Abstract

Development of a Balance Measure for Amputees

Authors

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Background: Loss of balance is a significant problem for those who have undergone lower-limb (LL) amputations. 52.4% of LL amputees have reported falling in the previous year [1] and 66% of above-knee amputees report falling annually, which is twice the rate of able-bodied adults over the age of 65 [2]. Balance impairment is also a significant issue for older amputees, as the sense of balance changes with age and walking on a prosthesis requires a heightened awareness of balance. Falls can have a significant impact on subsequent morbidity, disability, and mortality risk. Falls in amputees can also have serious consequences to the residual limb and damage to the prosthesis, as well as result in the lack of confidence in, and the often discontinued use of, a particular prosthesis. Currently, there are no quantitative outcome measures that determine balance during ambulation for amputees that can be used in the clinic. This information could be fundamental in guiding the selection of components used by an amputee to obtain the optimum blend of stability and function possible with their prostheses. To address the lack of quantitative measures for balance, Liberating Technologies Inc. (LTI), a College Park company, is developing a tool for use in the clinic which assesses the balance of LL amputees during ambulation and provides an objective measure to aid practitioners in selecting the optimal prosthetic components for their patients. This objective measure would allow the clinician to provide the patient with the most dynamic foot possible without compromising the patient's balance and confidence in the prosthesis.

Solution: To achieve our goals of developing a balance measure, we first had to design a system that could provide similar information to expensive and cumbersome motion capture systems that was more clinic-friendly in price and ease-of-use. Our system is comprised of three components. (1) To provide information similar to that obtained by force plates (multi-axis ground reaction force and center of pressure), we worked with Sandia National Laboratories to develop custom pressure-sensing insoles, leveraging their optical force sensor technology. The sensors were embedded into a silicone insole and the design of the insoles and placement of the sensors were optimized for both intact and prosthetic feet. (2) In lieu of a full motion capture system, several commercially-available wearable kinematic sensing systems were evaluated for accuracy and consistency to determine the best solution for our application. (3) The final component consists of a human model and custom algorithms to assess static and dynamic balance during gait and a user-interface to present the information to the clinician in an intuitive and clinically-relevant format.

Methods: To verify that our prototype system provides functionally-equivalent data to the gold-standard motion capture and force plate systems, we synchronized the two systems and collected data on five unilateral below-knee amputees. The subjects were asked to walk at their comfortable walking speed across a gait laboratory walkway with two force plates while wearing reflective markers for the motion capture system and the insoles and sensors of the prototype system. The data was processed, and a variety of gait parameters were compared between the two systems.

The above testing was done while wearing two different prosthetic feet to allow the data to also be used to develop the algorithms to detect balance changes. The two prosthetic feet were chosen such that physical characteristics (height, weight, etc) were all very similar, while functional characteristics were quite different based on their rollover shapes [3-4]. We measured the rollover shape of 11 commercially-available prosthetic feet and identified two for our comparison: the Horizon, a carbon-fiber K3 prosthetic foot (College Park Inc.) and the Celsus, a fiberglass K2 foot (College Park, Inc.). Both feet are within 10 grams of each other in weight and 0.3 inches in height for a given size, but had distinct rollover shapes with effective radii of curvature that differed by 49mm. The data from these two feet were used to develop algorithms to assess the user's balance.

A customizable human model was developed to measure key parameters during gait that are used in the balance system's algorithms. An analysis was performed on the human subject test data to discover the key parameters which may highlight a change in balance between different prosthetic feet. To avoid testing the algorithms on the same data from which they were developed, data from additional subjects not included in the algorithm development will be tested.

Results: The comparison of the gait parameters between the two systems showed that the systems were functionally equivalent during the task performed for this development (level over ground walking at a comfortable gait speed). For example, the center of pressure was found to have a RMSE of 19.6mm or less in the anterior-posterior direction and 6.6mm or less in the medial-lateral direction, which falls with well within the ranges determined acceptable in the literature [5-7]. The algorithm development is currently ongoing.

Conclusion: Loss of balance is a serious issue for many lower-limb amputees. This work is a first step in developing a tool to aid clinicians in selecting the optimal components for their patients.

References:

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