Risk-Sensitive Forward Modeling for Delayed Teleoperation Using Cumulative Prospect Theory

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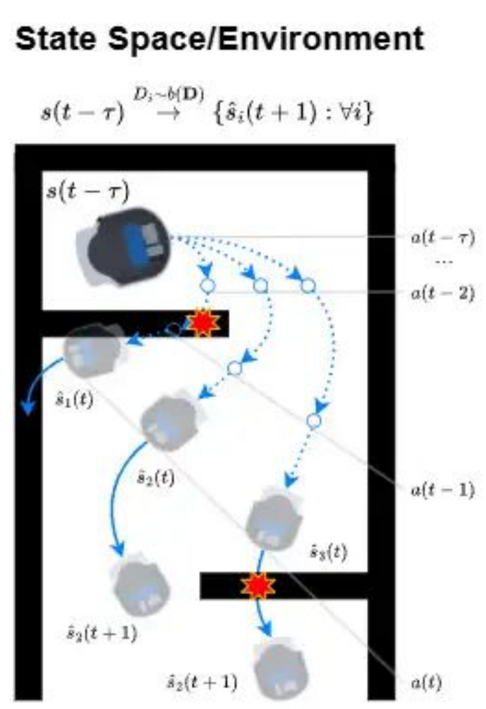
Introduction & Motivation

Communication delays cause robots to execute outdated commands, leading to collisions and mission failures. Current forward models assume rational decision-making, but humans exhibit complex risk-biased action patterns.



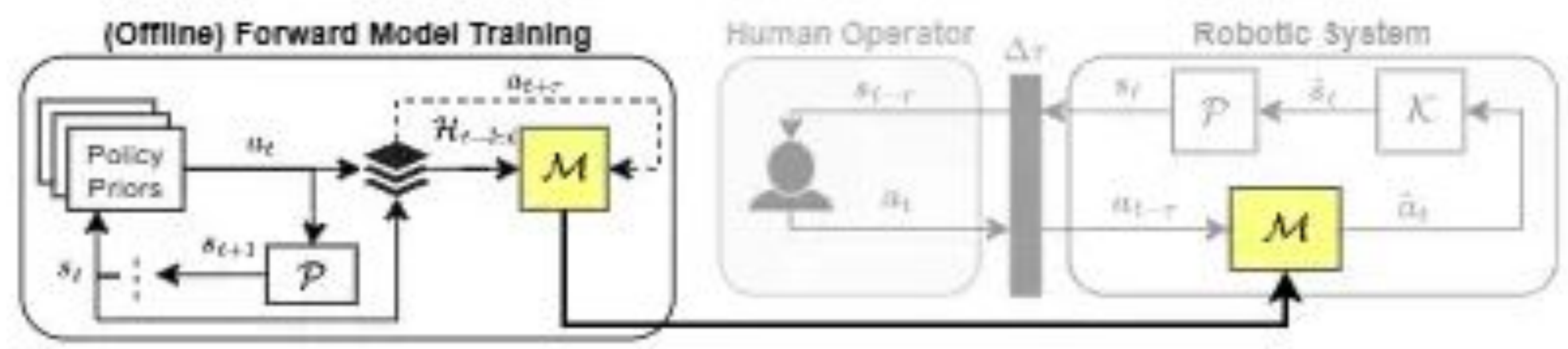
This study integrates **Cumulative Prospect Theory (CPT)** to model how operators actually make decisions under uncertainty. By capturing individual risk preferences, we can predict human actions more accurately during delayed teleoperation scenarios.

Applications & Impact

Space Exploration - Mars/lunar rover teleoperation with 10+ minute communication delays.
Underwater Operations - Deep-sea ROV teleoperation with acoustic communication constraints.
Disaster Response - Emergency robots in areas with degraded network infrastructure.
Medical Teleoperation - Remote surgery with network latency considerations.

Understanding human risk preferences in time-critical scenarios enables safer human-robot collaboration during communication disruptions.

Current Approach



1. Collect human teleoperation data in 2D navigation environment with obstacles and time delays
2. Compare ML architectures: **Autoencoder, VAE, Bayesian Networks, Transformer, Linear baseline**
3. Systematic hyperparameter optimization using 3-fold cross-validation
4. Integrate CPT parameters (λ, α, β, γ) to model individual risk profiles

Cumulative Prospect Theory

CPT describes human decision-making under uncertainty. **Loss Aversion** (losses weighted ~2.25x more than gains) and **Probability Weighting** (overestimating rare events, underestimating common ones) create risk-biased behaviors. CPT Parameters (λ, α, β, γ) capture operator-specific risk tolerance. *CPT-parameterized models will better predict operator actions in high-risk scenarios than risk-neutral baselines.*

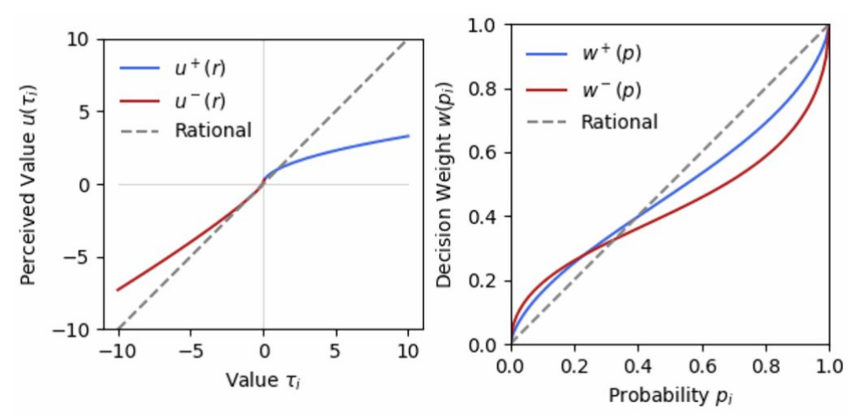


Fig. CPT's transformations on utility and probability where the cumulative expected return of τ (CPT-Value) is expressed as $\rho_{cpt}(\tau)$ in place of the expectation $\mathbb{E}[\tau]$

Next Steps

Implementing CPT-based policy blending with risk parameters. Human subject studies to collect risk profile data. Validate CPT-integrated models predict operator preferences across risk scenarios. Compare CPT-integrated vs. risk-neutral models

References

[1] Tversky, A. & Kahneman, D. (1992). Advances in prospect theory: Cumulative representation of uncertainty. Journal of Risk and Uncertainty, 5(4), 297-323.
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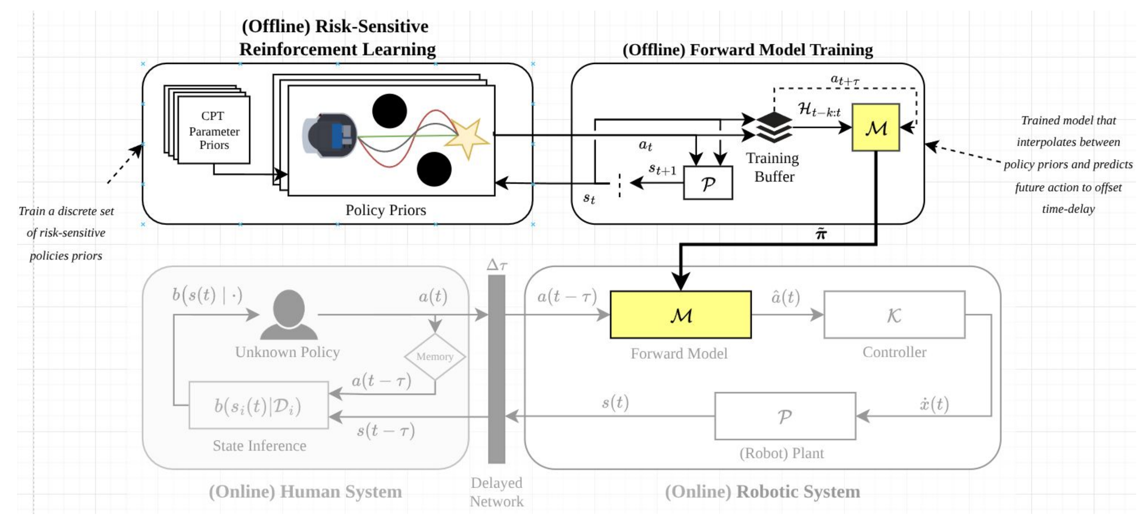
Experimental Setup

2D continuous navigation with static obstacles. Goal-directed tasks with collision penalties. Variable communication delays simulate real-world teleoperation constraints. 1000 training episodes, 50 test episodes. State: robot (x, y, θ), obstacles (x_i, y_i), goal. Actions: (v, ω).

Variational Autoencoder (VAE), Bayesian Neural Networks, Transformer (attention-based), Standard Autoencoder, Linear baseline. 3-fold cross-validation for hyperparameter tuning.

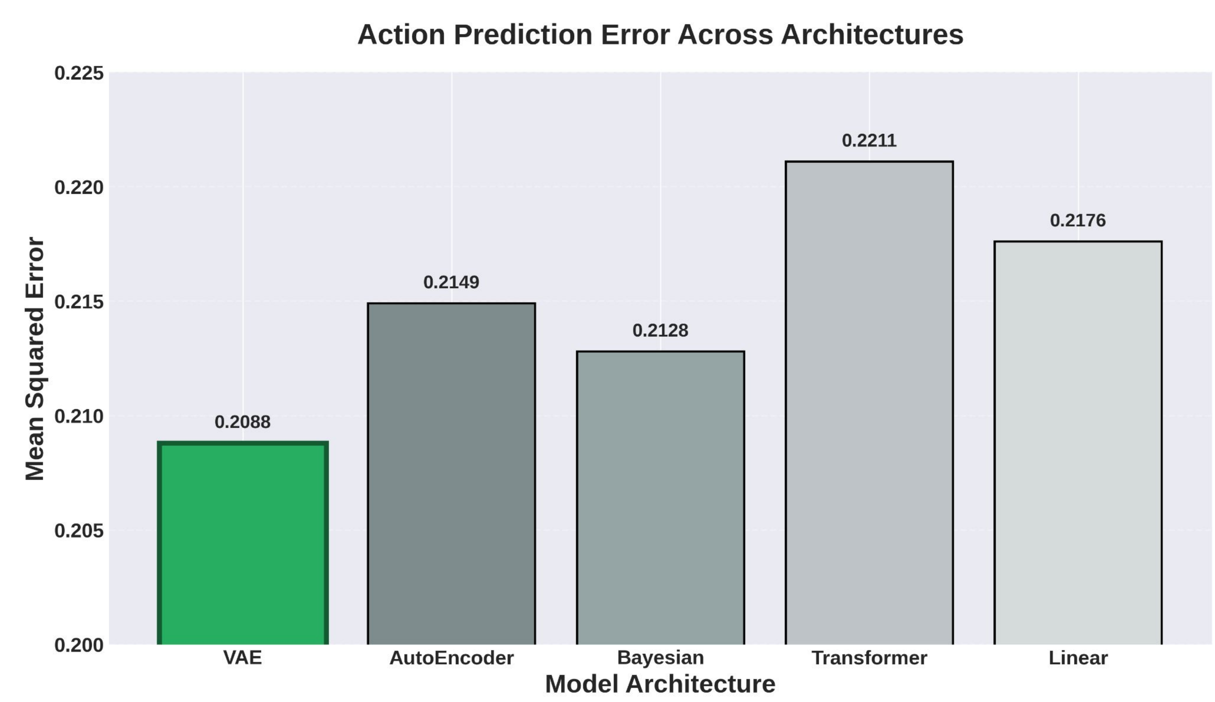


MSE, success rate, collision frequency. 700 epochs, early stopping at validation plateau.

Preliminary Findings

We trained five architectures on teleoperation data. **Variational Autoencoders** show lowest prediction error in earlier experiments.

All models converge within 200 epochs. Comprehensive evaluation framework establishes performance baselines.



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