RESEARCH HIGHLIGHT

- Achieving the slope walking for a powered transfemoral prosthesis with a unified control framework
- Avoiding heavy optimization for real-time performance
- Smooth transitions for any sloped surfaces without prior knowledge of slope

INTRODUCTION

Background

- Transfemoral amputees have faced more difficulties compared to healthy individuals and transfibial amputees.
- Especially, a slope walking is one of the most challenging daily task for transfemoral amputees [1].

Previous studies

- There have been several studies on a powered prosthesis to tackle this problem.
- Impedance control using sets of impedance parameters (i.e., k, b, \( \theta^0 \)) could handle this problem, but it requires heavy tuning process to decide the parameters from the finite walking phases [2].
- The other study tackles the prosthetic slope walking using human-inspired constraint to track the given trajectories. It reduced a tuning process, but this requires a prior knowledge for the slope and for the downslope walking, they only tried on a small gradient [3].

BACKGROUND KNOWLEDGE

Human walking phases

- Human walking consists of several events: heel-strike (HS), foot-drop (FD), heel-off (HO), push-off (PO), and toe-off (TO) [4]. Considering these events, human gait can be discretized into finite phases.

- In this study, a human gait is considered to consist of two walking phases: i) stance phase (HS to PO): 0 – 60% of the gait cycle ii) swing phase (PO to HS): 60 – 100% of the gait cycle

Human gait synchronization

- To synchronize the human walking and prosthetic walking and provide the appropriate control over the prosthesis, a human walking detection is required [3].
- By using a phase variable (calculated from \( \theta_{\text{high}} \)) and force sensors under the foot (toe, mid-foot, heel), human walking phase and events can be detected.

Human kinematics on the sloped surfaces

- Depending on the slope, human joint kinematics (ankle and knee) are varying [5].
- Providing the appropriate joint control to the prosthesis is required to provide the powered prosthesis for avoiding a conflict with the slope.

CONTROL FRAMEWORK

- The optimal stiffness, damping, and equilibrium were chosen from the previous studies [7-10].

Swing phase: Trajectory tracking

- Cubic Bezier polynomials generates the desired walking trajectories during the swing phase.
- The generic cubic Bezier polynomials are described as below where \( t \in [0,1]: \)
  \[ Z_t = (1-t)^3P_0 + 3(1-t)^2tP_1 + 3(1-t)t^2P_2 + t^3P_3 \]
- In Fig. 3, by controlling \( P_0 \) and \( P_3 \) any different slope walking curves can be generated.

Experimental results

- Note that since the experiment was conducted with a healthy subject using a simulator, the subject’s gait itself could be altered.
- The results show that both ankle and knee joint trajectories (Fig.5 cdgh) are qualitatively similar compared to human slope walking trajectories (Fig.5 abef).
- Specifically, at the knee joint, compliant walking during the stance phase and the enlarged flexion depending on the downslope stiffness are clearly shown.
- For both upslope and downslope, PO can be observed in the prosthetic walking even though this is not as great as human walking.

Discussions

- It is shown that knee flexion on the downslopes are still small compared to human. This is mainly because of the hardware limitation; the knee flexion is restricted by 63°.
- In the results, the prosthetic walking results have quantitative differences during the stance phase, even though the trends are similar. This result can be improved by a further tuning process to provide better impedance parameters.

CONCLUSIONS

- The proposed study is having a benefit to unify the trajectory generation process for slope without prior knowledge of slope.
- This results in a fast trajectory generation with a proper foot clearance for human-like slope walking.
- By using a function of impedance parameters, a compliant interaction during the stance phase can be achieved with a simple tuning.

FUTURE WORKS

- For a better adaptation and a more powerful push-off as like human, a deeper impedance control studies will be conducted.
- Related to push-off, the deeper prosthetic study including the characteristic of toe joint and the foot pad are planned.
- For a solid validation, amputee walking study will be conducted with this control framework.

REFERENCES