UniMTS: Unified Pre-training for Motion Time Series

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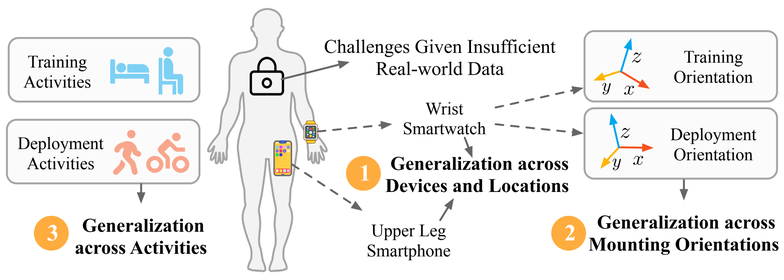
NEURAL INFORMATION PROCESSING SYSTEMS

TL; DR

The **first unified pre-training** framework for motion time series / human activity recognition that **generalizes across diverse device placements and activities**

Motivation

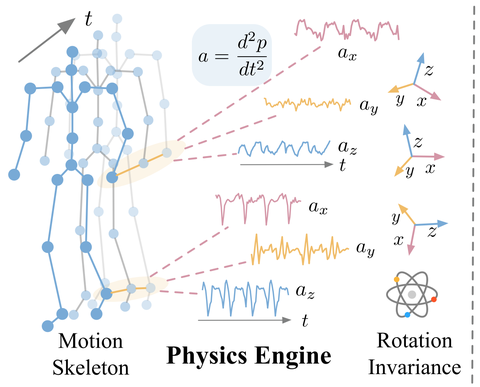
Task: Motion Time Series Classification / Human Activity Recognition (HAR) identifies human activities based on sensor time series collected from wearable devices (e.g., smartphone, smartwatch)

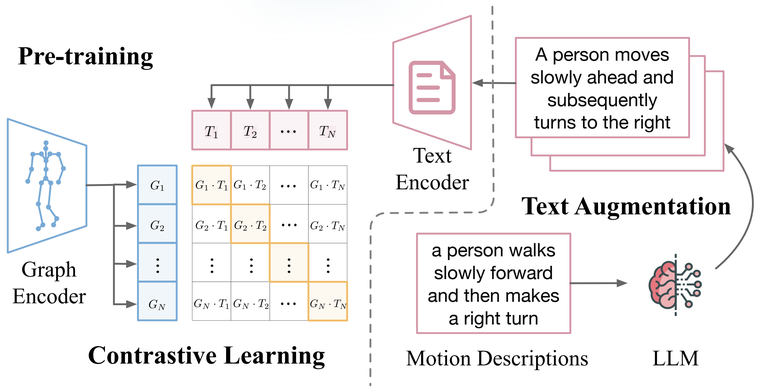


Challenge and our solution:

- ❓ **Generalization across devices and locations**: Smartwatch on the wrist vs smartphone near the upper leg
  - ✅ Synthesize time series from existing large-scale motion skeleton data with comprehensive joint coverage
  - ✅ Spatio-temporal graph neural network to model relationships across different device locations
- ❓ **Generalization across mounting orientations**: Smartphone facing towards or against the body in a pocket
  - ✅ Rotation-invariant augmentation
- ❓ **Generalization across activities**: Stationary activities such as lying or sitting, vs dynamic movements such as walking or cycling
  - ✅ Contrastive learning framework to align motion time series with LLM-enriched textual descriptions

Method

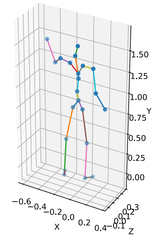




- **Physics engine for motion time series simulation**
- **Rotation-invariant augmentation**
- **Contrastive pre-training**
- **Text augmentation**

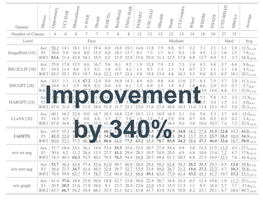
Experiments

Pre-training dataset: HumanML3D with 14,616 motion skeletons and ~3 textual descriptions for each motion skeleton. For example, the right figure shows the motion skeleton of “a person waves his hands”

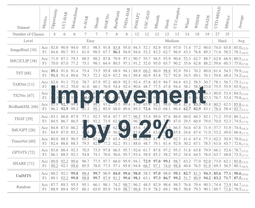


Evaluation dataset: 18 real-world datasets collected from various body locations, e.g., head, chest, back, arm, wrist, waist, leg, knee. 8 easy level datasets (< 10 activities), 8 medium level datasets (10 - 20 activities), 2 hard level datasets (> 20 activities)

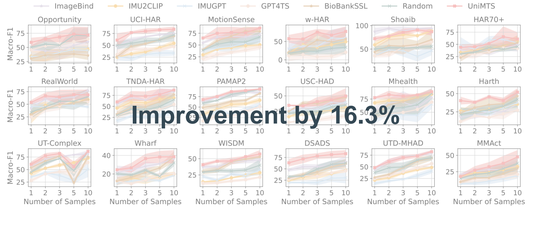
Baselines: (1) pre-trained HAR models (2) time-series classification models (3) traditional HAR models



Zero-shot setting

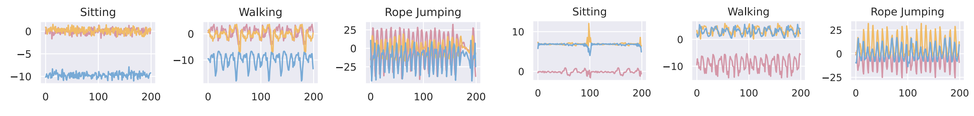


Full-shot setting



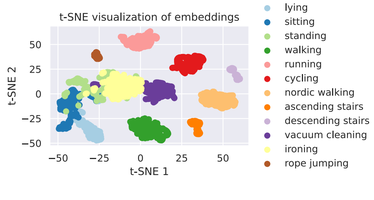
Few-shot setting

Simulated data have similar patterns as real data:

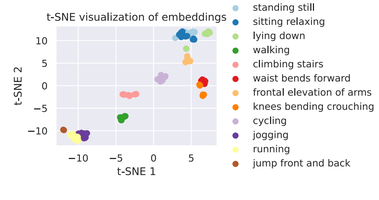


Simulated data | Real PAMAP2 data

Contrastive pre-training learns the semantics of time series:



PAMAP2



Mhealth

Paper

Code

Model