MECHANICAL ENGINEERING
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The Effect of Inclination and Walking speed on Foot Placement for Slope Walking

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RESEARCH SUMMARY

- Hypothesized that human foot placement is dependent upon the slope angle and walking speed during the slope walking
- Performed a statistical analysis on the human walking data with different slope angles and walking speeds
- Found that the step length varied with respect to the slope angle and walking speed

INTRODUCTION

Previous studies

- According to [1,2], human joint kinematics (e.g., ankle and knee) are barely changed with respect to the walking speed, but have distinct traits with respect to the slope angle (ϑ).
- When $\vartheta \geq 0$, as ϑ becomes greater, more flexion occurs at the ankle (dorsi-flexion) and knee (flexion) joint [1,2].
- When $\vartheta < 0$, ankle kinematics are barely affected by the slope angle while knee angles deviate from the level-walking trajectory as the slope becomes steeper [1,2].

- Sun et al. observed the relationship between the slope angle and the step length, walking speed, and cadence, respectively [3].
- The significant finding in [3] was the reduction in step length and increasing cadence with increasing ϑ during ramp descent, but this study has no consideration of the step length with respect to walking speed.

In this study,

- Hypothesized that human foot placement can be estimated with having the slope angle and walking speed during the slope walking
- Investigated the effect of the slope angle and walking speed on the foot placement during slope walking, which could be beneficial for the control of the lower limb assistive device to determine the optimal foot placement for better adaption to sloped surfaces

METHODS

Human slope walking

- We used publicly available human walking data from the University of Texas at Dallas (UTD) [4].
- Ten healthy subjects (5 male, 5 female) walked on a treadmill for one minute with 3 walking speeds (0.8, 1.0, 1.2 m/s) and 9 slope angles (-10° to 10° with 2.5° increments).
- Step length was estimated using the average step time and walking speeds.

Data analysis

- A two-way repeated measures ANOVA and a series of t-tests were performed to analyze the correlation between the slope, walking speed and step length.

RESULTS AND DISCUSSIONS

Results

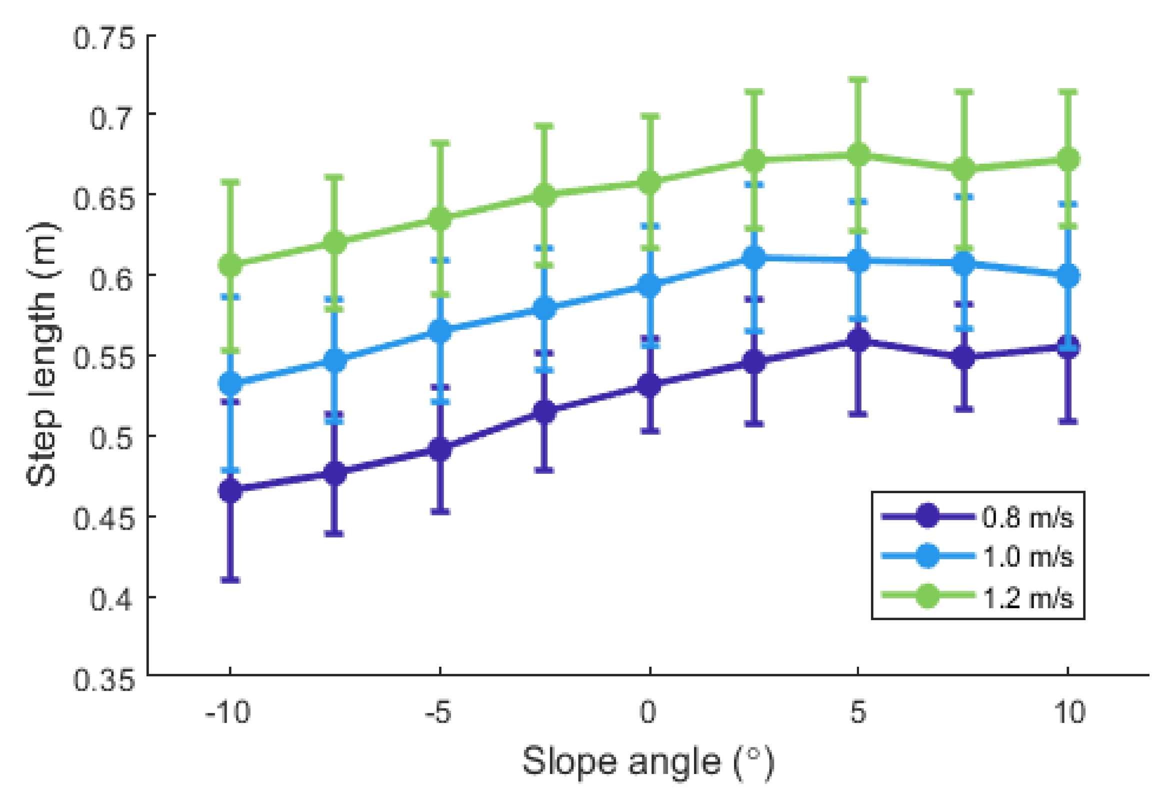

Figure 1 Markers (●) indicate the mean values of step lengths and the error bars indicate their ±1 standard deviation on each slope according to 3 different walking speeds.

- In Figure 1, the step lengths are shown according to 9 different slopes (from -10° to 10° with 2.5° increments) and 3 different walking speeds (0.8, 1.0, and 1.2m/s).
- When the slope angle $> 0°$, the step length has no significant trend with respect to the slope angle for all walking speeds.
- On the downslope, the step length decreases when the slope becomes steeper ($p < 0.005$) for all walking speeds, which is also supported by [3].

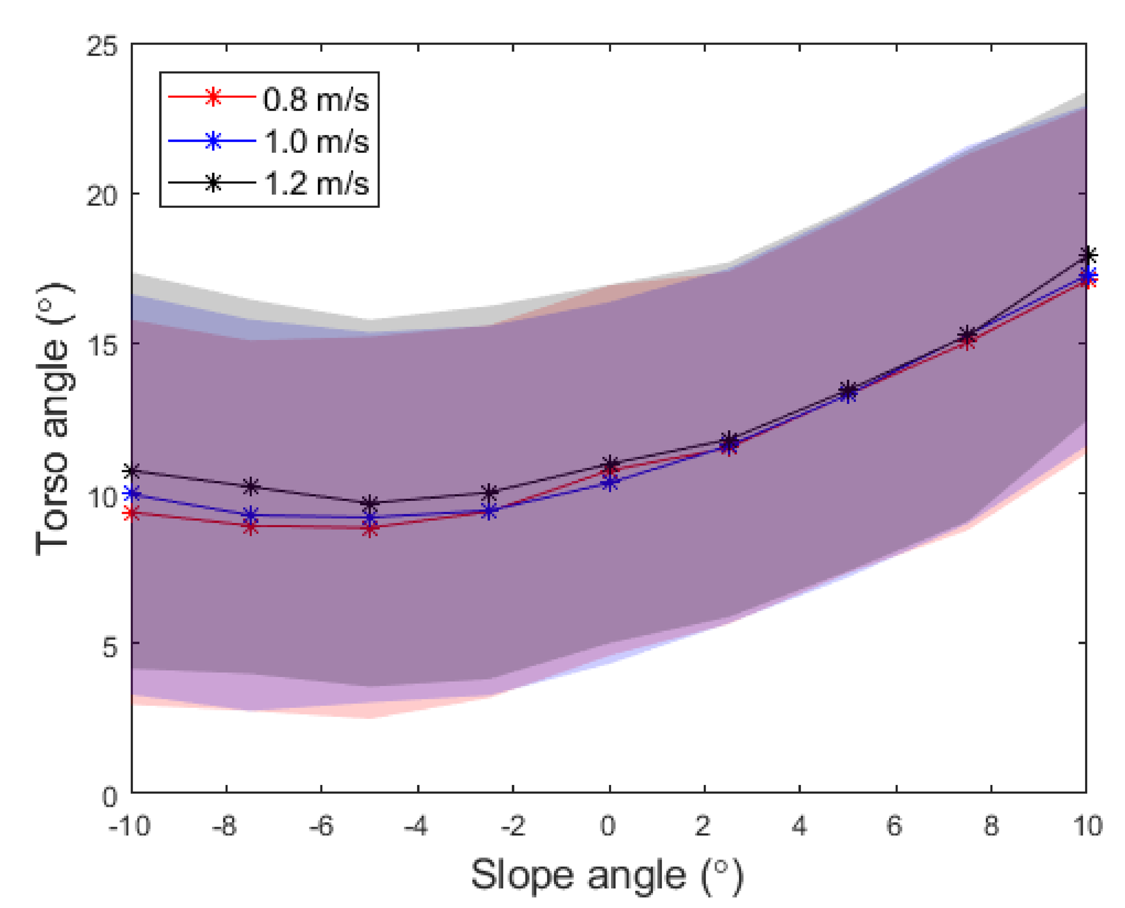

Figure 2 Markers (*) indicate the mean values of torso angles and the shaded regions indicate the ±1 standard deviation on each slope according to 3 different walking speeds.

- In Figure 2, the torso angles are shown according to 9 different slopes (from -10° to 10° with 2.5° increments) and 3 different walking speeds (0.8, 1.0, and 1.2m/s).
- On the upslope (including level-walking), the torso angle increased as the slope gets steeper for all walking speeds.
- On the downslope, the torso angles barely changed depending on the slope angle for all walking speeds.

Discussions

- When the downslope angle, ϑ, is steep, the equivalent friction coefficient ($f_c = \mu \cos\vartheta$) decreases, suggesting that the surface becomes more slippery.
- In this case, people tend to be more cautious, increase the cadence and decrease step length to avoid the excessive ground reaction force and the potential slippage on the surfaces.
- People try to use the Cautious Walking (CW) strategy when the downslope gets steeper.
- In Figure 2, torso angles on the downslope also support the CW strategy. On the downslope, it is shown that people tend to keep their torso angle close to upright to avoid potential slip which may indicate that people become more cautious on the downslope.

FUTURE WORKS

Powered transfemoral prosthesis

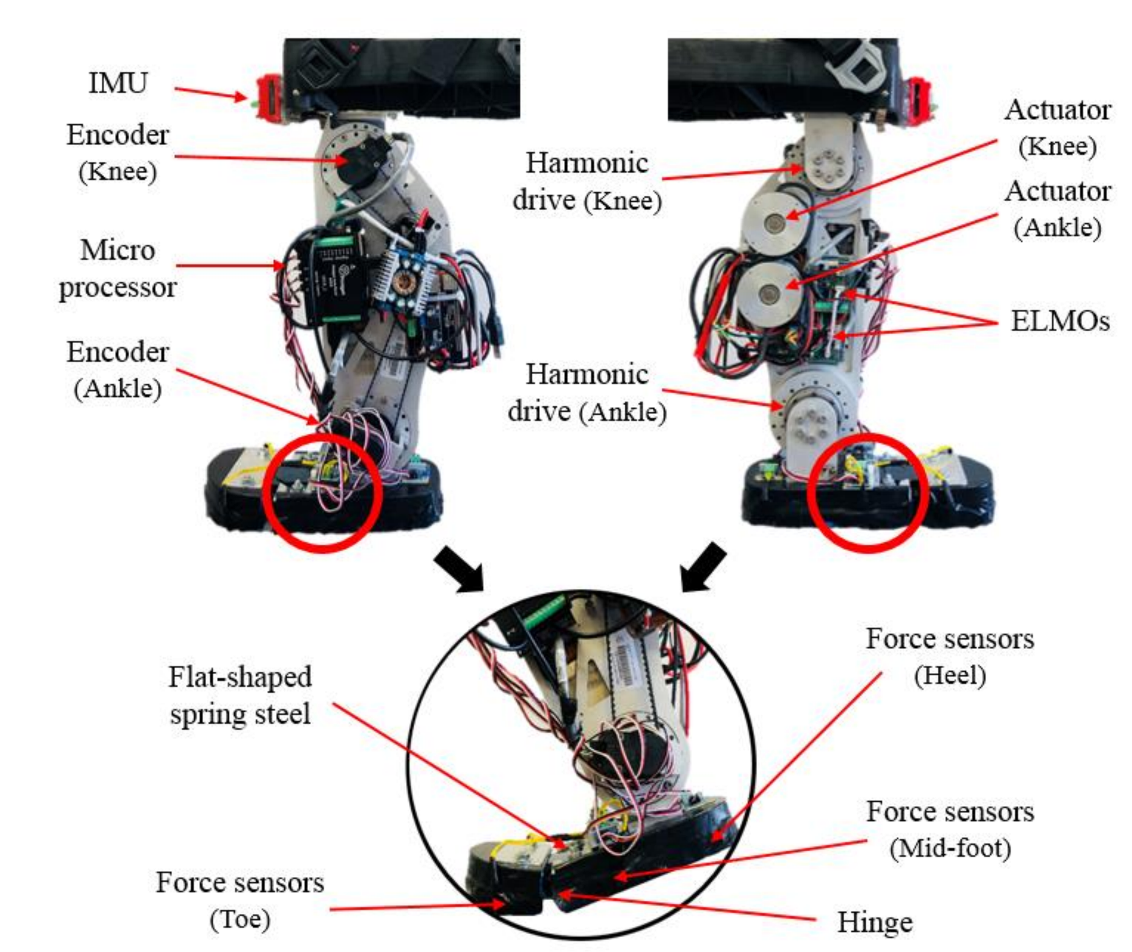

Figure 3 The powered transfemoral prosthesis (AMPRO II) has two active actuations at ankle and knee joints, and a passive actuation at toe joint.

- Numerical relationship between the step length, and slope angle and walking speed will be computed.
- Numerical relationship could be implemented for the foot placement control to provide better step to the sloped surfaces for the lower limb powered prosthesis (e.g., AMPRO II).

CONCLUSIONS

- In our analysis, it was shown that the slope angle and walking speed affected step length on the sloped surfaces.
- Humans tend to walk more cautiously on downslopes by limiting the step length and tend to change the step length to adjust their walking speed.

References

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[3] Jie Sun et al. (1996), *Ergonomics*, **39(4)**: 677-692.

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