# Physics-Informed Learning for the Friction Modeling of High-Ratio Harmonic Drives

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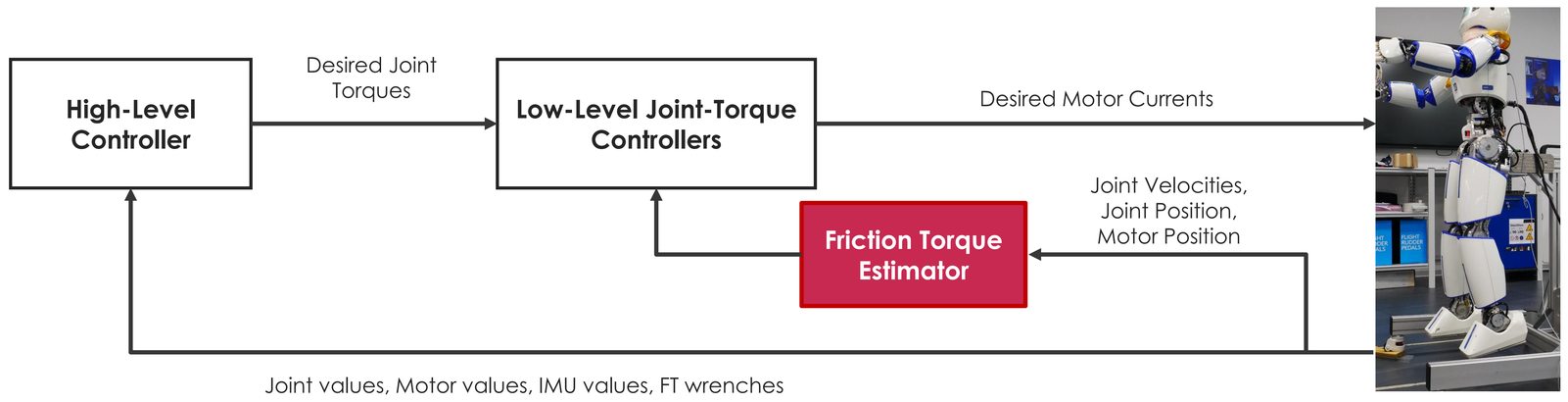
## Key points

- Online friction torque estimation for high-ratio harmonic drives mounted on humanoid robots
- Estimation based on **Physics-Informed Neural Network** technique using **Stribeck-Coulomb-Viscous model**
- The overall approach is tested in combination with a two-layer torque control architecture on the humanoid robot ergoCub
- The friction compensation ensures the **breaking** of the static friction and compensation of dynamic friction



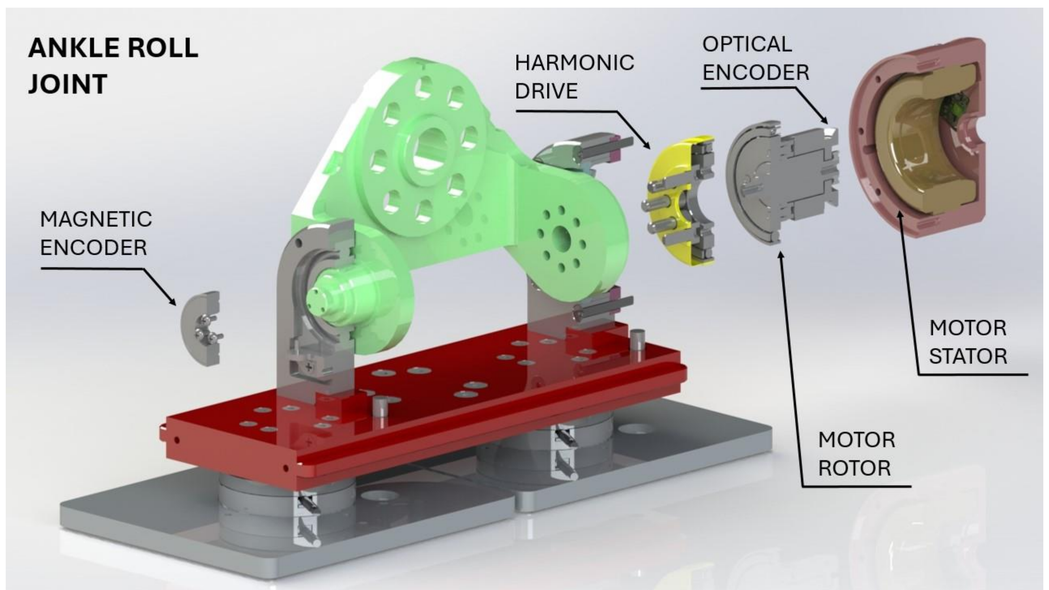

Download paper here!

SCAN ME

Check the code on GitHub!

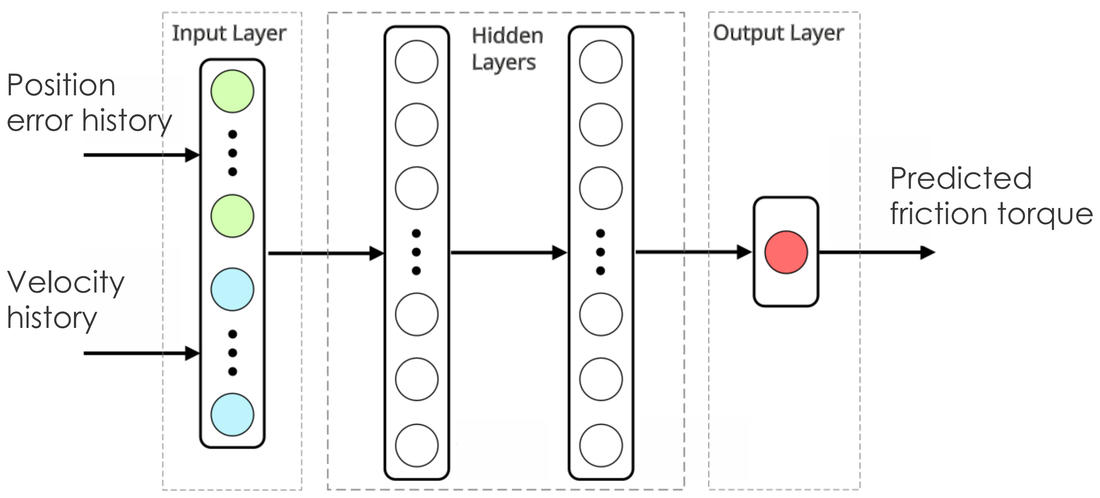
SCAN ME

## BLDC motor with high-ration HD




- A portion of the torque produced by the motor is absorbed by the high mechanical friction of the harmonic drive.
- Static friction torque can be estimated by analyzing the differential readings of the magnetic and optical encoders.
- When the motor moves but the torque does not exceed the static friction torque, the joint does not rotate.

## Physics-Informed NN architecture




### Loss functions

$$\mathcal{L} = (1-\lambda)\frac{1}{N}\sum_{i=1}^{N}\left(\tau_{F,pred} - \tau_{F,true}\right)^2 + \lambda\frac{1}{N}\sum_{i=1}^{N}\left(\tau_{F,pred} - \tau_{F,physics}\right)^2$$

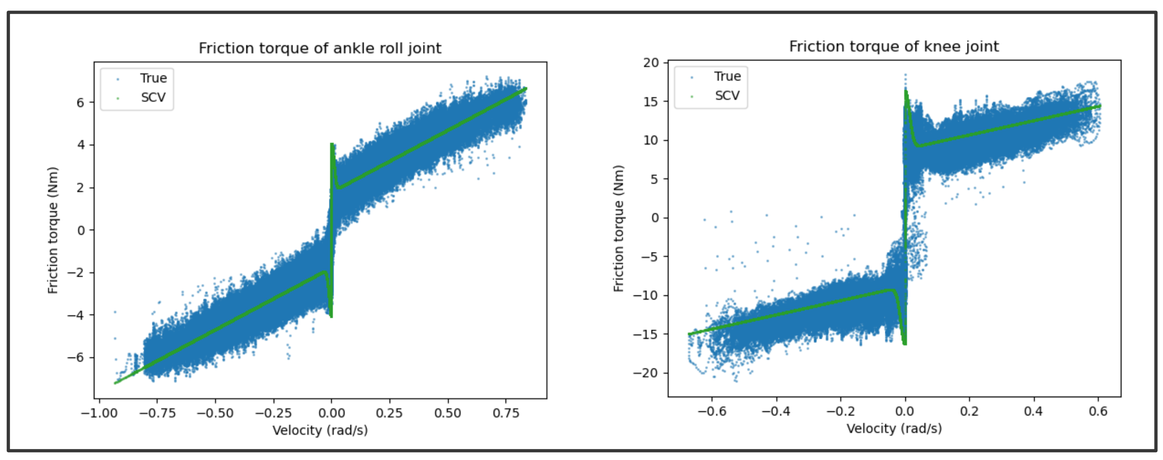
Data — Physics

### Friction model used in loss function

$$\tau_{F,physics} = k_v\dot{s} + k_c\tanh(k_a\dot{s}) + (k_s - k_c)e^{-\left|\frac{\dot{s}}{v_s}\right|^{\alpha}}\tanh(k_a\dot{s})$$

Viscous — Coulomb — Stribeck

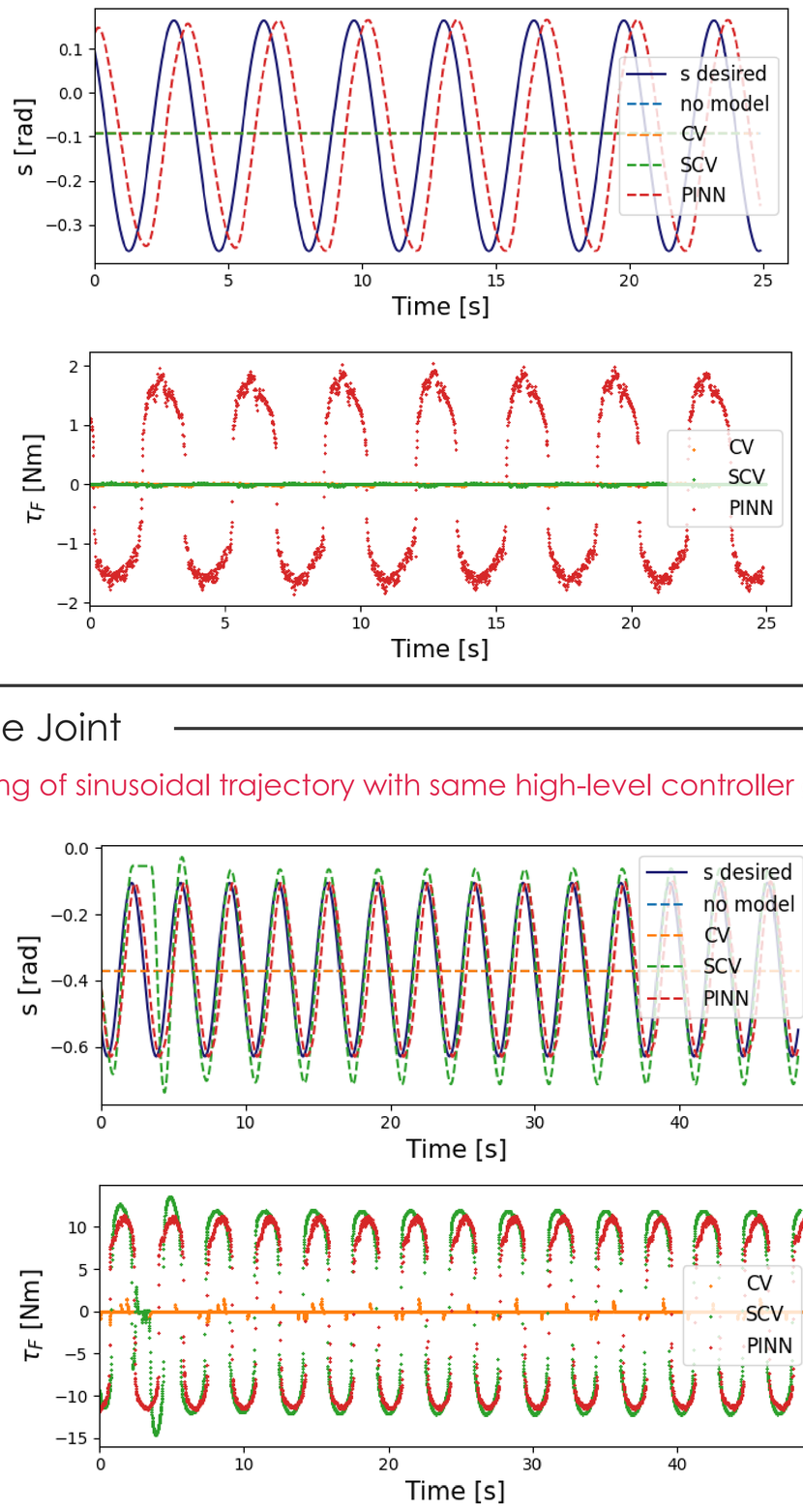
## Physics-Informed NN hyperparameters




## Comparison with different friction models

### Ankle Roll Joint

Tracking of sinusoidal trajectory with same high-level controller gains




### Knee Joint

Tracking of sinusoidal trajectory with same high-level controller gains