Walking and running with a powered ankle prosthesis

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1 Introduction

Common passive prosthetic feet are designed to enable amputees to perform both standing and walking tasks. Because of the limited range of motion of these feet [1], it makes it hard to run. Passive running prostheses have no heel element (e.g. Flex-Run, Ossur or 1E90, Otto Bock) which dramatically increases the effort for standing, but enables a good roll-over allowing forefoot running.

By using a powered ankle prosthesis, walking and running as well as comfortable standing might be performed with the same device. In order to mimic the locomotion capabilities of a healthy ankle, the Walk-Run ankle was designed (Fig. 1). It uses a 200 W brushless DC motor and a spring to mimic human gait angle-torque trajectories. To perform experiments, a controller capable of transitions between standing, walking, and running with speed adaptations was developed.

Model predictions of motor and spring interaction should be verified and limitations of such a technology should be evaluated.

Figure 1: Walk-Run ankle (Springactive)

2 Methods

The Walk-Run ankle is controlled using a gyro sensor and an accelerometer, fixed at the upper part of the prosthesis. Spring stiffness of the Walk-Run ankle was optimized to minimize motor peak power requirements at 2.6 m/s running. Motor movement complements the spring length change to match healthy subject reference torque and angle curves [2].

One able bodied subject (23 years, 63.5 kg) was walking (1.6 m/s) and running (2.6 m/s, 4 m/s) at different speeds on a treadmill using the Walk-Run ankle. For the evaluation the mean of multiple continuous steps is used.

A bypass system (Fig. 2) was used to mount the ankle prosthesis in parallel to the fixed healthy foot. The leg length of the opposite leg was increased by an additional sole on the shoe. Using the motor encoder and the ankle angle encoder of the Walk-Run ankle, the spring length, velocity, and force were determined. In combination with the spring lever arm at the ankle joint, ankle torque was calculated. Using the roller screw lever nut force, length, and velocity were determined. Spring and nut power were calculated by multiplying respective force and velocity. Power and torque were normalized to body mass.

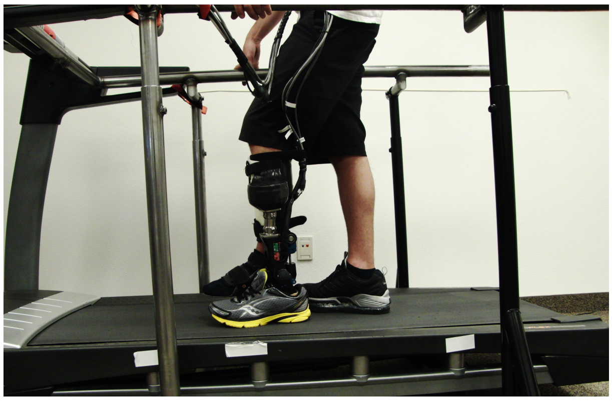

Figure 2: Experimental setup: A bypass device is used to fix the Walk-Run ankle at a non-amputee.

3 Results and Discussion

The Walk-Run ankle was capable of mimicking human torque and angle curves (Fig. 3) almost perfect in 1.6 m/s walking. In 2.6 m/s running the shape and also peak values were comparable to the reference data. The authors believe that small differences between the reference and the experiment were mainly caused by the difference in leg length due to the bypass setup. At 4 m/s running, ankle angle could almost be matched while peak ankle torque could not. Limited motor power was identified as the main reason that torque could not be matched. For the used stiffness about 8 W/kg mechanical peak output power at the nut of the roller screw were predicted

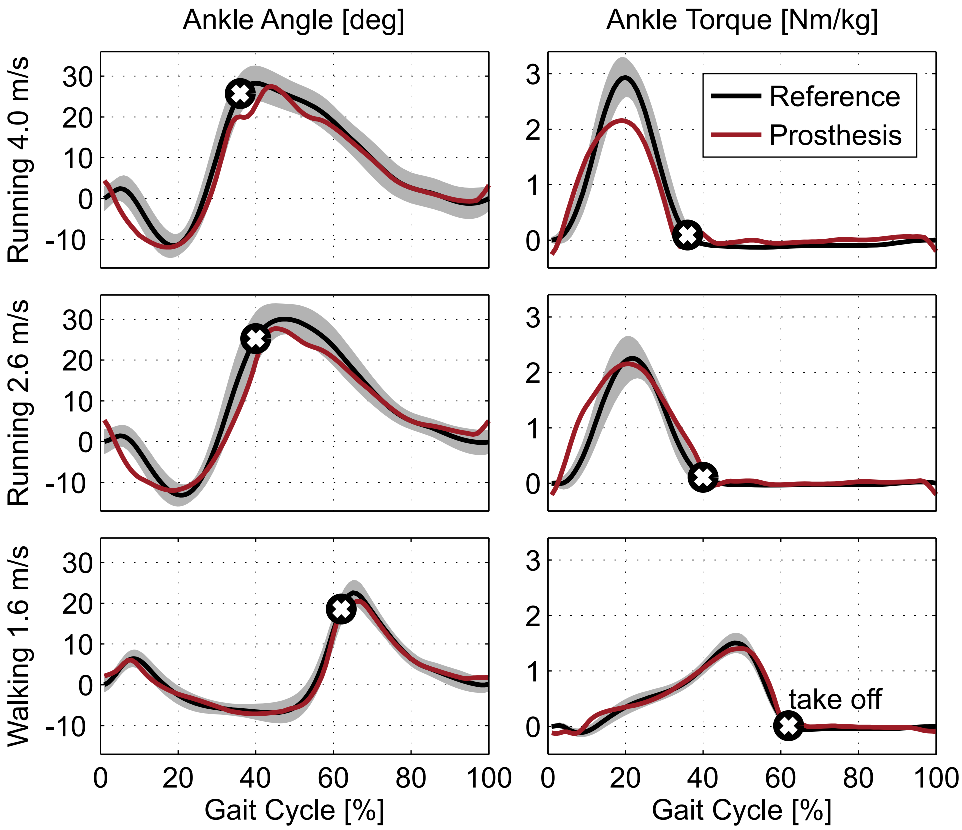

Figure 3: Ankle angle (left) and ankle torque (right) for the Walk-Run ankle (red) and the mean of up to 21 health human reference subjects (black, [3]). For the reference data also standard deviation is shown in (gray). An increase of the ankle angle implies plantarflexion.

by the model. Maximum mechanical nut output in the experiment was at about 3 W/kg. Modeling predicts that an optimal stiffness could reduce requirements for running at 4 m/s to 3.9 W/kg [4]. This could greatly improve the performance for the fastest running speed.

4 Conclusion

The first measurements on the Walk-Run ankle could demonstrate that a powered ankle prosthesis enables one to perform walking, running, and standing using one prosthetic design. The running trial for the highest speed of 4 m/s highlighted the importance of an optimal spring stiffness to reduce the motor assistance. The human reference ankle angle was almost achieved even without achieving the reference peak torque. The authors believe that it is worthwhile to investigate the compromise between following calculated optimal motor trajectories and gait quality. There might be a high potential to decrease energetic requirements when motor reference trajectories are manipulated in a way to reduce acceleration and minimize changes in direction.

5 Acknowledgements

Research reported in this abstract was supported by the the DFG grant SE1042/8 and the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institutes of Health under award number R43HD072402. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. The authors acknowledge M. Holgate, T. Sugar, and K. Hollander for project planing and organization. The authors acknowledge M. Holgate and R. Holgate for prosthesis design, sensor integration, wiring, assembling and assistance for experiments. The authors acknowledge A. Boehler for the setup of the PC-104 platform, including sensor and motor interfaces, used to control the robotic ankle. The authors acknowledge J. Ward for supervision on control developments and assistance for experiments.

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