Convolutional Neural Network-based Gait Phase Estimation & Classification using a Robotic Ankle Exoskeleton

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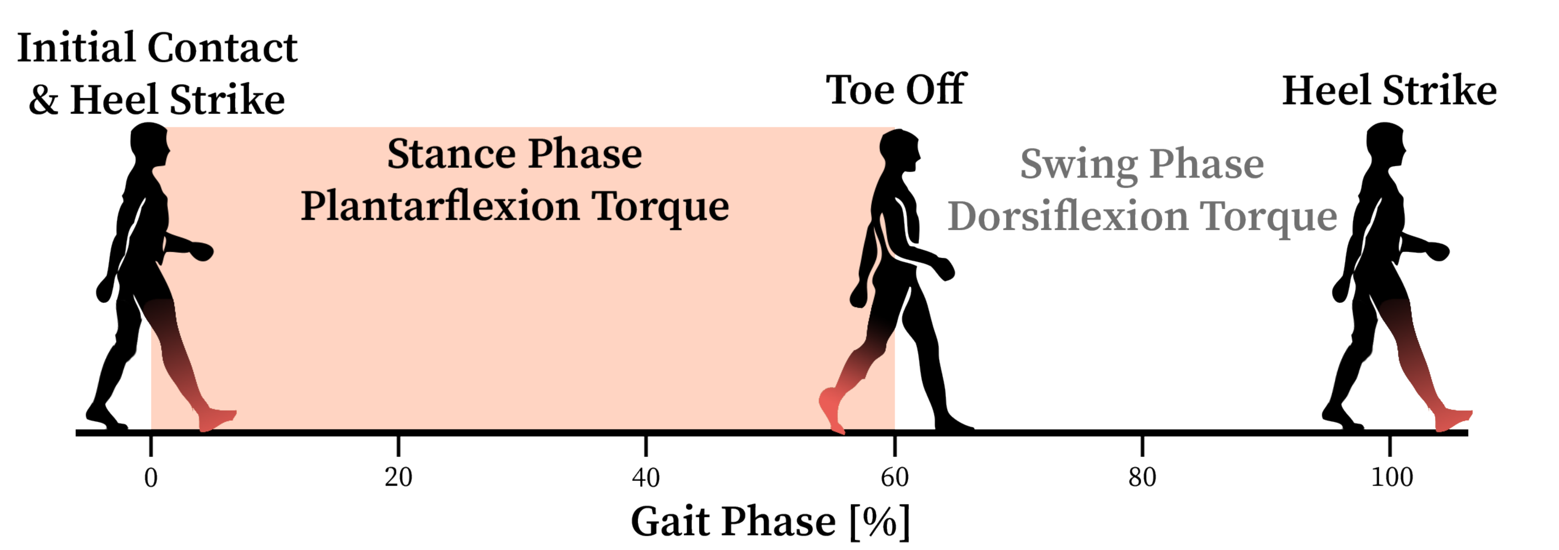
Introduction

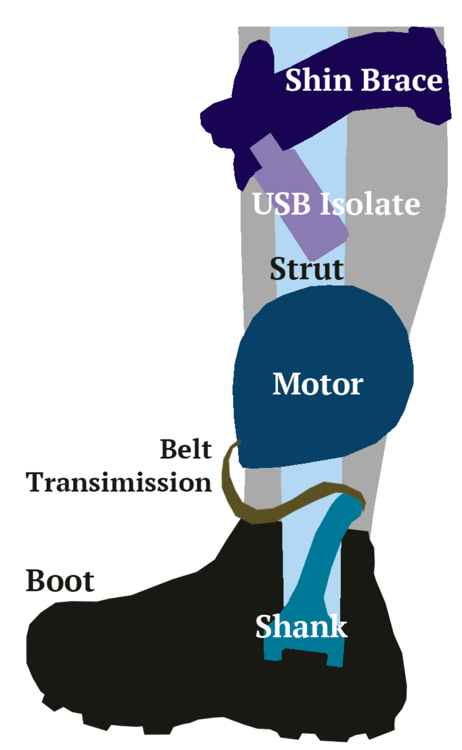
Among single joint exoskeletons, **ankle exoskeletons** have shown great potential in reducing the metabolic cost of walking [1]. In order to maximize the user benefit, it is critical to provide assistance with an accurate timing [2]. This timing variable is directly correlated with the user state information called gait phase which is a variable that dictates the user's joint configuration during the gait cycle [3].

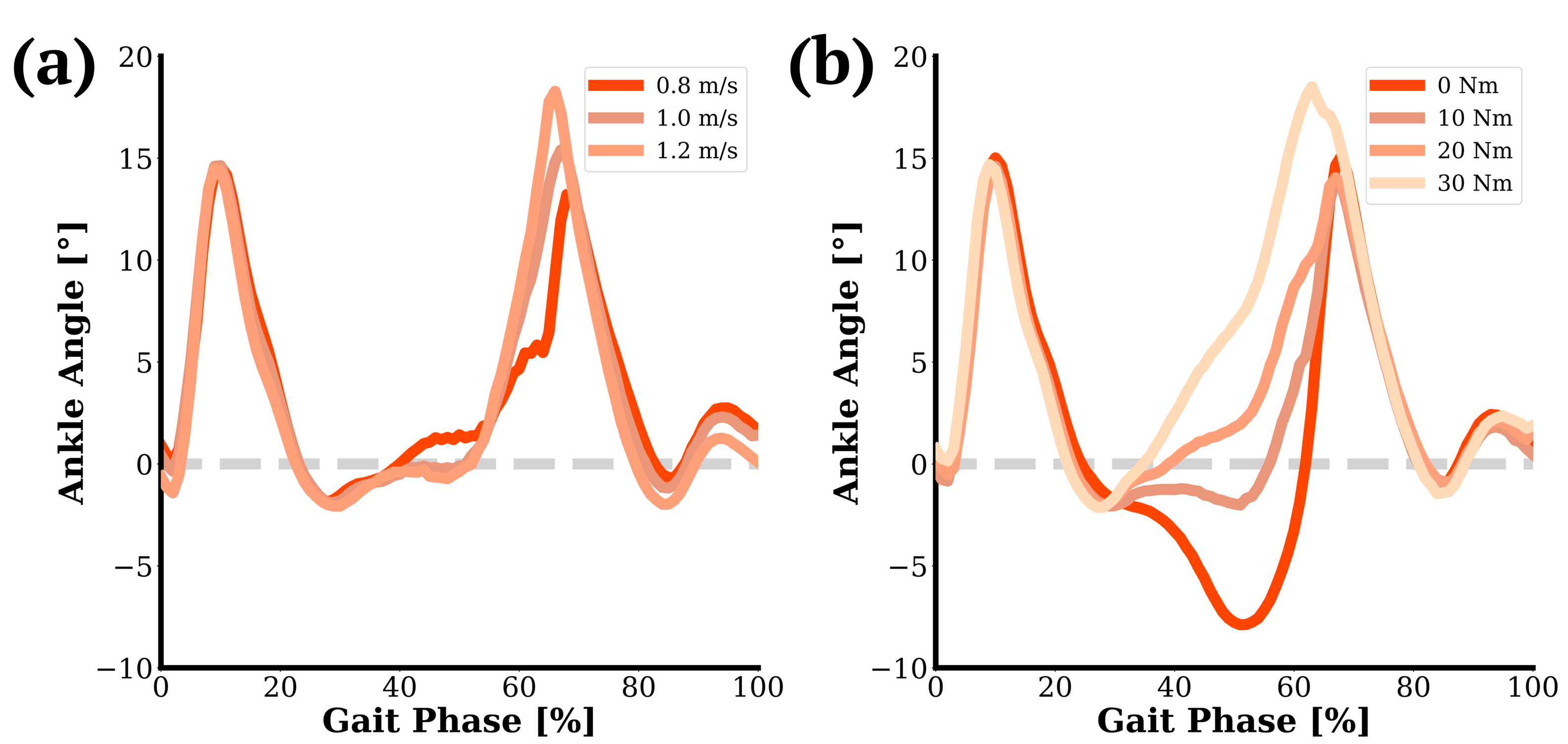
As it is paramount to develop a robust gait phase estimation method to better modulate the exoskeleton assistance, this study presents a **convolutional neural network-based gait phase estimator and classifier** that adapts to different walking speeds.



Exoskeleton Method

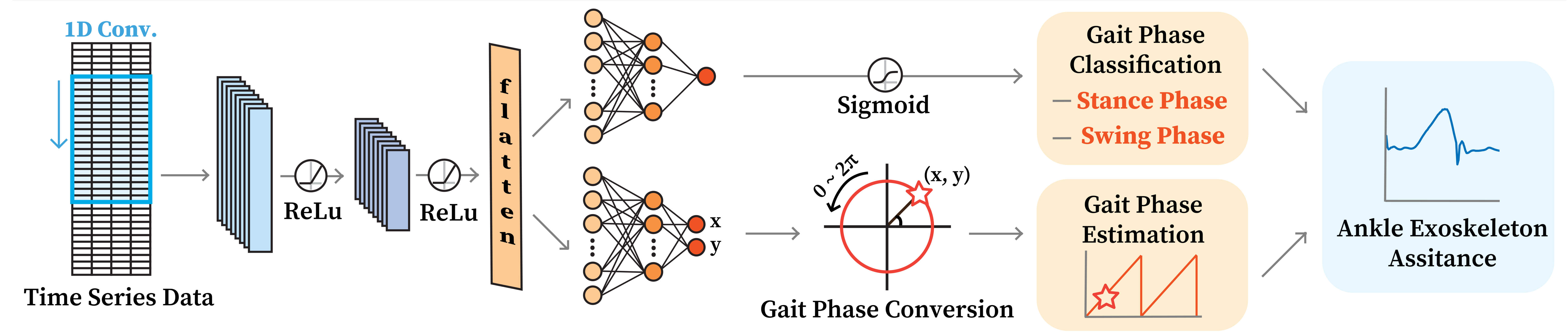
Robotic Ankle Exoskeleton





(a) Relationship between **ankle angle** and **speed** throughout a gait cycle
(b) Relationship between **ankle angle** and **assistance** throughout a gait cycle

Network Architecture



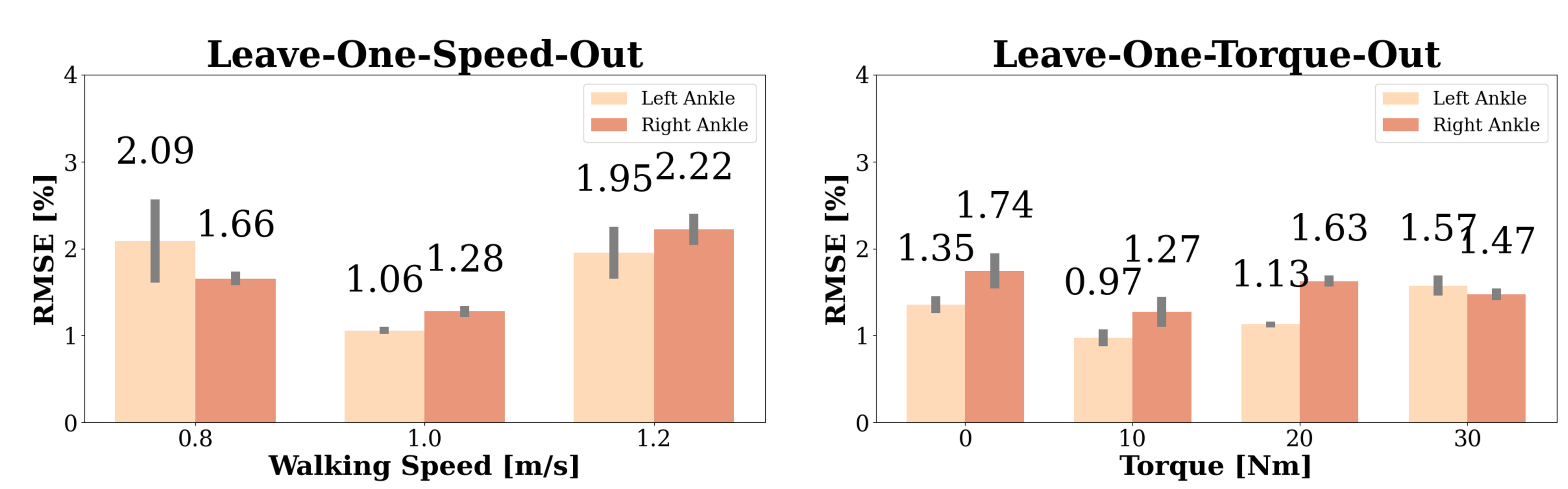
The proposed network produces two different outputs: **gait phase binary classification and estimation.** Our model was trained and tested on Joint Encoder, Inertial Measurement Unit, Force Sensing Resistor data which provide meaning information about the user's gait patterns.

Results

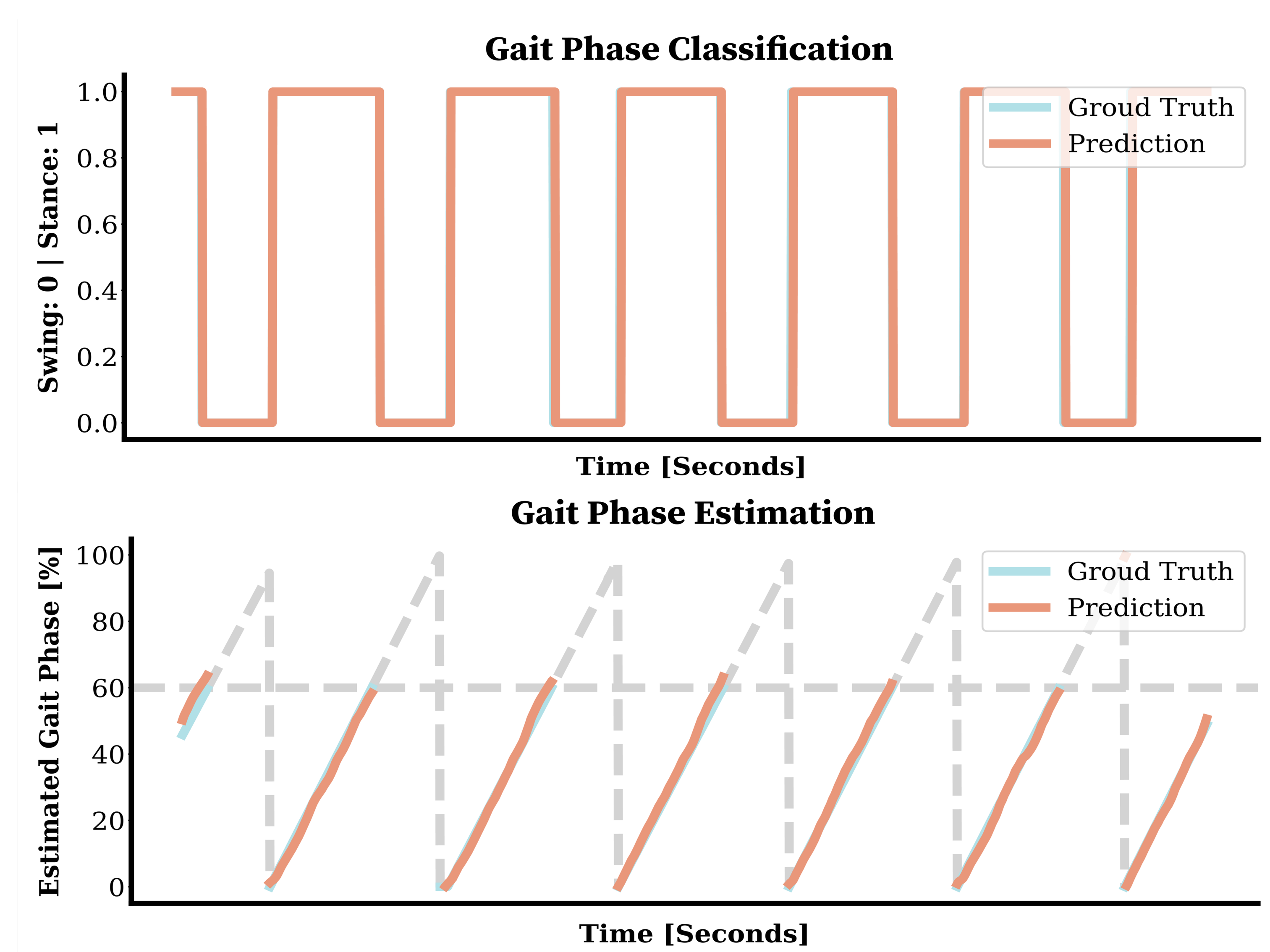
Gait Phase Binary Classification Result (Avg.)

accuracy	precision	recall	specificity	NPV	f1score
98.66%	98.22%	98.03%	92.35%	92.07%	98.06%

Gait Phase Estimation Result



- Exhaustive (5-fold) and non-exhaustive ("leave-*p*-out") validation were used to evaluate the validity and generalizability of the model.



Discussion

- The "leave-*p*-out" test results show that our deep convolutional neural network (CNN) can generalize well to unseen conditions (speed and assistance level).
- Our study also showcases that CNN enables multi-task learning, which can significantly improve device performance: Classification model can detect when to initiate or terminate exoskeleton assistance, while estimated gait phase from the regression model can be used to perform active modulation of exoskeleton assistance.

Future Direction

- Since the model was trained and tested offline, **online testing on overground walking** is needed to better evaluate the feasibility of translating the exoskeleton technology to more realistic settings.
- Training a **user-independent** model would help validate the generalizability of the gait phase prediction.

Acknowledgement

- This work was supported in by the National Science Foundation National Robotics Initiative Award.

References

[1] Sawicki et al., "The exoskeleton expansion: improving walking and running economy." *JNER*, 2020

[2] Galle et al., "Reducing the metabolic cost of walking with an ankle exoskeleton: interaction between actuation timing and power." *JNER*, 2017

[3] Kang et al., "Real-Time Neural Network-Based Gait Phase Estimation using a Robotic Hip Exoskeleton" *IEEE TMRB*, 2019