Personalization of Wearable Sensor-Based Joint Kinematic Estimation Using Computer Vision for Hip Exoskeleton Applications

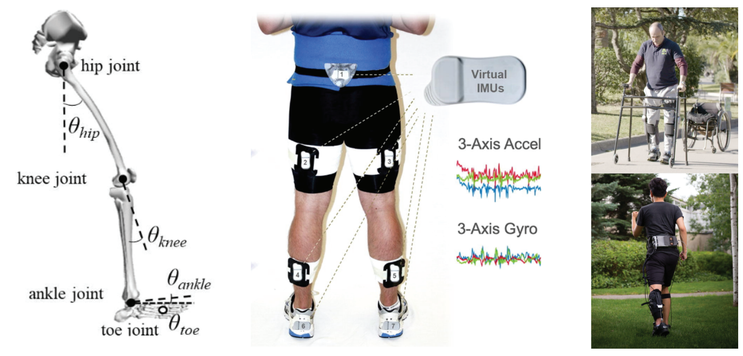
Changseob Song*, Bogdan Ivanyuk-Skulskyi*, Adrian Krieger, Kaitao Luo, Inseung Kang

Department of Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA

Carnegie Mellon University
MetaMobility Lab

ICORR
rehabweek Chicago '25

Introduction



Accurate estimation of joint angle is essential for exoskeleton controller. **IMU and machine learning-based estimation** [1] is not easibly applicable to unseen gaits.

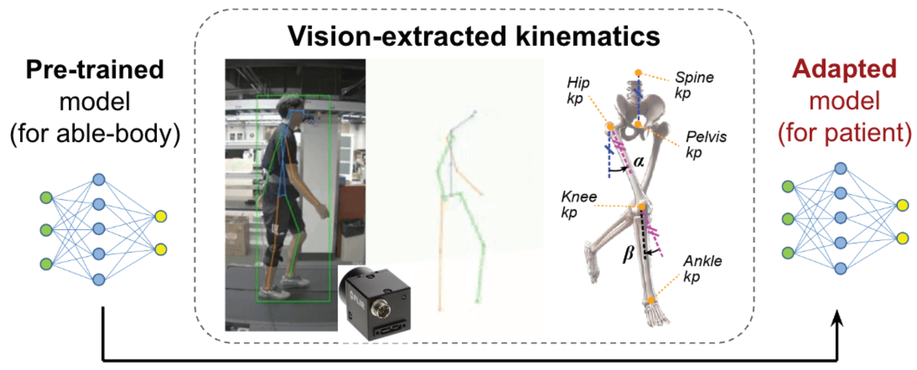


Motion capture systems are costly, time-consuming, and proprietary [2].

vs.



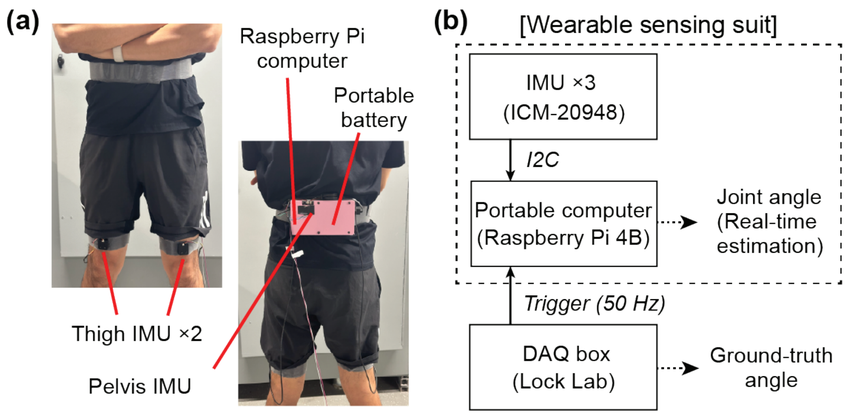
Computer vision-based human pose estimation are easily approachable by using only single camera [3].



We present an adaptation pipeline of ML-based kinematic estimation expedited by computer vision and transfer learning.

Methods

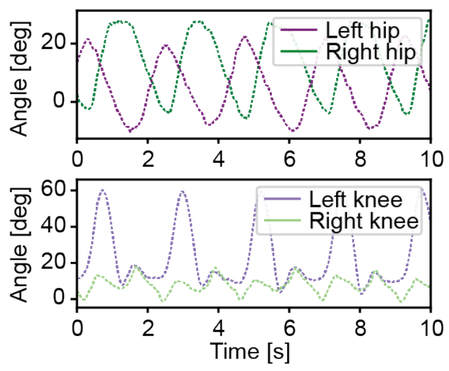
Wearable sensing suit



We used 3 IMUs (1 for pelvis, 2 for thighs) and portable computer to real-time estimate the joint angles in 50 Hz.

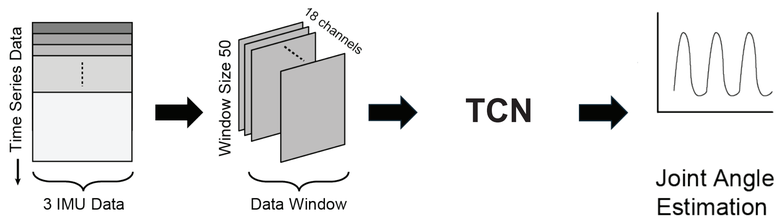
Stiff-knee gait emulation





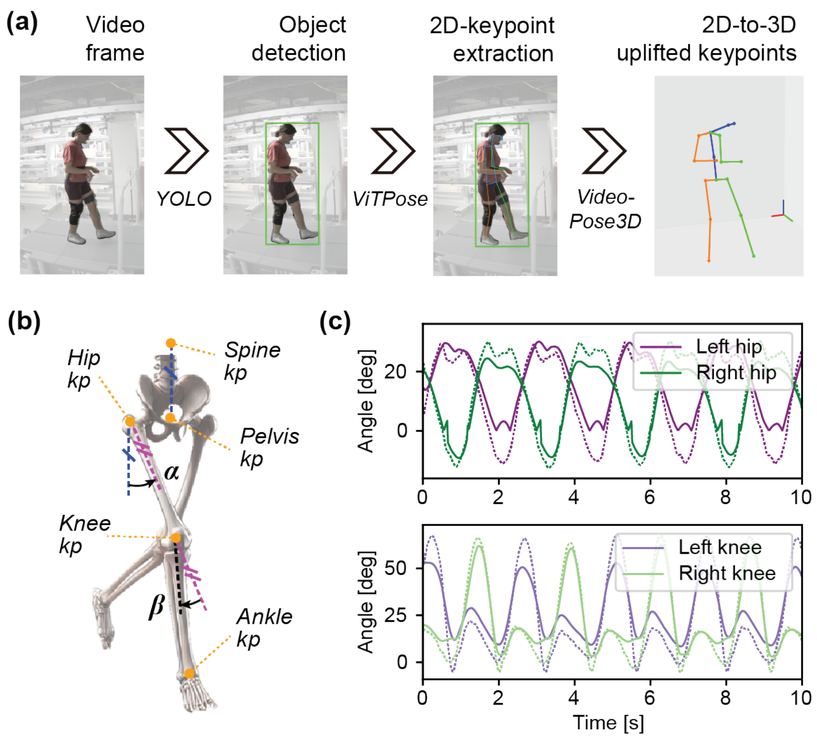
To simulate the irregular gait pattern, we put a knee brace to mimic stiff-knee gait pattern.

Temporal convolutional network



We trained the temporal convolutional network with the window size of 1 sec.

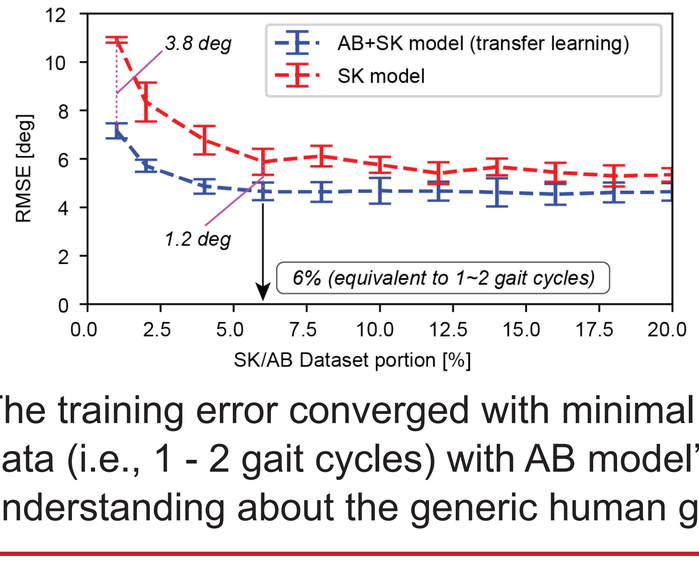
Vision-based kinematic extraction



We recorded a monocular camera video to
1) detect human,
2) extract 2D keypoints
3) 2D-to-3D uplifting,
thereby calculating the joint angles of hip, knee joints.

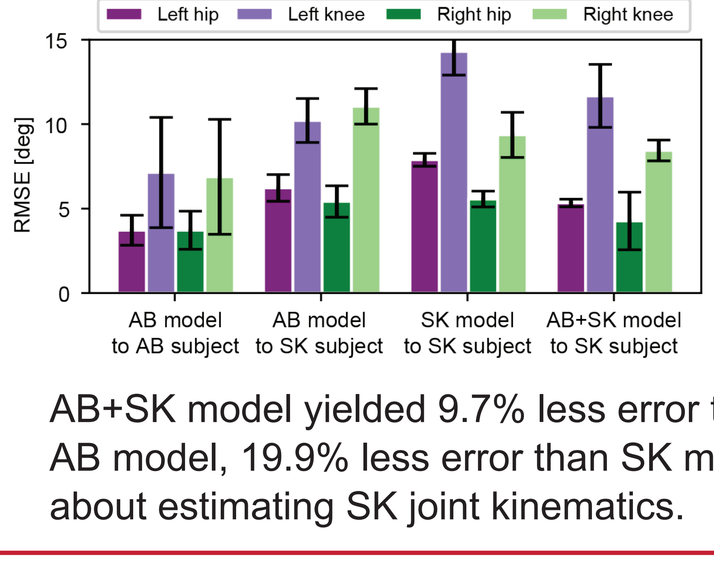
Results

Effect of dataset portion on adaptation

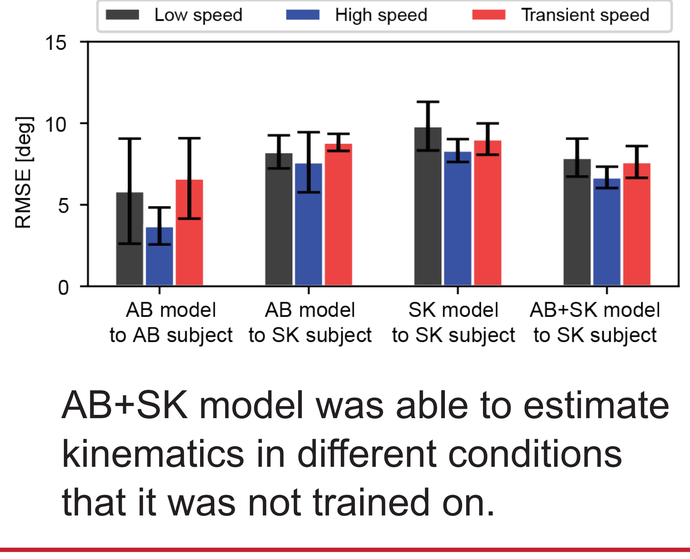


The training error converged with minimal data (i.e., 1 - 2 gait cycles) with AB model's understanding about the generic human gait.

Estimation performace of the adapted model

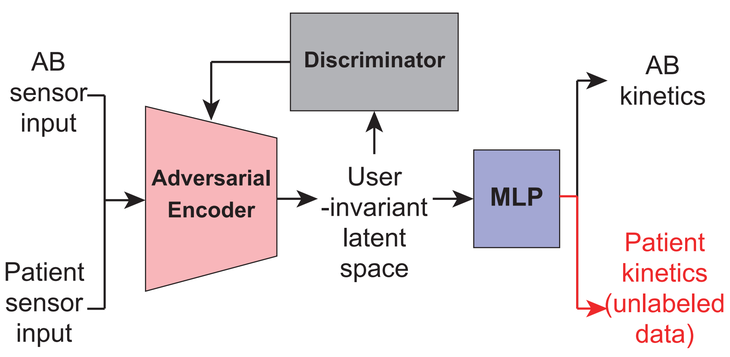


AB+SK model yielded 9.7% less error than AB model, 19.9% less error than SK model about estimating SK joint kinematics.



AB+SK model was able to estimate kinematics in different conditions that it was not trained on.

Future work - Encoder-based domain adaptation for unlabeled kinetic data



To further estimate the unlabeld kinetic data, we aim to get user-invariant features from both able-body and patient input data, and train the biotorque controller that can provide assistance to patients whose data was not collected.



[Hip Exo]

On-bard controller

Motor (w/ encoder)

IMU (2 for thigh, 1 for pelvis)

Acknowlegement

This work was supported by National Institute of Health (grant No. 1R21EB037268-01) and Gwanjeong Educational Foundation.

References

[1] S. Shin, Z. Li, and E. Halilaj, "Markerless motion tracking with noisy video and imu data," IEEE Transactions on Biomedical Engineering, 2023
[2] S. D. Uhlrich et al., "Opencap: Human movement dynamics from smartphone videos," tPLOS Computational Biology, 2023.
[3] Y. Xu, J. Zhang, Q. Zhang, and D. Tao, "ViTPose: Simple Vision Transformer Baselines for Human Pose Estimation" NeurIPS 2022.