Modeling of a Foot-Shoe System Using IMU-Based Rotational Data and Multibody Dynamics

Hyun Seong Shin[1], Namkeun Kim[1]
[1]Department of Mechanical Engineering, Sogang University, Seoul, Republic of Korea
Email: nkim@sogang.ac.kr

Summary

This study introduces a calibration method for developing an integrated foot-shoe model using IMU-based rotational data and a multibody dynamics approach. The validated model effectively captures foot–shoe interactions under applied forces, demonstrating its potential for applications in exosuit anchor point optimization and biomechanics.

Introduction

Foot biomechanics research commonly employs three methods: (1) reflective marker-based 3D motion capture [1], (2) IMU-based motion analysis [2], and (3) finite element modeling using MRI or CT imaging [3]. While these methods provide valuable insights, they require extensive time and cost for experimental setup and model generation [2], limiting their practical application in wearable systems such as exoskeletons and footwear. To overcome these limitations, we propose an IMU-based approach to measure ankle rotations in shod conditions and calibrate a multibody dynamics model of the foot-shoe system. This method offers a cost-effective and adaptable modeling framework applicable to exosuit design and biomechanical studies.

Methods

A standardized shoe was equipped with multiple anchor points, each connected to a motor via tendon-like strings. An IMU, positioned at the shoe's base, recorded rotational data during controlled pulling at different anchor points, while the motor system logged force and displacement. A single-segment foot-shoe model was developed using COMSOL's multibody dynamics module, modeling the ankle as a three-degree-of-freedom (3-DOF) ball joint. Calibration was performed by iteratively adjusting the model's parameters to align the simulated force-rotation responses with experimental data. The model's accuracy and robustness were validated through additional tests under varying conditions.

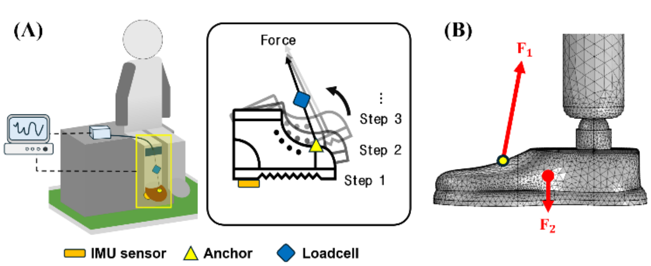

Figure 1: (A) Experimental setting, (B) foot-shoe model

Results and Discussion

The calibrated model successfully replicated the rotational behavior of the foot–shoe system, with simulated responses closely matching experimental data. Figure 2 presents a comparison of the force–rotation relationship, demonstrating strong agreement between experimental and simulated results. The *x*- and *y*-components of the rotation axis showed minimal deviation, while a minor discrepancy in the *z*-component was attributed to sensor noise and soft tissue effects.

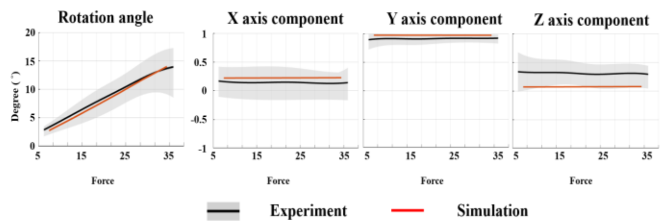

Figure 2: Expected abstracts for ISB2025 in January 2025.

These findings confirm the reliability of the proposed calibration approach, suggesting that further refinements in calibration and validation could enhance accuracy, particularly under complex loading conditions.

Conclusions

The proposed calibration method successfully generated an integrated foot-shoe model, accurately replicating rotational behavior under applied forces. This approach provides an efficient and cost-effective framework for studying foot-shoe interactions, with potential applications in biomechanical research and wearable system design.

Acknowledgments

This work has been supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2023-00218379).

References

[1] Hossain MSB. et al. (2022). *Journal of Biomedical and Health Informatics*, **26.8**: 3906-3917.
[2] Abdullah M. at al. (2024). *Journal of NeuroEngineering and Rehabilitation*, **21.1**: 178.
[3] Song Y. et al. (2022). *Heliyon*, **8.10**