Research Proposal

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1 Introduction

- General Area to be studied
  - Personalization of Prosthesis / Orthoses / Exoskeleton design [1]
- Why this area is important
  - many people suffer from locomotor defects, thus significantly modify the biomechanics and muscle activity of joints (e.g. asymmetrical gait patterns) [2]
  - correct locomotion (e.g. gaits) defect for disabilities [3]
  - reduce energy cost for long-distance locomotion [4]

2 Research Questions

- what is already known in the field (with several critical studies)?
  - common design goals for prostheses exoskeletons
    * light-weight [5]
    * high energy density and efficiency [6]
  - Therefore: 2 approaches to design prostheses / exoskeletons
    * tethered [7]
    * autonomous [8]
- Why these studies are not sufficient, thus requiring my further research?
  - both design are trade-offs: tethered exo has a smaller added mass penalty [9], while autonomous exo is easier to generate light-weight features [6].
  - The ultimate goal of prostheses / exoskeleton design is to be generalized in design and personalized in user experience.
- **Key Research Questions, and Relevant Rationale**
  - how to weigh the benefits of drawbacks of different prostheses / exoskeleton design, and generalize the design flow for personalized prostheses / exoskeleton devices?

3 Plans and Methods

- Biomechanics: multiple ways to evaluate metabolic cost, by **Sensor Fusion** (respirometry, electromyography (EMG))
  - Lead to: mixed control strategy (data driven + classical control)
  - benefit: better understanding of mechanics (mid-level control side), contributes to the high level control (e.g. locomotion modes, various walking speed), make it more adaptable to dynamic movement.
- Mechatronics (wearable robotics) design: variable stiffness and impedance (interchangeable components [5], compact energy storage devices [6], impedance control [10]).
  - Goal: provide net energy gain for the user, thus reducing the metabolic cost of locomotion
  - Components should be adjustable (e.g. series spring), while maintaining control bandwidth [11]

4 Significance

- personalized in **assistance**
  - reduce energy cost [4]
- personalized in **rehabilitation**
  - correct gait patterns [3]

References

[1] P. Slade, M. J. Kochenderfer, S. L. Delp, and S. H. Collins, "Personalizing exoskeleton assistance while walking in the real world," *Nature*, vol. 610, no. 7931, pp. 277–282, 2022.

[2] L. Nolan, A. Wit, K. Dudziñski, A. Lees, M. Lake, and M. Wychowañski, "Adjustments in gait symmetry with walking speed in trans-femoral and trans-tibial amputees," *Gait & posture*, vol. 17, no. 2, pp. 142–151, 2003.

[3] J. F. Lehmann, S. M. Condon, R. Price, *et al.*, "Gait abnormalities in hemiplegia: their correction by ankle-foot orthoses.," *Archives of physical medicine and rehabilitation*, vol. 68, no. 11, pp. 763–771, 1987.

[4] K. L. Poggensee and S. H. Collins, "How adaptation, training, and customization contribute to benefits from exoskeleton assistance," *Science Robotics*, vol. 6, no. 58, p. eabf1078, 2021.

[5] P. G. Kulkarni, N. Paudel, S. Magar, M. F. Santilli, S. Kashyap, A. K. Baranwal, P. Zamboni, P. Vasavada, A. Katiyar, and A. V. Singh, "Overcoming challenges and innovations in orthopedic prosthesis design: an interdisciplinary perspective," *Biomedical Materials & Devices*, vol. 2, no. 1, pp. 58–69, 2024.

[6] Z. Bons, G. C. Thomas, L. M. Mooney, and E. J. Rouse, "A compact, two-part torsion spring architecture," in *2023 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 7461–7467, IEEE, 2023.

[7] K. A. Witte, A. M. Fatschel, and S. H. Collins, "Design of a lightweight, tethered, torque-controlled knee exoskeleton," in *2017 international conference on rehabilitation robotics (ICORR)*, pp. 1646–1653, IEEE, 2017.

[8] A. F. Azocar, L. M. Mooney, J.-F. Duval, A. M. Simon, L. J. Hargrove, and E. J. Rouse, "Design and clinical implementation of an open-source bionic leg," *Nature biomedical engineering*, vol. 4, no. 10, pp. 941–953, 2020.

[9] G. S. Sawicki, O. N. Beck, I. Kang, and A. J. Young, "The exoskeleton expansion: improving walking and running economy," *Journal of neuroengineering and rehabilitation*, vol. 17, pp. 1–9, 2020.

[10] L. M. Mooney, *The use of series compliance and variable transmission elements in the design of a powered knee prosthesis*. PhD thesis, Massachusetts Institute of Technology, 2014.

[11] F. Sergi, D. Accoto, G. Carpino, N. L. Tagliamonte, and E. Guglielmelli, "Design and characterization of a compact rotary series elastic actuator for knee assistance during overground walking," in *2012 4th IEEE RAS & EMBS international conference on biomedical robotics and biomechatronics (BioRob)*, pp. 1931–1936, IEEE, 2012.