Terrain-Attentive Learning for Efficient 6-DoF Kinodynamic Modeling on Vertically Challenging Terrain

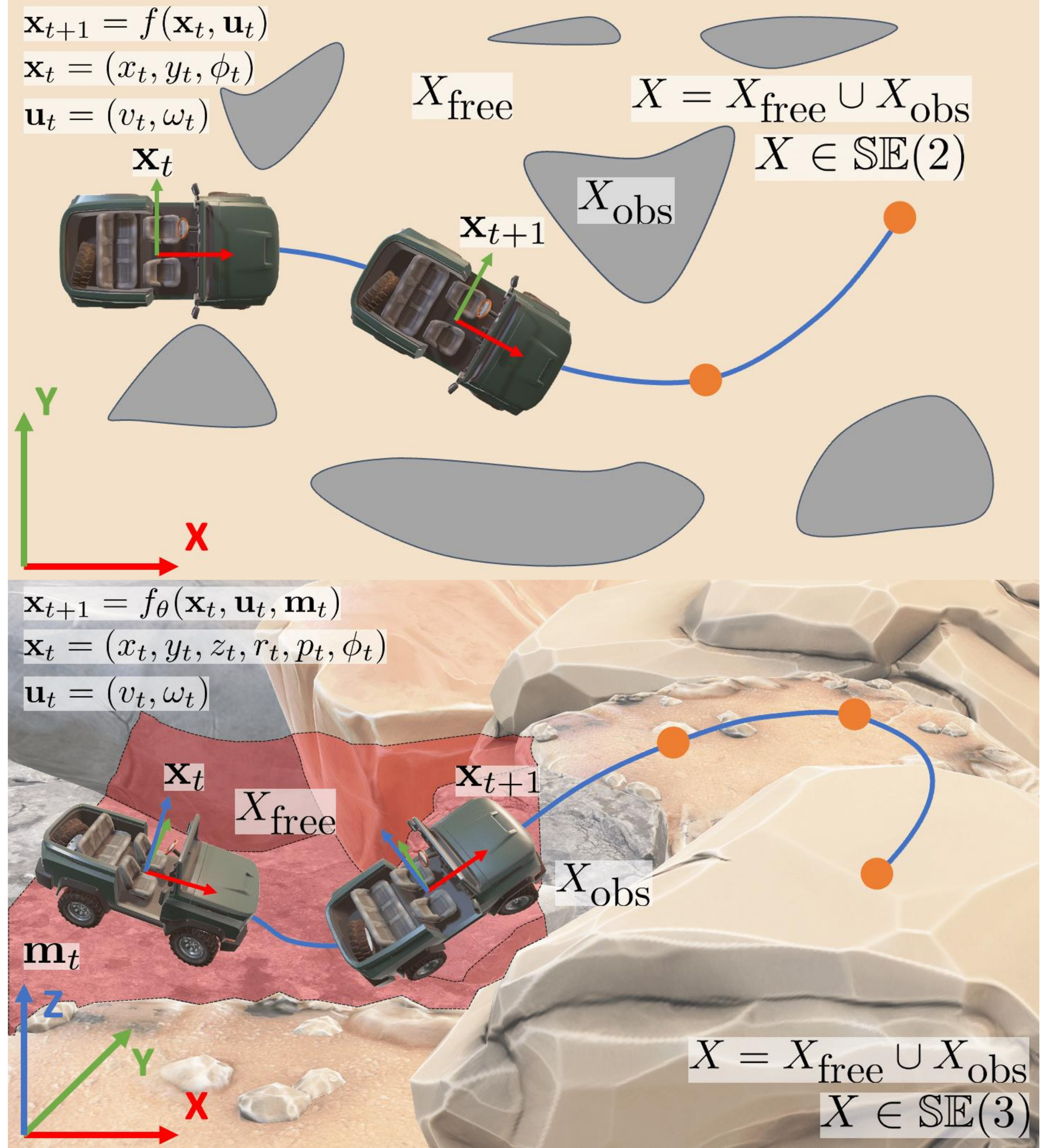
Aniket Datar, Chenhui Pan, Mohammad Nazeri, Anuj Pokhrel, and Xuesu Xiao
George Mason University

INTRODUCTION

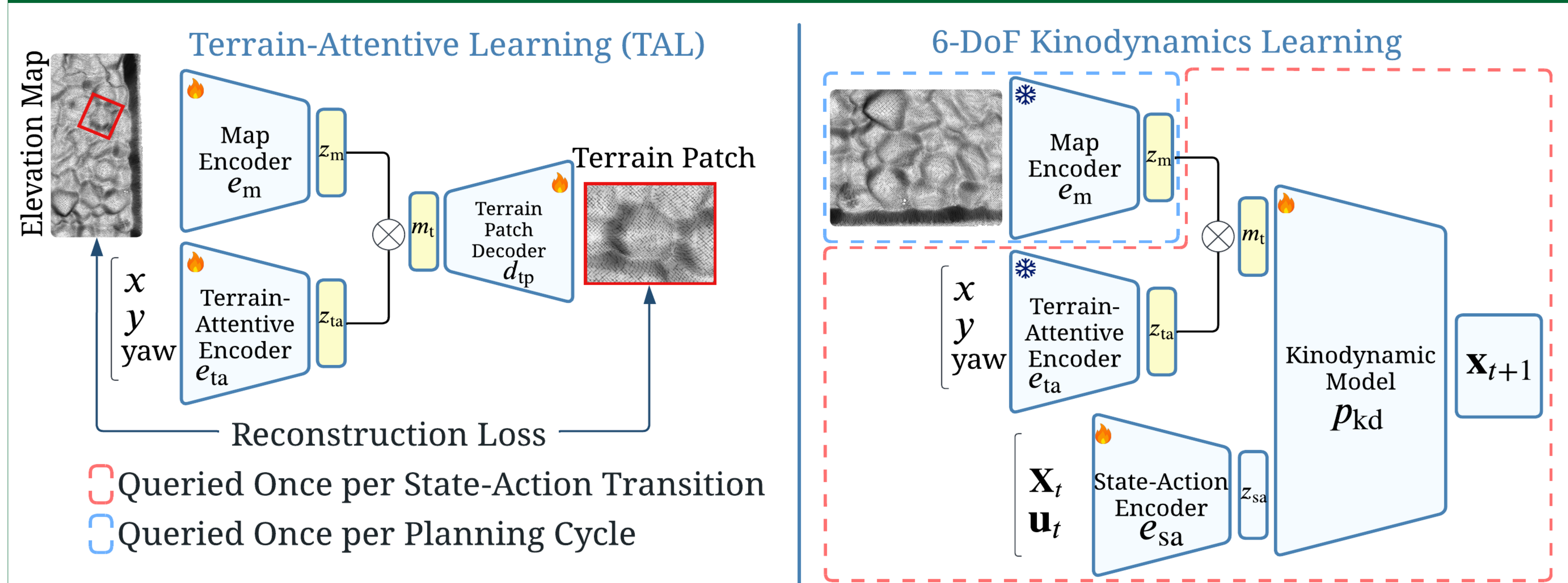
- Despite their wide availability, wheeled mobile robots are usually limited in terms of mobility, mostly moving in 2D flat environments.
- Recent advances in wheeled mobility have shown that even conventional wheeled vehicles without sophisticated hardware modification have unrealized mobility potential on vertically challenging terrain.

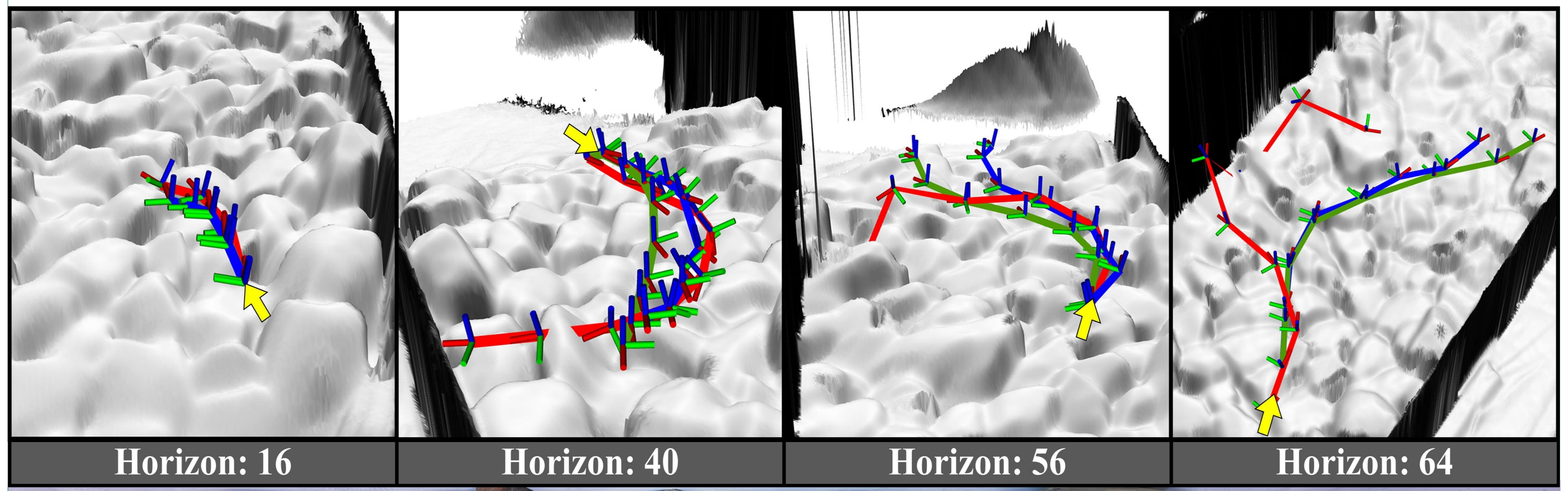
PROBLEM FORMULATION

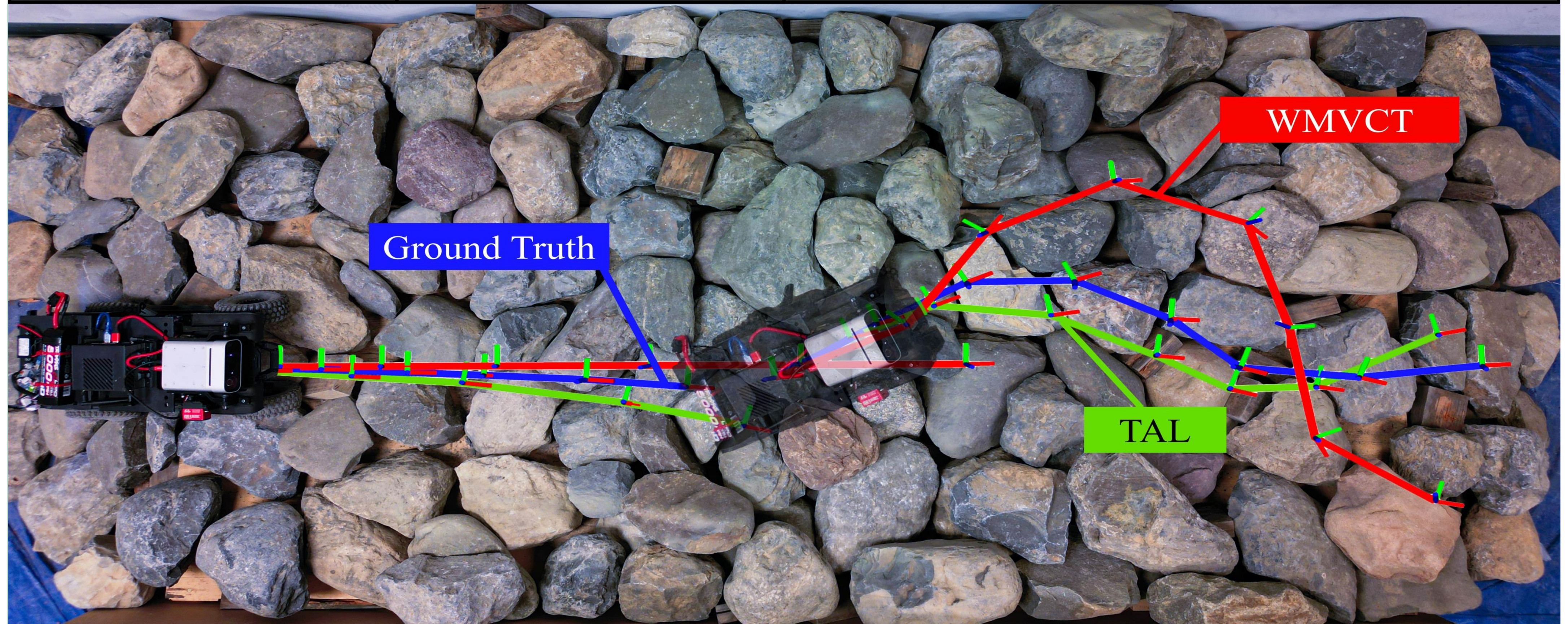
- While most traditional 2D navigation problems are defined in a 2D state space, i.e., $X \subset SE(2)$, our vertically challenging terrain requires the state space to be extended to $X \subset SE(3)$.



Our Terrain-Attentive Learning (TAL) allows a learned 6-DoF kinodynamic model to efficiently attend to the specific underlying terrain for real-time sampling-based planning.







ALGORITHMS

- Data-Driven Kinodynamics:

To avoid the difficulty in analytically modeling f_θ, we adopt a data-driven approach and θ can then be learned by minimizing a supervised loss function:

$$\theta^* = \underset{\theta}{\operatorname{argmin}} \sum_{(\mathbf{x}_t, \mathbf{x}_{t+1}, \mathbf{m}_t, \mathbf{u}_t) \in \mathcal{D}} \| f_\theta(\mathbf{x}_t, \mathbf{u}_t, \mathbf{m}_t) - \mathbf{x}_{t+1} \|$$

- Terrain-Attentive Learning (TAL):

The map and terrain-attentive encoders and the terrain patch decoder are trained in an end-to-end fashion using a self-supervised representation loss:

$$\mathcal{L}_{\text{TAL}} = \sum_{i=1}^{I} \sum_{j=1}^{J} \| p_i^j - d_{\text{tp}}(e_{\text{m}}(E_i), e_{\text{ta}}(\langle x_i^j, y_i^j, \text{yaw}_i^j \rangle)) \|$$

RESULTS

Model Prediction Error: TAL achieves lower prediction error and variance than WMVCT, a previous 6-DoF model based on decomposition for efficiency, in all cases.