Design of a Stumble Detector for Artificial Legs

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THINK BIG WE DO

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Introduction

- There are approximately 1.7 million people living with limb loss in the United States in 2008; lower limb amputations are much more frequent than upper limb. (Ratio: 4.9:1)

- The number is still growing as the population ages and the incidence of dysvascular disease increases.

- The risk of falling for lower limb amputees is high, because:

(1) lower limb amputations lead to altered balance, strength, and gait pattern;

(2) more than half of the population with lower limb amputations is elderly people, who are prone to falling.

Introduction

- Consequences:

(1) soft tissue injury
(2) boney injury
(3) deterioration in balance
(4) fear of falling
(5) reduced participation in activities of daily living.

- It is demanded to prevent falls in leg amputee patients to improve the quality of their life.

- One potential solution: to improve the **safety** of lower limb prostheses.

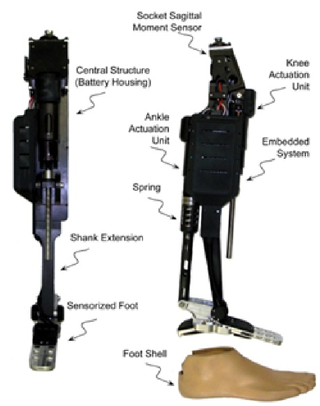
Introduction

C-Leg, Otto Bock

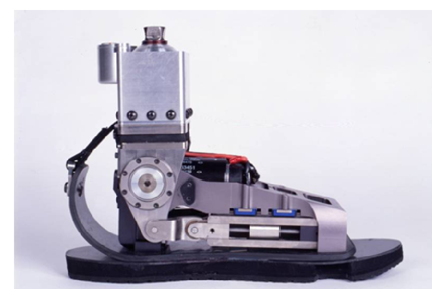
- Currently, a simple mechanism (i.e. locking knee joint) is incorporated in microcomputer-controlled passive prostheses to prevent falls.
- Dealing with various types of unexpected perturbations (e.g. slipping on a wet surface) is still **challenging** for leg amputees when wearing the passive prostheses.

- **Powered lowed limb prostheses** have the potential to allow the leg amputees to actively recover from stumbles in a natural way.

Ossur Power Knee



Vanderbilt Powered Prosthesis



MIT Powered Ankle-Foot Prosthesis

Introduction

- It is necessary to design a **stumble detection system** so that the powered prosthesis can produce protective reactions corresponding to the stumble.
- **Challenges:**

(1) not only detect the stumbling events but also recognize different stumble types;

(2) a fast response time;

(3) self-contained and practical for lower limb prosthesis design.

The goals:

1) to select potential stumble detection data sources that react reliably and quickly to stumbles and can be measured from a prosthesis;

2) to investigate two different approaches based on selected data sources to detect stumbles and classify stumble types.

Methods: Selection of potential data sources

- This study was conducted with Institutional Review Board (IRB) approval at the University of Rhode Island and the Providence VA Medical Center and with the informed consent of all subjects.

- Subjects: seven patients with transfemoral (TF) amputations

	Age	Weight (kg)	Height (cm)	Gender	Years post-amputation	Residual limb length ratio*	Prosthesis for daily use
TF01	57	75.8	175.3	M	31	51%	RHEO
TF02	46	97.0	160.0	F	3	93%	C-Leg
TF03	38	65.7	162.6	F	29	68%	RHEO
TF04	48	63.1	166.4	M	7	94%	C-Leg
TF05	52	64.0	164.0	F	31	84%	RHEO
TF06	56	75.2	173.4	M	38	62%	SNS Knee
TF07	42	66.1	165.8	F	11	77%	C-Leg

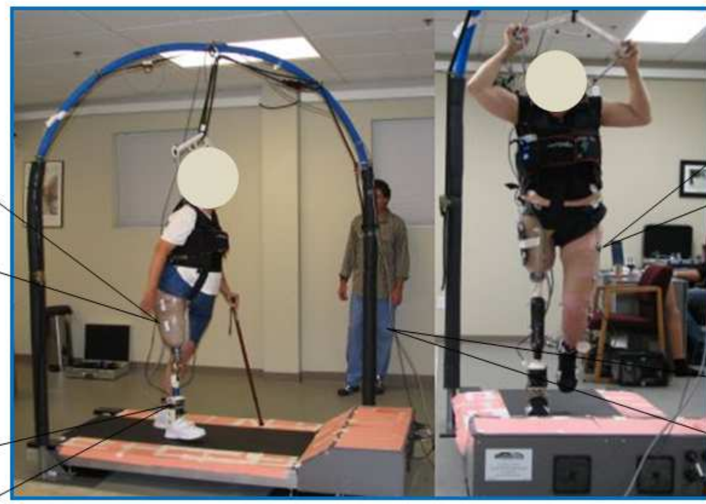
* Residual limb length ratio: the ratio between the length of residual limb (measured from the ischial tuberosity to the distal end of the residual limb) to the length of the non-impaired side (measured from the ischial tuberosity to the femoral epicondyle).

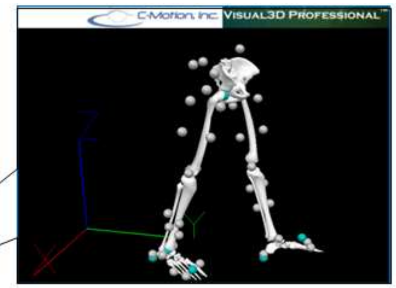
Methods: Selection of potential data sources

- Measurements: 7-9 surface electromyographic (EMG) signals from residual thigh muscles, kinematics and kinetics of passive prostheses.

Surface EMG Electrode (Delsys, MA, US)

6-DOF Load Cell (Bertec,OH,US)



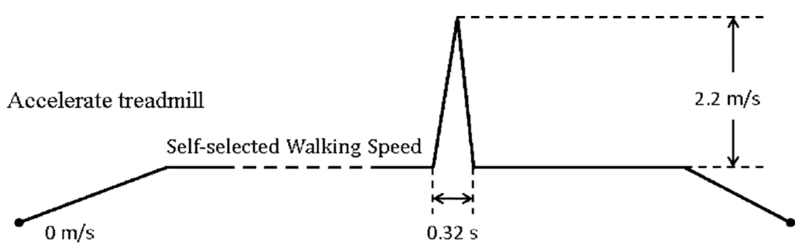


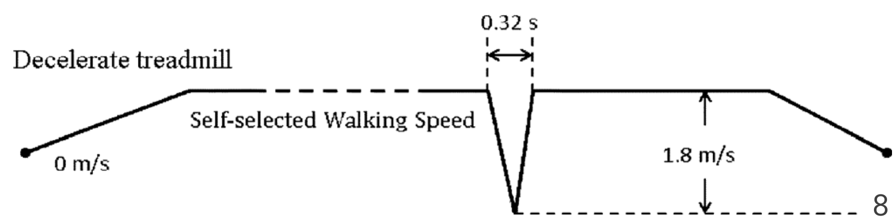
Oqus, Qualisys, Sweden

Pedar-X system (Novel Electronics, Germany)

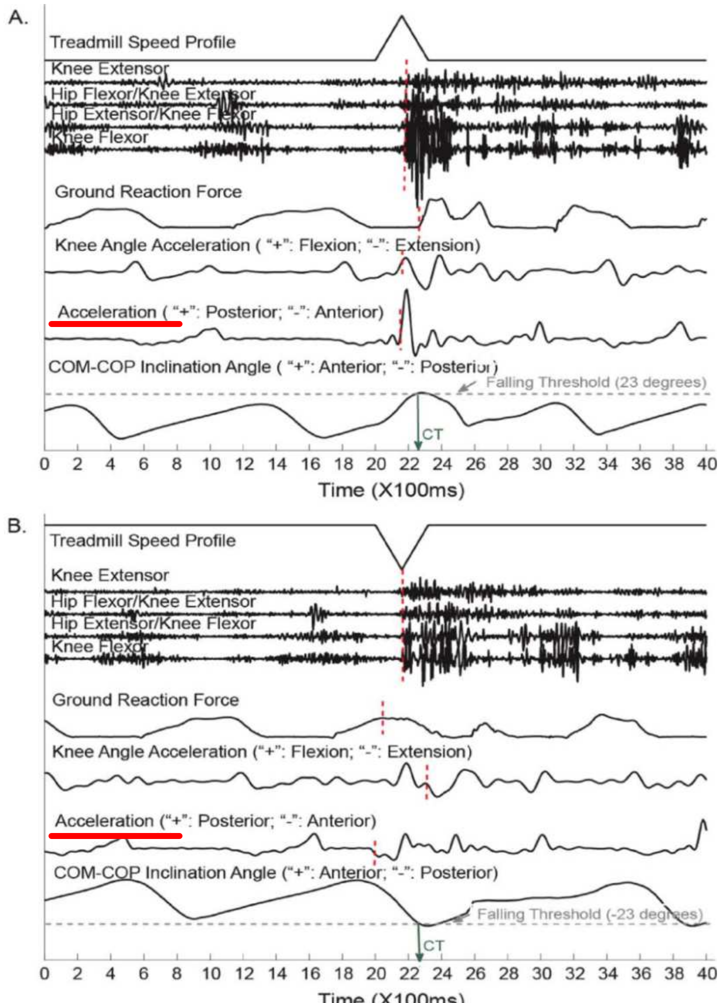
Methods: Selection of potential data sources

- Experimental Protocol: the normal gait of the subjects was perturbed (tripped or slipped) by the sudden accelerations or decelerations of a controllable treadmill or when they walked on an obstacle course.





Methods: Selection of potential data sources



Examples of collected data sources aligned with treadmill speed profiles and computed COM-COP inclination angle. Representative data were recorded from one subject.

Choosing the potential data source …

- **Prosthetic foot acceleration**

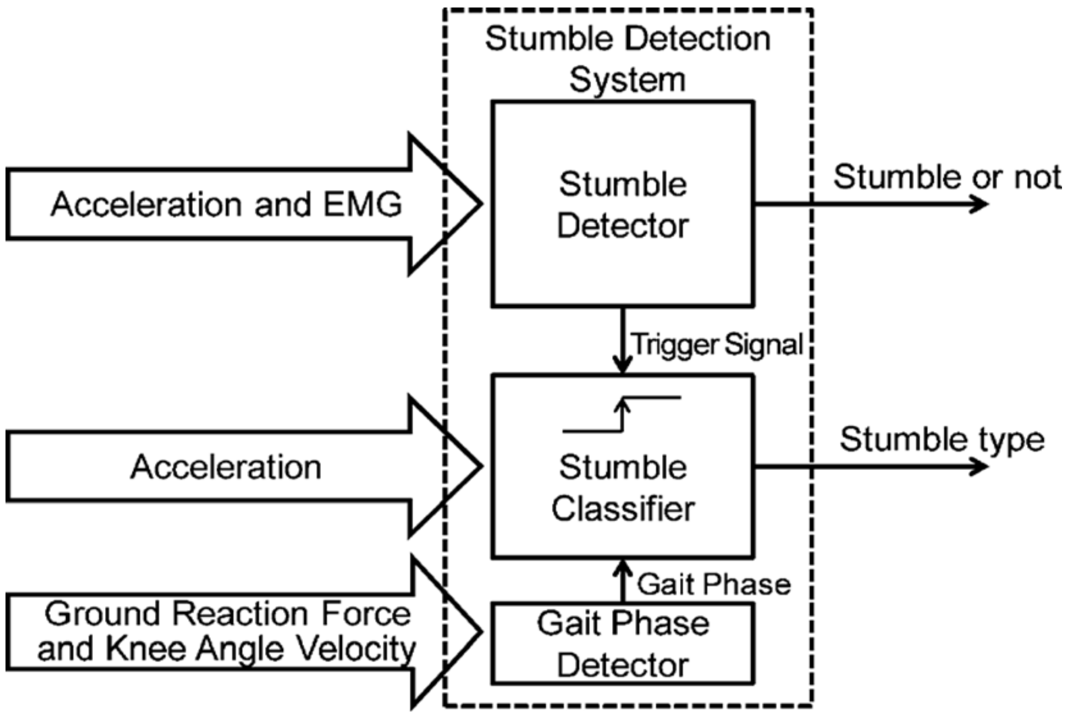
1) responded fastest to all applied perturbations with an obvious change in magnitude;
2) acceleration direction was associated with the stumble types.

- **EMG** signals from residual limbs

1) showed significantly high activation level, long activation duration, and co-contraction during stumbling;
2) responded before the defined critical timing;
3) combining foot acceleration with EMG may reduce the false alarm.

Methods: Design of stumble detection systems

Architecture of stumble detection system



The stumble detection system consisted of two modules:

(1)Stumble detector used to detect whether or not there is a stumble;

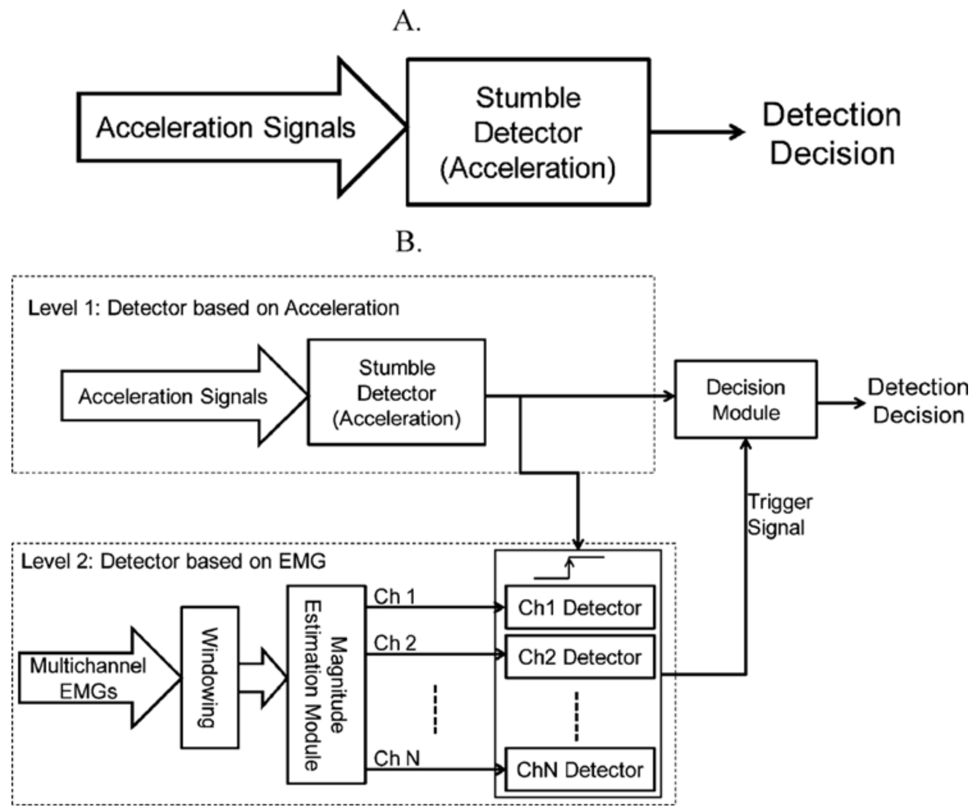
(2)Stumble classifier used to recognize the type of the stumble.

Methods: Design of stumble detection systems

- **Two stumble detectors:**

A: Detector based on foot acceleration alone;

B: Detector hierarchically fused foot acceleration and EMG signals.



- **Features:**

Foot acceleration: absolute magnitude of foot acceleration in anterior–posterior;

EMG: the root mean square (RMS)

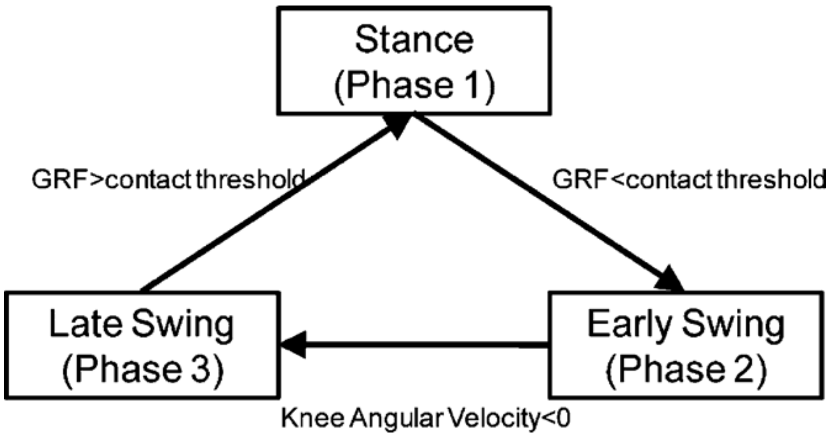
- Both detectors were formulated as outlier detectors based on *Mahalanobis* distance.

Methods: Design of stumble detection systems

- **Three-class classifier** were designed to identify:

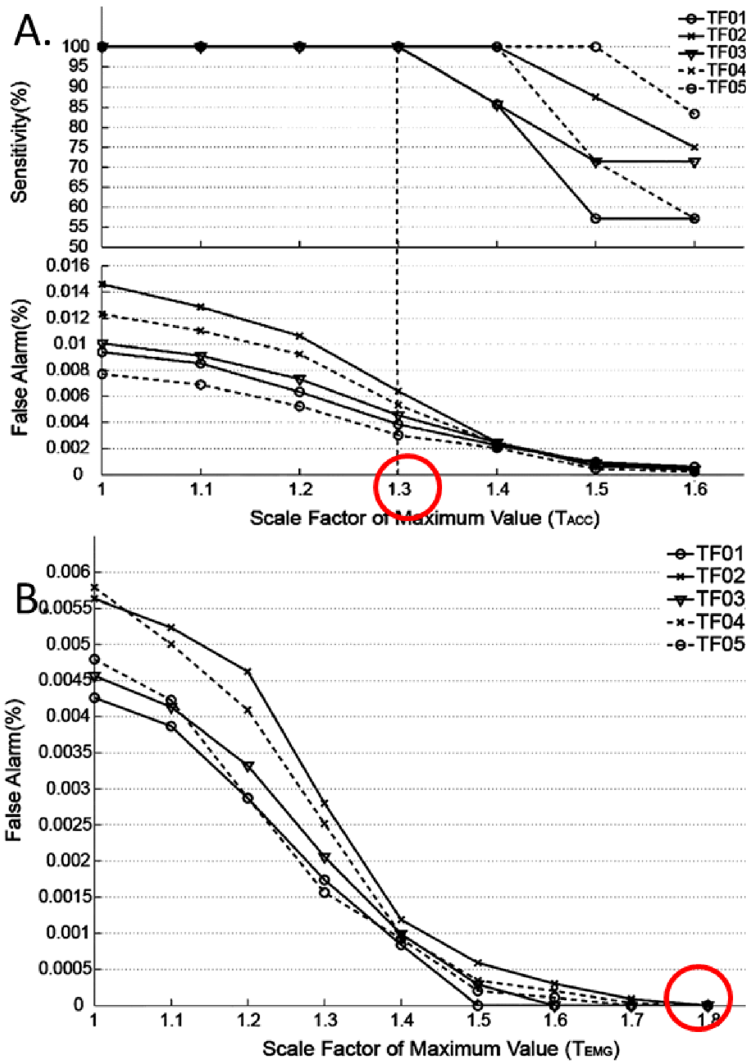
1) tripping in early swing phase;
2) tripping in late swing phase;
3) slipping in initial double stance phase.

- Tripping and slipping were classified by the direction of foot acceleration;
- The phase detector identified the phase when tripping happened.



The criteria for gait phase detection. The contact threshold was 1% of maximum vertical ground reaction force measured from individual subjects.

Results



Optimal detection threshold selection:

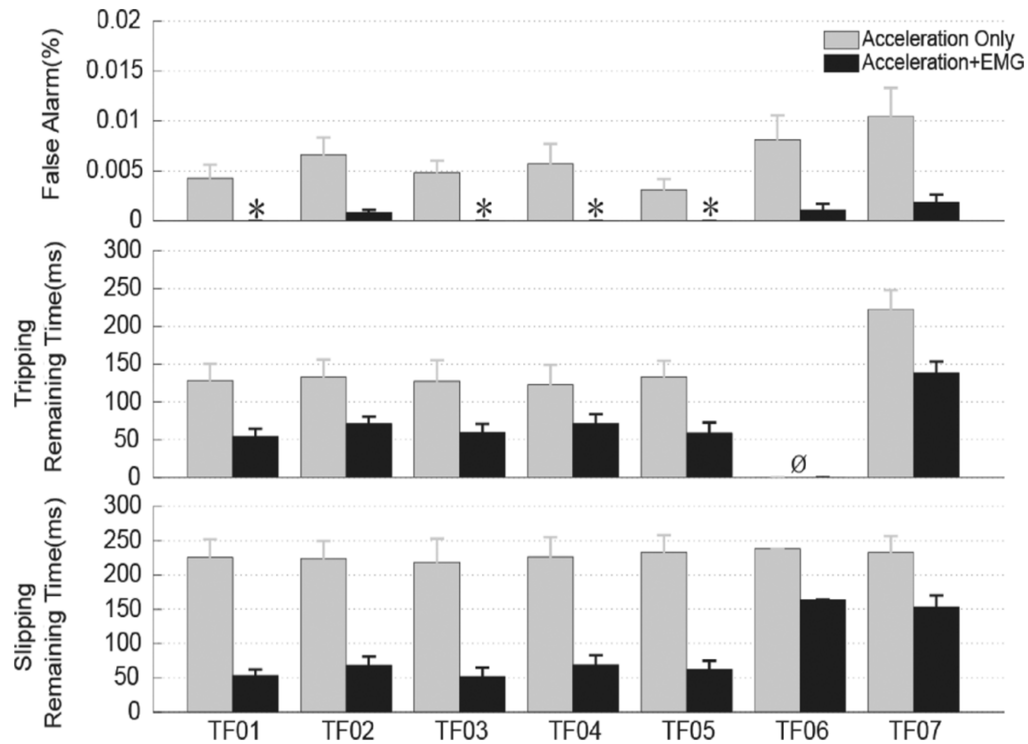
- Evaluation parameters: detection sensitivity (*SE*) and false alarm rate (*FAR*).

$$SE = \frac{\text{Number of correctly detected stumbles}}{\text{Total number of stumbles}} \times 100\%$$

$$\text{FAR} = \frac{\text{Number of observations misdetected as a stumble}}{\text{Total number of observations in normal walking}} \times 100\%$$

- The detection threshold was optimized by using receiver operating characteristic (ROC) curve, to simultaneously maximize the sensitivity and minimize the false alarm.

Results



Comparison of the performance of the first design of the detector (based on the foot acceleration only) and the second design (based on both acceleration and EMG signals) for transfemoral amputees (TF01-TF07). *denotes FAR equals 0. Ø means no stumbling was captured.

- All the tested stumbles were correctly detected and classified for all the subjects;
- The false alarm was significantly reduced by combining the foot acceleration and EMG signals, compared to that of detector based on acceleration only;
- However, the remaining time for stumble recovery was sacrificed by using the fused detector by 70-150ms.

Conclusion

- The acceleration of prosthetic foot and EMG signals measured from residual limb were selected as the potential data sources of the stumble detection for the powered artificial legs;

- Two approaches based on these two data sources were used for identifying stumbles.

- Foot acceleration was sufficient to detect all the stumbling events applied to the amputated side;

- Fusing EMG signals into the foot-acceleration-based detection significantly reduced the detection false alarm, but sacrificed the remaining time of stumble recovery.

Conclusion

- The results of this study may aid the future design of a stumble detection system which can be integrated into self-contained, powered artificial legs, and eventually enhance the safety of the prosthesis operations.

- Additional engineering efforts are still needed:

1) further improvement of the stumble detection performance;

2) investigation of the stumble recovery strategies for prosthesis control;

3) integration of the stumble detector with prosthetic legs.

Thank you !

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