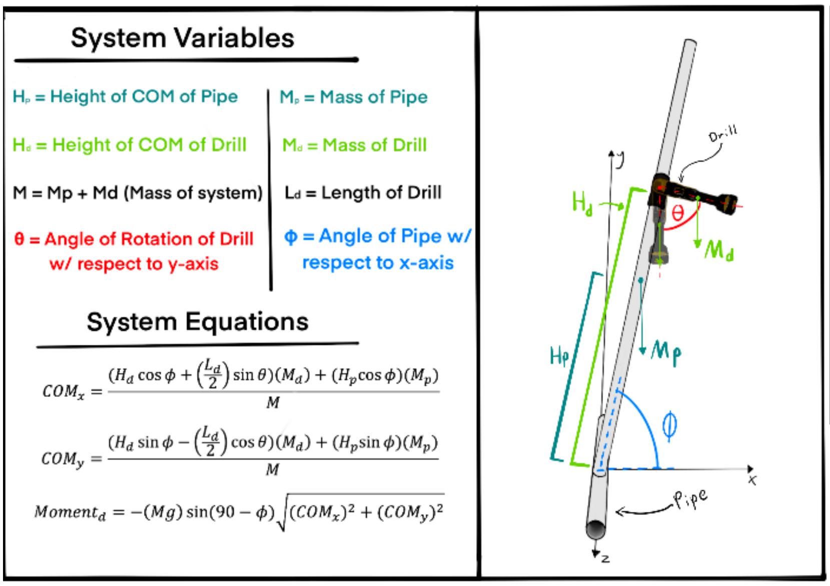
Inertia-Based Prosthetic Tails: Balance Improvement, Equation Development, and Proof-of-Concept

Nathaniel Mitrik[1], Zachary Roy[1], Alexandra Delazio[1], David Brienza[1], Goeran Fiedler[1]

[1]University of Pittsburgh

Introduction: Maintaining balance is essential for mobility and preventing fall-related injuries while walking. In the US, more than one in four adults over the age of 65 falls each year.[1] Conventional approaches to fall prevention include wheeled mobility devices and canes or crutches. Orthotic devices achieve their function by mechanically stabilizing the body and, in the case of exoskeletons, replacing or supplementing some muscle function. A previously proposed alternative solution to the problem of body balance is the use of a prosthetic tail, inspired by balance strategies employed in the animal kingdom.[2] Previous tests have shown that a motorized tail is able to disrupt balance in humans, suggesting that the inverse effect (i.e., establishing balance) should be viable.[3] The aim of the present work was to determine the necessary properties of such a tail and to validate calculations alongside a simplified bench test. We hypothesized that appropriately dosed tail action can generate the required torque to return a tipping pendulum to an upright position.

Materials and Methods: A simplified biomechanical model of human stability has long been the "inverted pendulum", describing the angular motion of the body's center of gravity around a pivot. The inverted pendulum is inherently unstable, and various existing mechanisms (e.g., arm motion, ankle joint control, etc.) are naturally applied to prevent falling. We utilized basic physics equations (Fig. 1) to calculate the angular disruption (lean angle) that a tail with a given torque rating could correct on a person. We then tested if a prosthetic tail could practically function as a mechanism for balance control using an actual inverted pendulum (Fig.2).



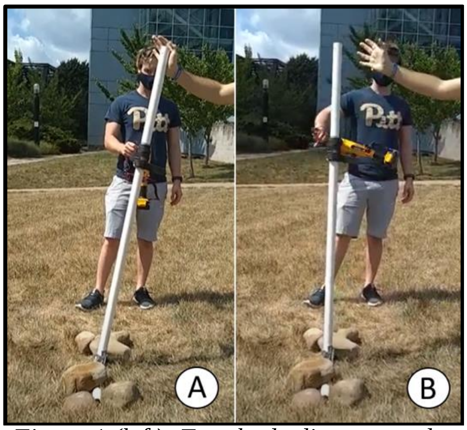


Figure 1 (left): Free body diagram and equations. Figure 2 (right): Illustrative example of the tail effect. The initial pendulum angle of 22 degrees (A) from the vertical position was corrected to 2 degrees (B) after activating the tail.

Results and Discussion: Based on our calculations for the center of mass for a simplified inverted pendulum and assumptions regarding a representative human subject (mass of 50 kg and height of 152 cm) and a viable motor torque of 100 Nm, the maximal perturbation angle that the tail could correct would be 17 degrees from the vertical. In the practical test, the tail action facilitated a correction of 20 degrees with a lower torque rating and a corresponding mass reduction. This supports our calculations regarding the needed tail torque and activation length for our human user.

The simplified testing revealed several technical issues that will be addressed in future work. The correction for human subjects will be done through a feedback loop, and our work thus far has shown great promise in effects on perturbations as well as increased accuracy of boundary conditions for regulation of tail effects. Of relevance for our application may be the inevitable vertical force component introduced by tail de/accelerations when not in neutral position. If it is determined that this side effect is clinically significant, the maximal "wagging angle" of the tail will have to be limited and the torque be increased to compensate accordingly.

Conclusion: A prosthetic tail is effective in stabilizing an inverted pendulum. Utilization of this model on humans is promising and within commercial reach. Prosthetic tails have promising biomedical applications in assistive technology for people with balance impairments and will improve quality of life for those with such impairments.

Acknowledgements: First Gear-Program Award by the University of Pittsburgh Innovation Institute

References: [1]Bergen et al. MMWR Morb Mortal WklyRep. 2016; 65:993–998. | [2]Mitrik, et al. AOPA Assembly 2020, Sep 9-12, *under review* | [3]Roy, et al. AOPA Assembly 2020, Sep 9-12, *under review*