**IITISoC 2025**  
**PROJECT PROPOSAL**

**Title:** Vehicle Dynamics System Identification using Physics-Informed Neural Networks (PINNs)  
**Domain:** Intelligent Vehicles and Robotics  
**Problem Statement Number:** 01  
**Preference Number:** 02

**Team Details**

**Team Leader:**

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* Skills: Machine Learning, python, ros2

**Team Member 2:**

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**Team Member 3:**

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**Team Member 4:**

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**Team Member 5:**

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* Skills: python

**Project Overview**

We propose a PINN-based system for vehicle dynamics parameter identification and state estimation using sensor data and embedded physics. Building on the FTHD framework (Fine-Tuning Hybrid Dynamics) and traditional 2DOF bicycle and Pacejka tire models, our approach integrates physical knowledge directly into neural network training.

**Key Objectives:**

* Estimate unmeasurable parameters (cornering stiffness, mass, inertia, etc.)
* Reconstruct unobservable states (slip angles, forces)
* Ensure physical consistency through differential constraints
* Enable real-time model usage in control applications

**Model Architecture and Methodology**

1. **Encoder with GRU/LSTM and Attention:**  
   Processes time-series input: velocity, yaw rate, acceleration, steering angle, throttle.
2. **Physics Guard Layer:**  
   Applies bounds and physical constraints using sigmoid-scaling:
3. **Residual Loss Module (AutoDiff):**  
   Uses automatic differentiation to enforce physics residual:
4. **Hybrid Loss Function:**  
   Combines supervised MSE and physics-based losses:  
   Adaptive weighting using uncertainty quantification.
5. **Fine-Tuning Strategy:**  
   Pre-train on large dataset, freeze partial network, fine-tune with physics loss on smaller datasets.

**Mathematical Formulation**

We use the single-track model with nonlinear Pacejka forces. Dynamics update:

Pacejka lateral forces:

**Validation Strategy**

1. **Open-loop Testing:**
   * Dataset: open source sensor data
   * Metric: RMSE lateral force errors
2. **Closed-loop Testing:**
   * Integrate into MPC controller
   * Track performance on trajectory following tasks
3. **Physical Plausibility Check:**
   * Custom metric to verify bounds and interpretability of

**Simulation Tools**

* MATLAB for preliminary dynamics modeling
* PyTorch + AutoGrad for PINN implementation

**Timeline**

| **Week** | **Task** |
| --- | --- |
| 1 | Literature review, dataset collection, bicycle model implementation |
| 2 | GRU encoder, physics guard implementation |
| 3 | AutoDiff residual loss + supervised loss setup |
| 4 | Training on linear model using clean data |
| 5 | Nonlinear extension with Pacejka tire forces |
| 6 | Adaptive loss tuning, fine-tuning architecture setup |
| 7 | MPC integration and validation |
| 8 | Final report, results analysis, documentation |

**Expected Deliverables**

* Modular PINN codebase with encoder, guard, and residual modules
* Trained weights and test scripts
* Validation report (RMSE, force plots, trajectory error)
* Documentation (equations, model descriptions, network structure)
* Project repository with setup instructions
* Proposal report and final presentation

**Further Work**

* Extend to 6DOF models with load transfer and 3D effects
* Real-time inference optimization using TensorRT
* Real-world testing on scaled platforms (F1tenth)

**References**

1. Fang, S. & Yu, K. (2024). Fine-Tuning Hybrid Physics-Informed Neural Networks for Vehicle Dynamics Model Estimation. *IFAC PapersOnLine* 58(28), 810-815.
2. Chrosniak, J. et al. (2024). Deep Dynamics: Vehicle modeling with physics-constrained networks.
3. Pacejka, H. & Bakker, E. (1992). The Magic Formula tire model.
4. Jain, A. et al. (2020). Bayesrace: Learning to race autonomously.
5. Liu, D. & Wang, Y. (2021). Physics-constrained neural networks with minimax architecture.