Prosthetic foot control for ground adaptation

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Abstract

Wearers of prosthetic feet find walking on inclined ground difficult or uncomfortable. A major reason for this is a limitation in ankle motion in existing prostheses. In this thesis foot ankle control in prostheses was studied with a focus on sensing and actuating principles for varying ground conditions in the sagittal plane during continuous gait.

Kinematical sensors, such as gyroscopes and accelerometers, made it possible to estimate swing motion and ground inclination. Ground slope angle was estimated at stance by measuring a gravitational component. Position estimation during swing included integration where the noise influence was reduced by using initial and final conditions of swing. Tests showed that ascending and descending stairs and level walking can be classified from swing motion.

Alternatively, kinetic sensors, such as strain sensors measured the resulting torque effect caused by the ankle limitation. A linear relation between strain and slope angle was found using Fourier series representation. This made it possible to estimate ground slope angle with the same accuracy as with kinematical sensing.

Two actuation principles with an emphasis on low power consumption have been proposed. The first compensated for ground inclinations by adapting ankle angle with a DC motor during swing. Since the controller only activated the motor when the foot was lifted and thus not loaded, a small powered system could be embedded. The large contact forces at heel strike were handled by springs, just as in passive prosthesis. In combination with the kinematical estimators, the system could autonomously correct the ankle angle to the inclination during gait.

The second actuation principle exploited the large forces during ground contact for ankle angle adaption. A magneto-rheological damper was used to achieve ankle damping during foot down and locking at swing, thereby avoiding foot slap and foot drop. The controller used feedback from the ankle angle only. Experiments on an ankle-foot-orthosis verified the behavior in stair gait and in level walking where gait speed and ground inclinations varied. As a consequence, toe strike was possible in stair gait as opposed to heel strike in level walking.

It has been shown that it is possible to design a prosthesis that autonomously adapts to ground variations such as inclinations and stairs. The proposed technologies show promising results for use in future prosthetic and orthotic feet.

Keywords: Foot prosthesis, embedded computing, sensor fusion, kinematical sensors, autonomous systems.