Toward Non-Contact Pavement Friction Measurement Using Physics-Informed Deep Learning

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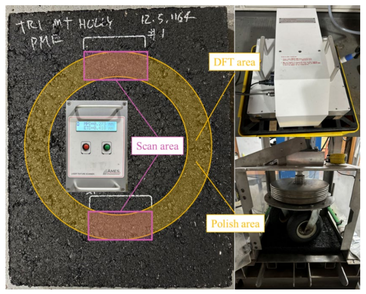
Motivation

- Pavement friction is essential for vehicle braking and roadway safety.
- Conventional friction measurements rely on inspection vehicles (contact-based, low coverage, time-consuming, traffic control).
- Non-contact, vision/laser-based texture measurement can enable efficient, large-scale friction evaluation



- **Goal:** Develop a physics-informed framework that estimates pavement friction directly from surface texture, enabling future **non-contact and network-level friction assessment**.

Experiment Program



Laboratory test setup

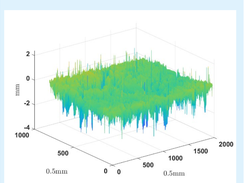
Key elements:

- Controlled polishing cycles
- Measured DFT friction
- 3D texture laser scanning
- Multiple pavement surface types

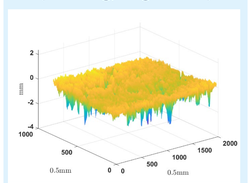
Dataset & Preprocessing

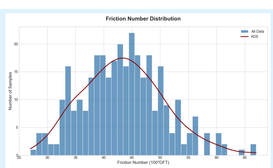
- 3D pavement surface scan with paired friction measurements.
- Process to obtain a clean, aligned surface topography.
- 326 paired data with HMA, SMA, OGFC, HPTO, and chip seal.

Raw 3D texture



Preprocessing (filtering, alignment)

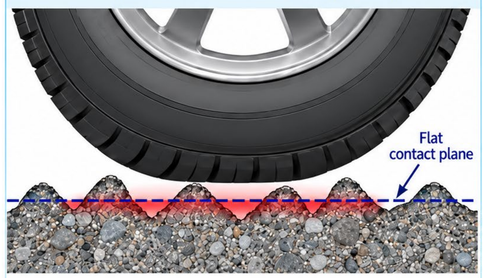




Friction distribution

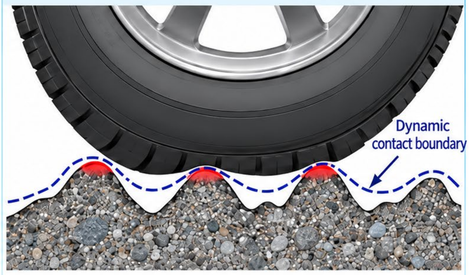
Key Challenge: What Texture Actually Contacts the Tire?

Global flat contact plane (conventional assumption)



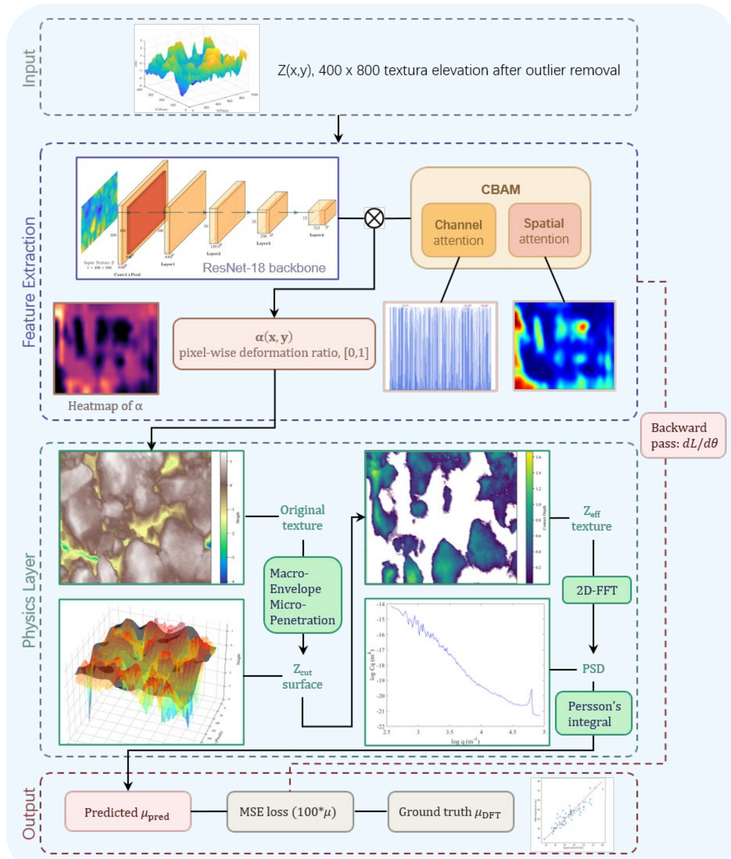
- Single global contact plane
- Ignores local texture variation

Dynamic contact boundary (proposed concept)



- Contact varies with texture
- Local deformation creates dynamic contact

Physics-Embedded Deep Learning Framework



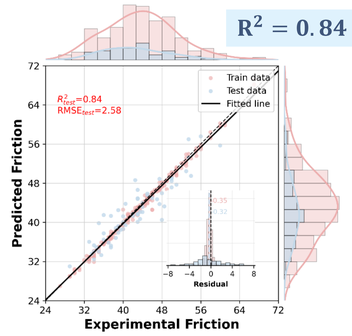
Data-driven feature learning (with attention)

Physics-based contact modeling

Spectral analysis and friction prediction

Physics is embedded in the network architecture - not just loss penalty.

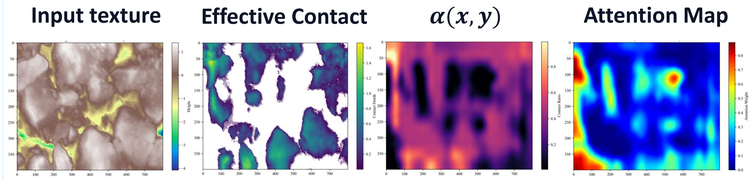
Friction Prediction Results



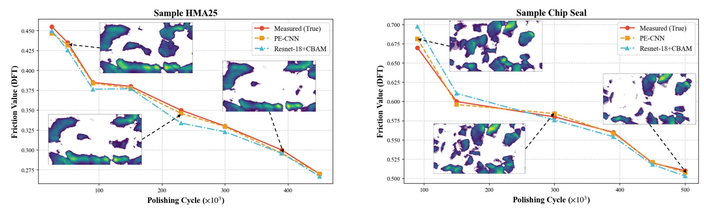
Comparison with baseline

Models	R^2	RMSE
Proposed	**0.84**	**2.58**
Resnet18 baseline	0.77	3.11
Resnet18+CBAM	0.75	3.34
Global-plane PE-CNN	0.77	3.08

Physics Guided Contact and Attention



Contact Evolution with polishing



Key Findings & Future Vision

- Physics-informed deep learning can accurately predict pavement friction with texture.
- Dynamic contact modeling provides a physics-meaningful contact representation.
- Attention mechanism highlights friction-relevant surface features.
- Enabling large-scale, non-contact friction estimation from remote sensing.

