An Auto-Adaptive External Knee Prosthesis

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The Problem: In order for a trans-femoral (above-knee) amputee to walk in a variety of circumstances, a prosthetic knee must provide stance control to limit buckling when weight is applied to the prosthesis. In addition, it must provide aerial swing control so that the knee reaches full extension just before heel strike. Unlike a biological knee, a prosthetic knee must accomplish both stance and swing control without direct knowledge of its user's intent or of the environment. Rather, a prosthetic knee must infer whether its user desires stance or swing behavior and predict when future stance/swing transitions should occur. It must also determine when changes occur in the environment such as when an amputee lifts a suitcase or walks down a slope.

Further, an external knee prosthesis must not only be safe for the patient to use but should also help the patient walk in a smooth, non-pathological manner. Conventional prosthetic knees often force the amputee to walk with an awkward gait. As an example many prosthetic knees now being sold on the market lock up during ground contact, not allowing the amputee to go through normal knee flexion and extension motions found in early stance. The amputee is therefore forced to roll over a perfectly straight leg, resulting in large vertical fluctuations in the amputee's center of mass and diminished shock absorption.

Using state-of-the-art prosthetic knee technology, a prosthetist must pre-program knee damping values until a knee is comfortable, moves naturally, and is safe to use. However, these adjustments are not guided by biological gait data, and therefore, knee damping may not be set to ideal values, resulting in pathological gait movements. Our knee prosthesis automatically adapts to the amputee without pre-programmed information of any kind from either amputee or prosthetist.

Motivation: The development of an adaptive knee controller that helps above-knee amputees to walk with minimal gait pathologies has been a long standing goal in lower extremity prosthetic research. Such a control system would enhance the dynamic cosmesis of amputee gait, improve gait metobolic economy and prosthesis shock absorption characteristics.

Previous Work: External, lower-extremity prosthetic devices have been around for centuries, if not millennia. However, until recently, there were few attempts at applying engineering rigor to improve mechanism function[1]. External assistive devices were made from crude materials such as wood and leather, making them heavy, non-adaptive and difficult to use.

In the 1970's and 80's all this began to change. Professor Woodie Flowers at MIT conducted research to advance the prosthetic knee joint from a passive, non-adaptive mechanism to an active knee with damping characteristics that could be controlled by an onboard computer as an amputee walked[3, 4, 5, 6]. Using Flowers' knee, the amputee experienced a wide range of knee torques throughout a single walking step. During ground contact, high knee damping inhibited knee buckling, and variable damping throughout swing allowed the prosthesis to swing freely and then to decelerate smoothly just prior to heel strike. Unfortunately Flowers' knee was never sold commercially. In recent years several prosthetic knee manufacturers have introduced computer-controlled knee products to the market, but these devices are not auto-adaptive; before a patient can take the prosthesis home, a prosthetist must program the knee to output adequate resistances so that the prosthesis is comfortable and safe to use.

Approach: Our knee prosthesis automatically adapts to the amputee, accounting for variations in both forward speed and patient size. With this technology, knee damping is modulated about a single rotary axis using a combination of magnetorheological and frictional effects, and only local sensing of axial force, sagittal plane torque, and knee position are employed as control inputs. Early stance damping is automatically adjusted by the controller using sensory information measured when a patient first walks on the prosthesis. With measurements of foot contact time, the controller also estimates forward speed and modulates swing phase flexion and extension damping profiles to achieve dynamic cosmesis throughout each walking swing phase. The adaptation scheme successfully controls early stance resistance, swing phase peak flexion angle (see Figure 1) and extension damping, suggesting that local sensing and computation are all that is required for an amputee to walk in a safe, comfortable and natural manner.

Difficulty: Most knee prostheses do not allow the patient to flex and extend during early stance, forcing the amputee to walk with a straight locked knee. Because amputees are accustomed to walking with a straight leg, they must first be trained to allow knee flexion and extension to occur before any control strategy can be evaluated.

Impact: It is our hope that an auto-adaptive external knee prosthesis will allow above-knee amputees to walk more naturally and will diminish the fatigue normally experienced by amputees. We also hope that amputees will experience less job discrimination and a greater acceptance in society with a prosthesis that exhibits an enhanced dynamic cosmesis.

Future Work: This past year we evaluated the performance of our knee prosthesis on nine patients. To fully characterize our prosthesis, we plan to test fifty knee prostheses early next year on a diverse patient population.

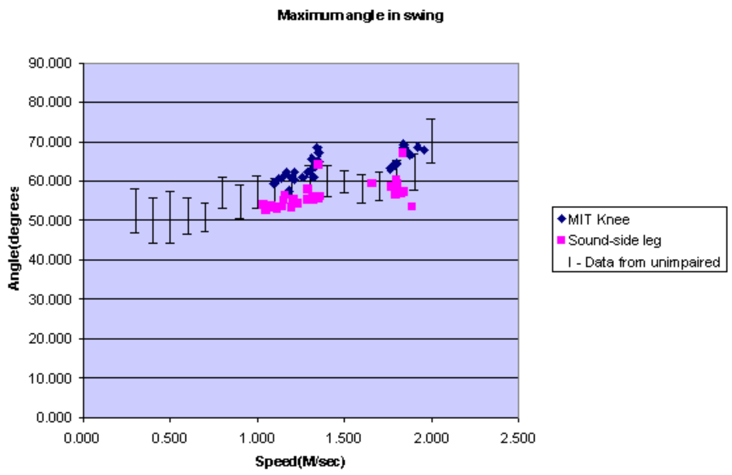

Figure 1: For one subject, peak flexion-angle data during swing phase are shown for the MIT prosthesis and the subject's sound-side leg. In addition, reference data from unimpaired walkers are noted. The MIT prosthesis promotes gait symmetry between the amputated and sound-side leg, producing natural and biological movements.

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References:

[1] T. Inman Human Walking. *Williams and Wilkins*, MD, 1981.

[2] M. Goldfarb Control for a Self-Contained Microcomputer-Controlled Above-Knee Prosthesis *Department of Mechanical Engineering Masters Thesis*, MIT, 1992.

[3] W.C. Flowers A Man-Interactive Simulator System for Above-Knee Prosthetics. *Department of Mechanical Engineering PhD Thesis*, MIT, 1972.

[4] M. Donath Proportional EMG Control for Above-Knee Prosthesis. *Department of Mechanical Engineering Masters Thesis*, MIT, 1974.

[5] M.L. Tanquary A Microprocessor Based Prosthesis Controller for Use During Early Walking Training of Above-Knee Amputee. *Department of Mechanical Engineering Masters Thesis*, MIT, 1978.

[6] S.E. Schechter Passive Self-Contained Microcomputer Controlled Above-Knee Prosthesis. *Department of Mechanical Engineering Masters Thesis*, MIT, 1981.