Mimicking Physiological Rollover Shape in a Prosthetic Foot with a Single Degree-of-Freedom Ankle Joint

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Abstract

The objective of this work is to design a low-cost, high performance prosthetic foot/ankle for use in developing countries. In order to achieve that, it is essential to understand how mechanical features affect the function of prosthetic feet. Thus a method was created for predicting the roll-over shapes of simple analytical prosthetic foot/ankle models. The ground reaction force magnitude and the center of pressure as found in published gait analysis data were applied to a prosthetic foot model consisting of a rigid foot and a single degree of freedom ankle joint. The resulting rotation of the ankle joint was calculated, and the center of pressure in the deformed state was found. The centers of pressure from each time interval provide the roll-over shape for the foot with the specified ankle stiffness and height, which were compared to the physiological roll-over shape from the published gait data. The optimal parameter values were those that resulted in the roll-over shape with the best fit to the physiological roll-over shape. It was found that there was no optimal ankle joint height, but as ankle height increases, the optimal stiffness also increases. At an ankle height of 8 cm, the optimal stiffness was 7.1 N/m/deg with an R² value of 0.94 compared to the physiological roll-over shape.

Motivation

Prosthetic feet currently on the market do not fully meet the needs of people with lower limb amputations in developing countries:

• With long distances through rough terrain
• Culturally specific activities, such as squatting and sitting cross-legged
• Waterproof
• Uninventive
• Unfit for activities of daily living
• Heavy and not easily worn

There is substantial demand for a prosthetic foot that meets these needs:

• $40.000 person/year with lower limb amputations in India
• $2.00 billion USD global market projected for orthotic prosthetics by 2017

The goal of this work is to create a low cost, mass manufacturable prosthetic foot that:

1) Provides greater metabolic efficiency during walking than existing passive prostheses
2) Is mass manufacturable
3) Costs less than $10 USD

Foot-Ankle Roll-Over Shapes

Roll-Over Shape as a Design Tool

• May lead to symmetric and metabolically efficient gait
• Invariant to walking speed, shoe heel height, and carried load
• Exists for any type of foot
• User-independent metric

Roll-Over Shape Measurement

Position of ankle, knee and center of pressure are tracked and measured in the laboratory reference frame for a complete step (top right)

At each time interval, center of pressure is rotated into ankle-knee reference frame (middle right)

The resulting path of the center of pressure from heel strike to opposite heel strike in the ankle-knee reference frame is the roll-over shape of the foot (bottom right)

Analytical Prosthetic Foot Model

Rigid prosthetic foot with single degree of freedom ankle joint of rotational stiffness k at height h above ground

Predicting Roll-Over Shape For Given k

Model prosthetic ankle angle was calculated using published gait data at each time interval during a step.

Each time interval results in a single point on the roll-over shape curve. Once the ankle angle was calculated, the coordinates of that point were found using geometry.

Optimization

The roll-over shape was calculated for a variety of ankle heights and ankle stiffnesses. An R² value was calculated for each combination to compare the results to the physiological roll-over shape. For every ankle height, an optimum stiffness was found such that the R² value was at least 0.93.

Conclusions

• The method presented here, the roll-over shape of an analytical model of a prosthetic foot is predicted using published gait data and calculating the deflection of the foot throughout a complete step. This allows for optimization of parameters, such as the ankle joint height and rotational stiffness in this case, to most closely match the physiological roll-over shape.

Future Work

• Method should be applied to different analytical models of prosthetic feet.

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