
- Equations of motion for training PINN provided by Bailey Hopkins

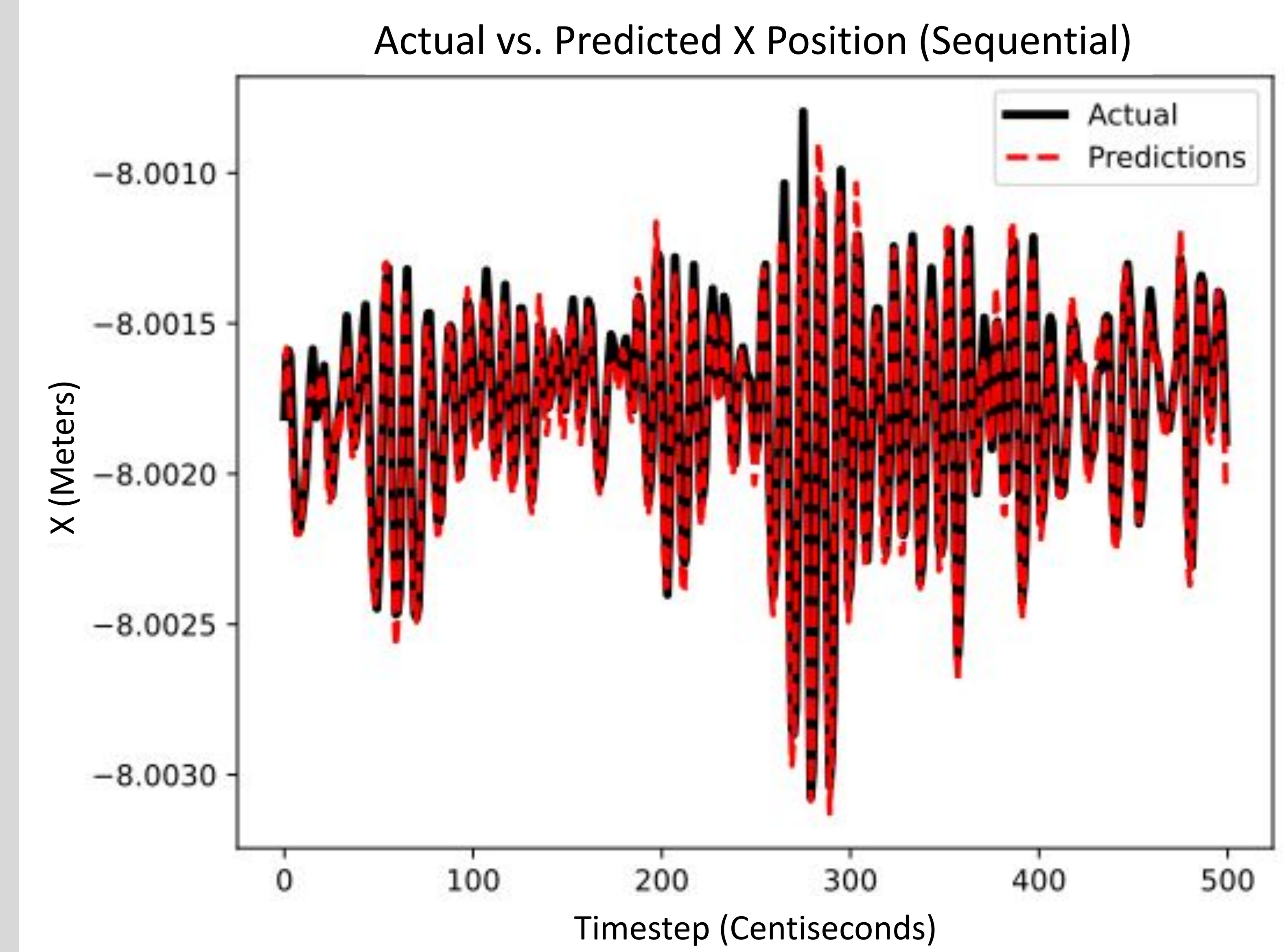


Equations of Motion

$$\dot{x} = v_x$$
$$\dot{y} = v_y$$
$$\dot{\gamma} = \omega_\gamma$$
$$\dot{v}_x = 90 * cos(\gamma) * u_{lin}$$
$$\dot{v}_y = 90 * sin(\gamma) * u_{lin}$$
$$\dot{\omega}_\gamma = 36 * u_{ang}$$

Mean Squared Error

$$\frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2$$



Neural Networks

- A neural network is a machine learning process that can learn patterns and relations from a dataset
- A PINN is a neural network that leverages known Partial Differential Equations(PDEs) that describe the laws of physics
- By learning these laws, a PINN makes predictions that are grounded in reality

Technical Methodology

- A vanilla neural network was created to show that the dataset was robust and to provide a baseline to judge the PINN with
- The PINN incorporates the above equations to predict the rover's X/Y position,X/Y velocity, angular velocity, and yaw

Solution

Tasks Accomplished

- Train and validate Sequential Neural Network on rover X/Y/Z displacement, velocity, and controller inputs using Keras library
- Acheived an average mean squared error(MSE) loss of 0.0057 on 10 cross-fold validation predicting rover position with sequential network
- Prove PINN works on toy Ordinary Differential Equations(ODE) system using DeepXDE library
- Train and validate PINN on time, X/Y position, velocity, yaw, angular velocity, linear acceleration, and angular acceleration
- Achieved an average MSE loss of 0.13 across 6 outputs

Challenges

- Having only a basic understanding of physics principles made it difficult to understand the core concepts of PINNs
- DeepXDE is a newer library, and is relatively niche, so the documentation and examples available online are sparse

Learnings

- Keeping an open line of communication was very important and allowed for problems to be solved from both a data science and a physics perspective
- Even when open source libraries aren't well documented, going through the source code and checking the project Github can be useful

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