„Terrainerkennung und Terrainanpassung für die Prothetik verschiedene Entwicklungsansätze."

TU Darmstadt, 15. August 2012

Fraunhofer IPA, Stuttgart Abteilung „Biomechatronische Systeme"
Dr. Urs Schneider, Florian Dennerlein, Felix Starker, Harald von Rosenberg

Stuttgart Minneapolis
Rehab Research

A Fraunhofer IPA and Minneapolis Veteran Affairs
Medical Center Cooperation

Research & Development

- Prosthetics & Orthotics and Rehabilitation
- Functional Testing
- Orthopedic Surgery

Education & Training

- Lecture „Mechatronics in Orthopedics“, Stuttgart University
- P&O Technology Seminars „Stuttgart Talks“ for CPOs
- Establishment of German P&O association O-PAEDIX

Standard activities

- Prosthetics test standards
  CEN/TC 293 / WG5 and ISO/TC 168 / WG3
- Initiation of German „sensor data fusion“ standard group

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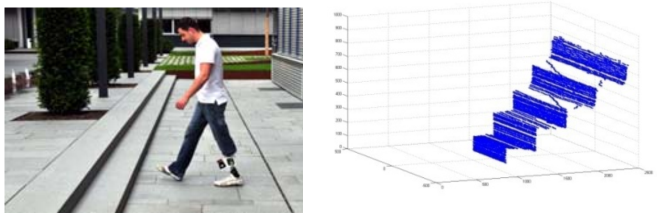
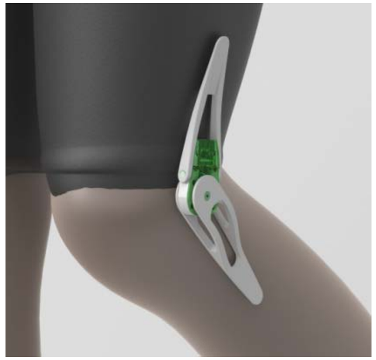
O-PAEDIX
Netzwerk für innovative Orthopädietechnik

Department „Biomechatronic Systems“

Prosthetics & Orthotics Research Examples

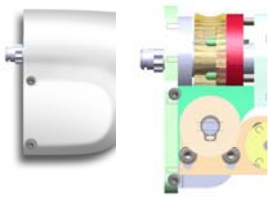


Terrain detection

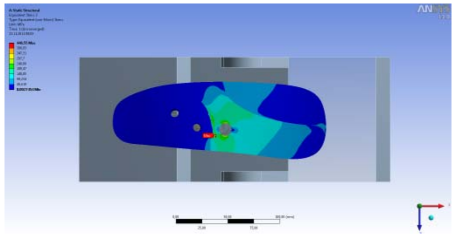


Activity Monitoring

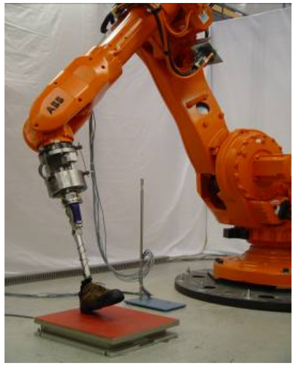
Foot engineering



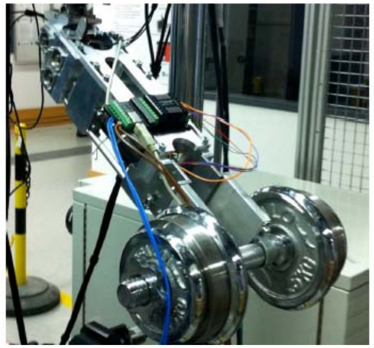
Orthotic Drives



Virtual 22675 testing



Robot Testing



Prosthetic Drives

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Rehabilitation Research Cooperation

between

Minneapolis VA Healthcare System & Fraunhofer IPA Stuttgart

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Incidence of falling

- Approx 1/3 of all above 65 fall once per year.
  Approx. 50% of those elderly who only stay inside (mobility class 2) fall once per year
  10 to 20% need therapy after falling
  5 to 6 % suffer from fall related fractures.

  [JH Downton 1995; ME Tinetti 2003]

- Approx. 70% of all above knee amputees falls once or more per year.
  Injury risk of above knee amputees with passive knee joints is approx. double relative to non amputee group of same age.

  [S Bunke 2010; C Gauthier-Gagnon et al. 1999; WC Miller 2001]

Reasons for falling

Half of all falling incidences on even terrain.

15% of falling incidences on stairs and ramps.

Amputee feedback on reasons for falling:

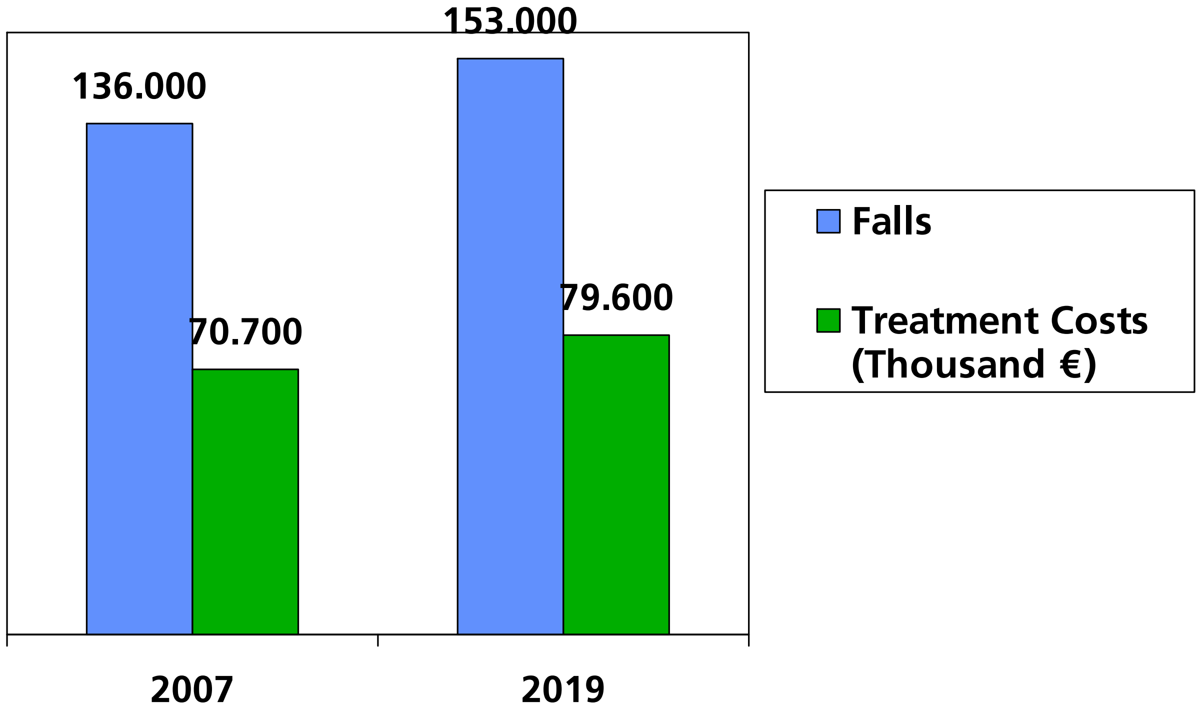
unseen obstacles > inattention > false estimation of terrain > malfunction of prostheses > false estimation of prosthesis function > imbalance

[S Bunke 2010]

Falling of Amputees

32% of all bellow knee amputees fall once per year (Brit. Prothetics Failure Registry, 2009)

Falls and related treatment costs in Europe (NHS, 2009)



Approach 1: Optic terrain detection for active terrain adaptation

Approach 2: Passive terrain detection for passive terrain adaptation

Approach 3: User foot control for active terrain adaptation

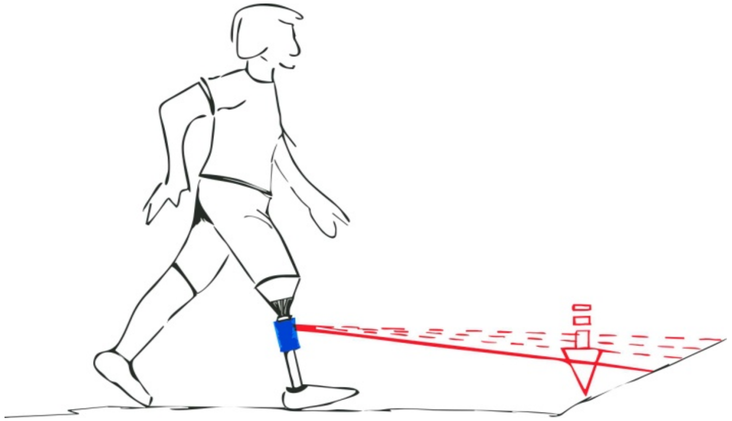
Definition:
„active“ stands for drive controlled;
passive stands for a mechanic solution without electronics and drives.

Approach 1: Optic terrain detection for active terrain adaptation

Basic idea:

real time obstacle detection

for automatic control of sagital ankle/ foot plate inclination



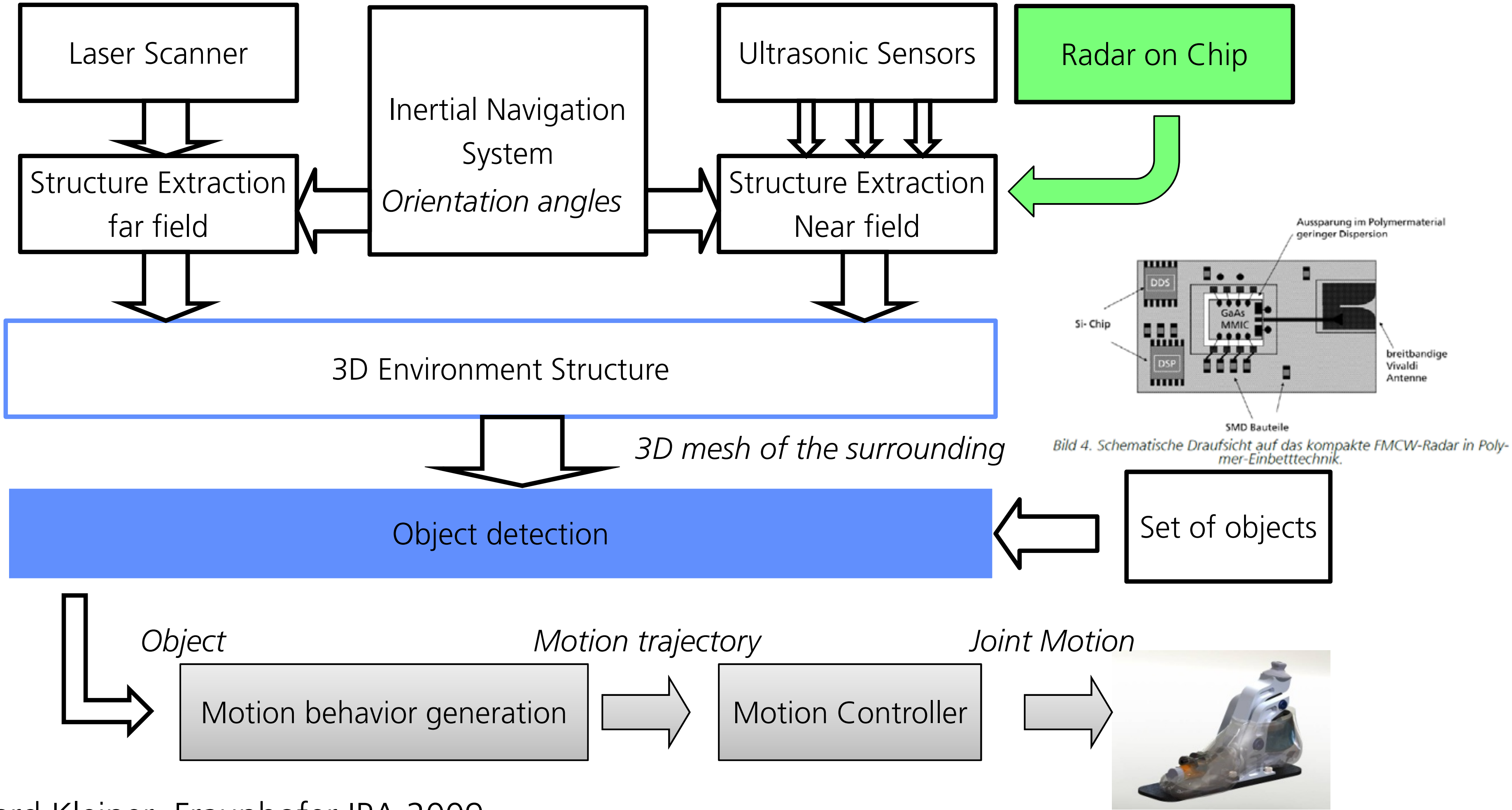
Approach 1: Optic terrain detection for active terrain adaptation

- Mechatronic foot concepts show that controls based on kinematic/ kinetic sensory:
  > cannot foresee obstacles
  > need > 3 steps for state detection
- Idea is sensory foresight for automatic foot lift in prosthetic feet and drop feet
- Development of a mobile sensor system including motion detection and distance measurement for detection of ground area in upcoming sagital stance phase
- as a control input of an active foot, shoe or orthosis

Approach 1: Optic terrain detection for active terrain adaptation

Control Architecture

foot



Engineering Bernhard Kleiner, Fraunhofer IPA 2009

B Kleiner, TAR 2012: “Foresighted control of active prosthetic feet.”

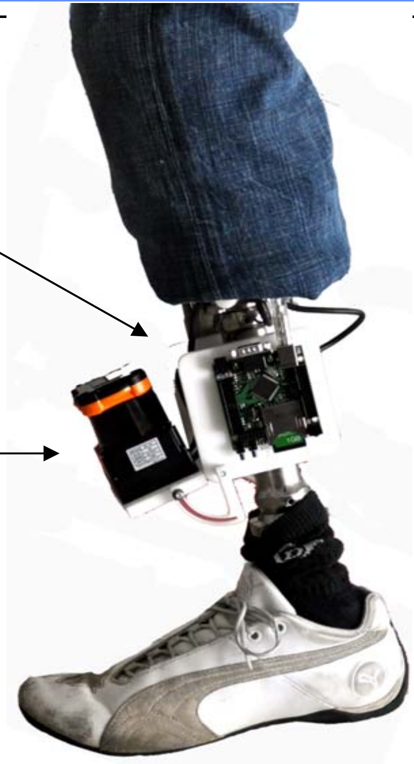
Approach 1: Optic terrain detection for active terrain adaptation

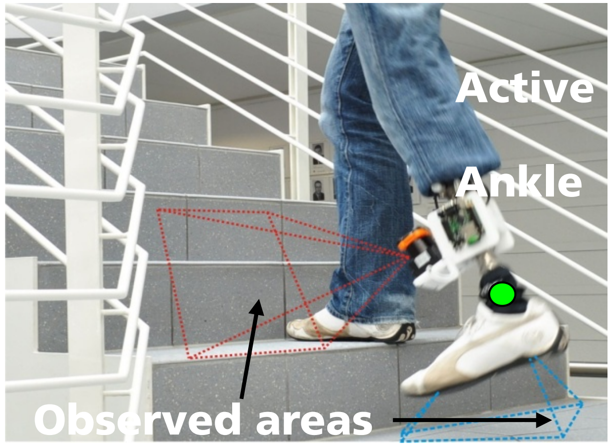
Inertial Measurement System

(Position and Orientation)

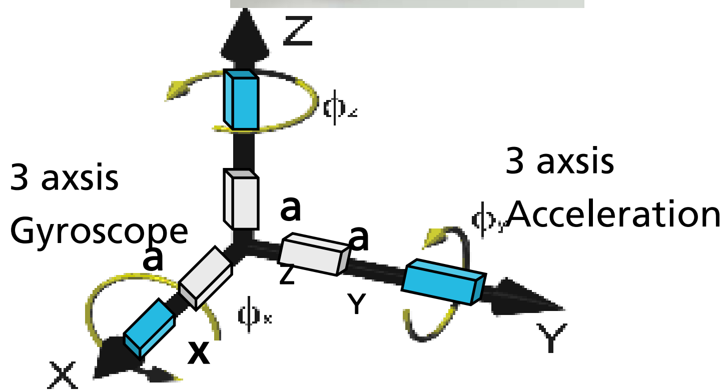
2D Laser Scanner

(270° horizontal scan)

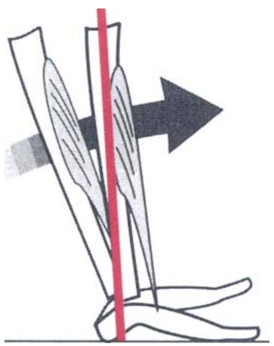


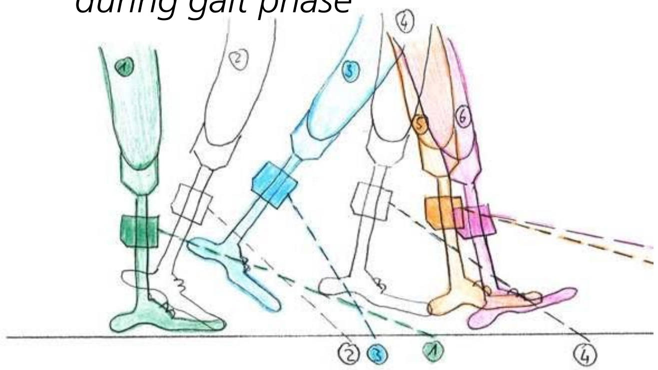


Inertial measurement unit by Fraunhofer IPA



Motion of the sensor unit during gait phase



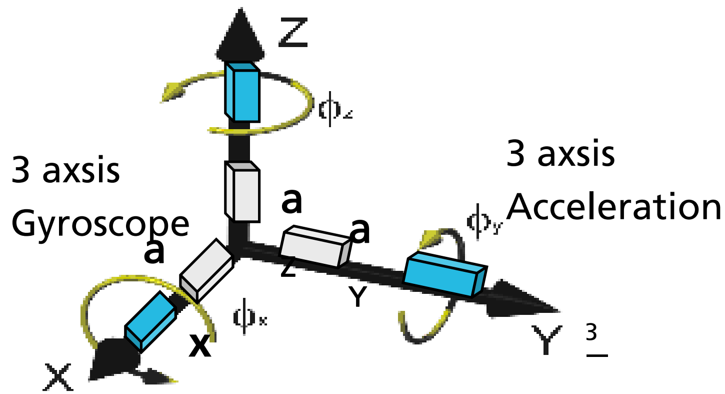


Engineering Bernhard Kleiner, Fraunhofer IPA 2009

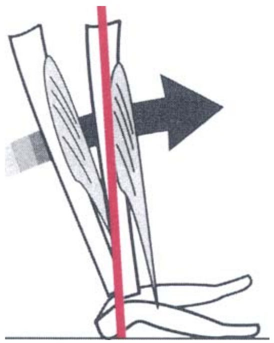
Approach 1: Optic terrain detection for active terrain adaptation

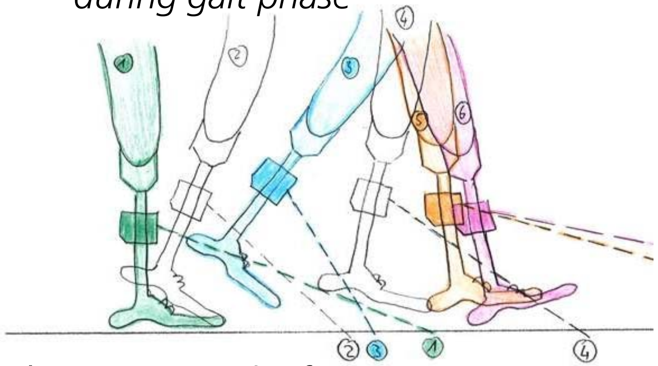
- Sensor system moves continuously with the prosthesis
- Inertial motion measurement and gait phase detection
- Tibia rotates around center of pressure during stance
- Position estimation of the sensor on the tibia with motion model during stance and swing

Inertial measurement unit by Fraunhofer IPA



Motion of the sensor unit during gait phase





Engineering Bernhard Kleiner, Fraunhofer IPA 2009

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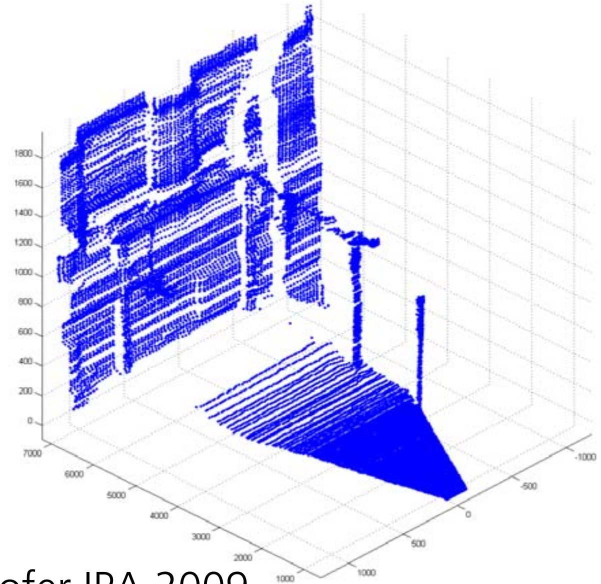
Approach 1: Optic terrain detection for active terrain adaptation

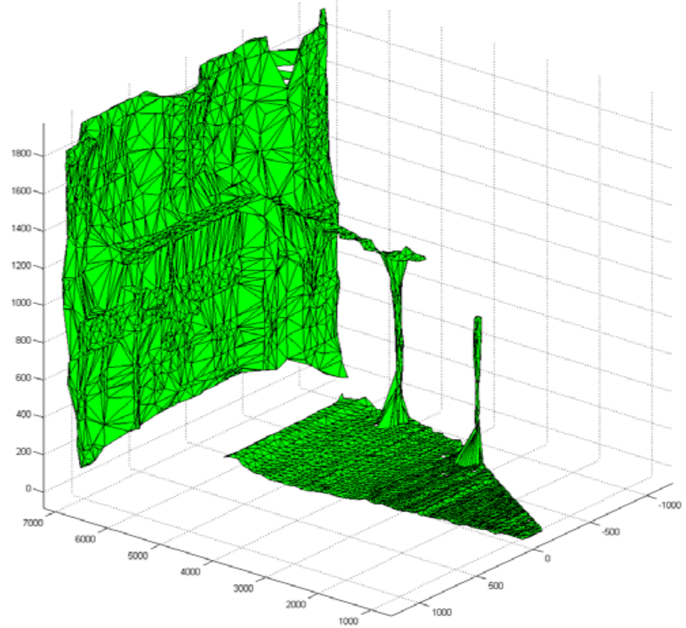
Measurements on ramps

Ramp in the Fraunhofer IPA gait lab

3D point cloud of the measured ramp



Mesh of the measured ramp



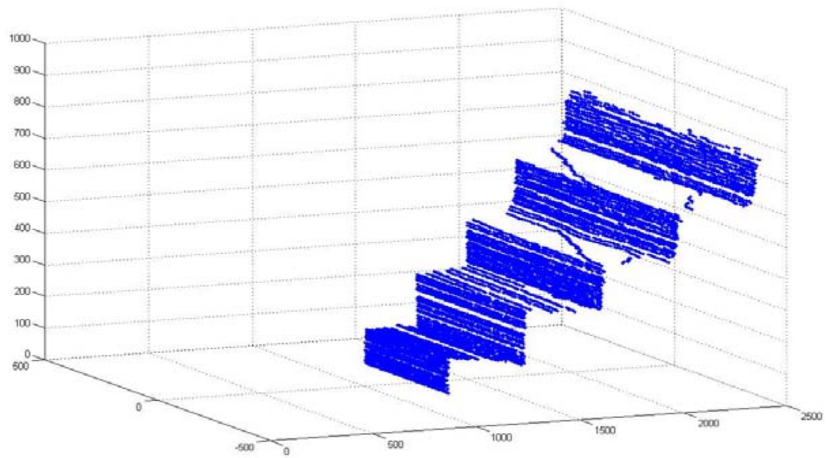
Engineering Bernhard Kleiner, Fraunhofer IPA 2009

Approach 1: Optic terrain detection for active terrain adaptation

Pylon mounted laser concept

Measurement of stairs

	Real	Measured
Distance to stairs:	1,2 m	1,2 m
Height of a stair:	15 cm	14,9 cm
Depth of a stair:	30 cm	29,9 cm



Engineering Bernhard Kleiner, Fraunhofer IPA 2009

Approach 1: Optic terrain detection for active terrain adaptation

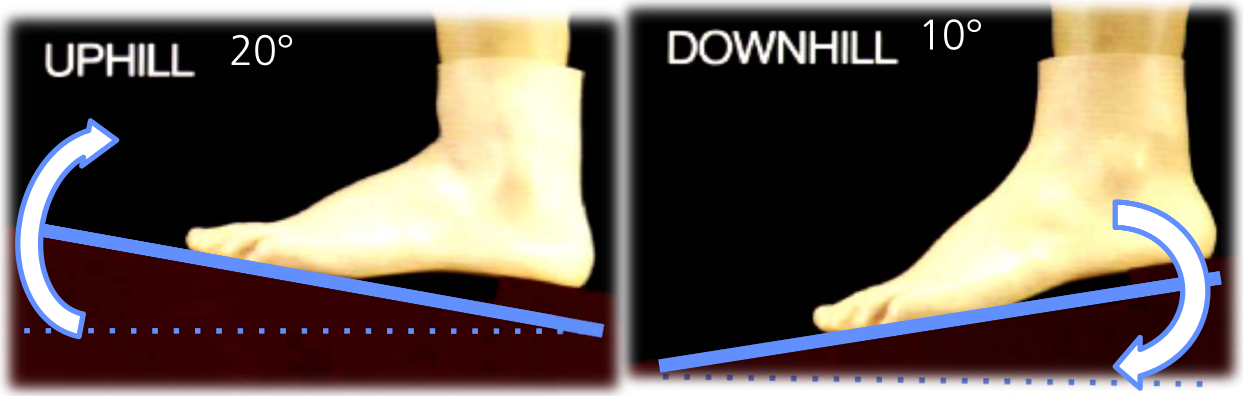
Approach 2: Passive terrain detection for passive terrain adaptation

Approach 3: User foot control for active terrain adaptation

Approach 2: Passive terrain detection for passive terrain adaptation

Basic idea:

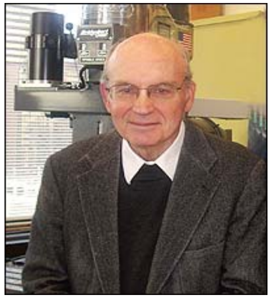
mechanical detection of vertical foot load in real time
for
passive hydraulic adaptation to sagital terrain inclination



Mauch Ankle Product Catalogue Fotos, 1980)

Approach 2: Passive terrain detection for passive terrain adaptation

The Story Behind



Dudley Childress

Andrew Hansen

Urs Schneider

June 2009:

Dudley Childress proposed to Andrew Hansen and Urs Schneider to revise the Mauch ankle

"Patients liked the terrain-adaptive behavior of this foot. Leakage problems led to its withdrawal from the market in the early 80ties"

Future Plan:

Via a master thesis at NUPAC (Chicago) we wanted to analyze the Mauch ankle technology properly before approaching a revision with modern hydraulics knowhow

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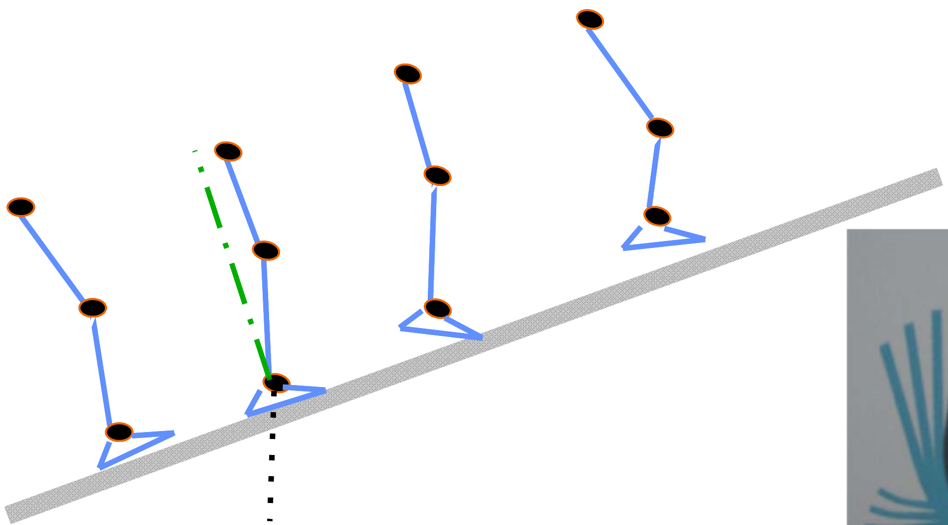
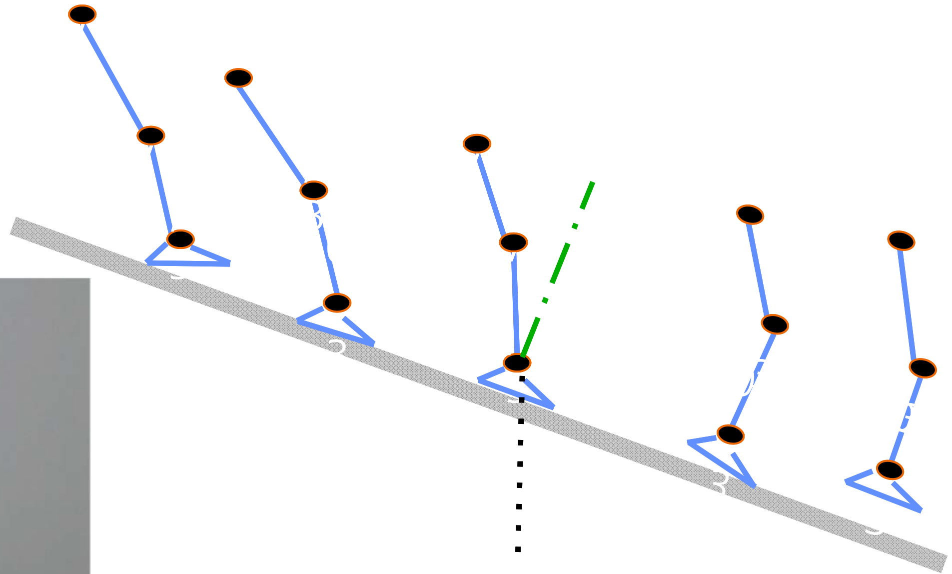
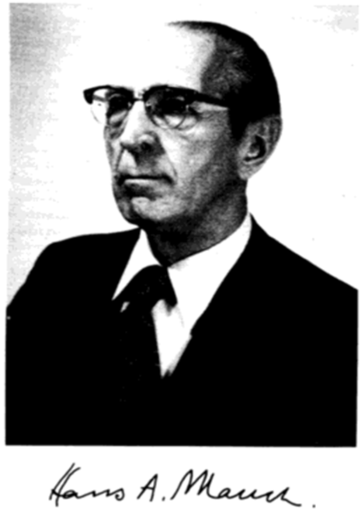
Approach 2: Passive terrain detection for passive terrain adaptation

- Falling on your back or your nose, you may choose
- Missing adaptation of vertical shank on inclined ground
- Adaptation meaning late stance torque not just increased range of motion
- Side effect: heel height adaptation





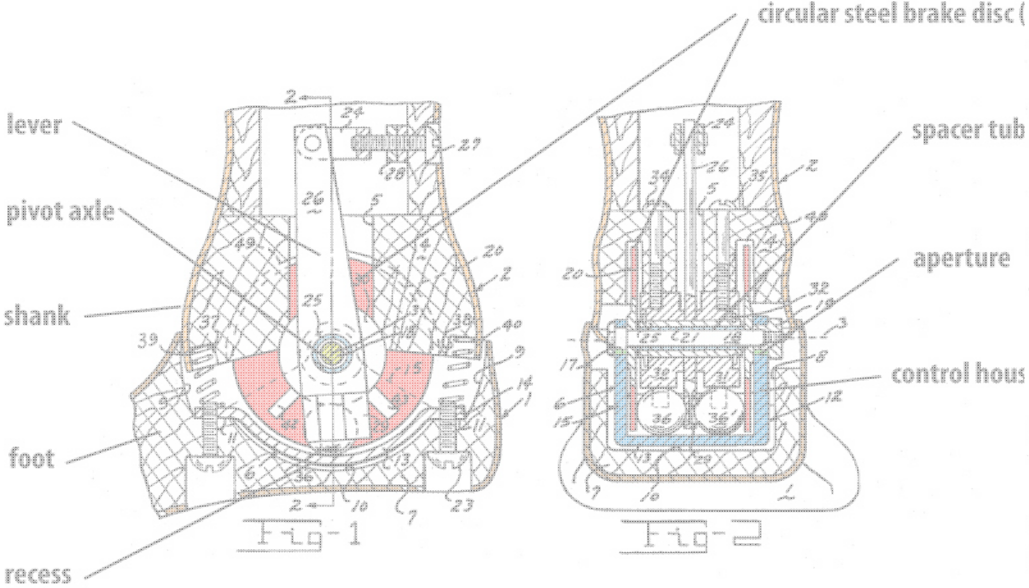
Approach 2: Passive terrain detection for passive terrain adaptation

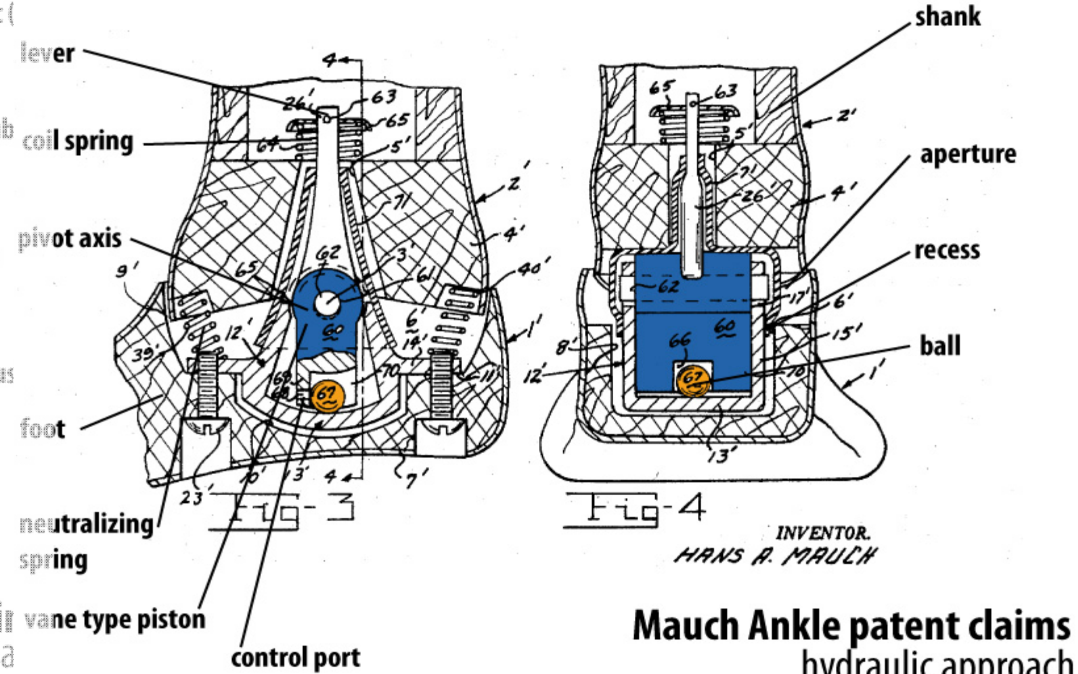


Hans A. Mauch

The Mauch Ankle Patent drawings

- **Mechanical approach**
  - Disc brake
  - Blocked by 2 balls
- **Hydraulic approach**
  - Piston forms 2 hydraulic chambers
  - Control channel blocked by ball

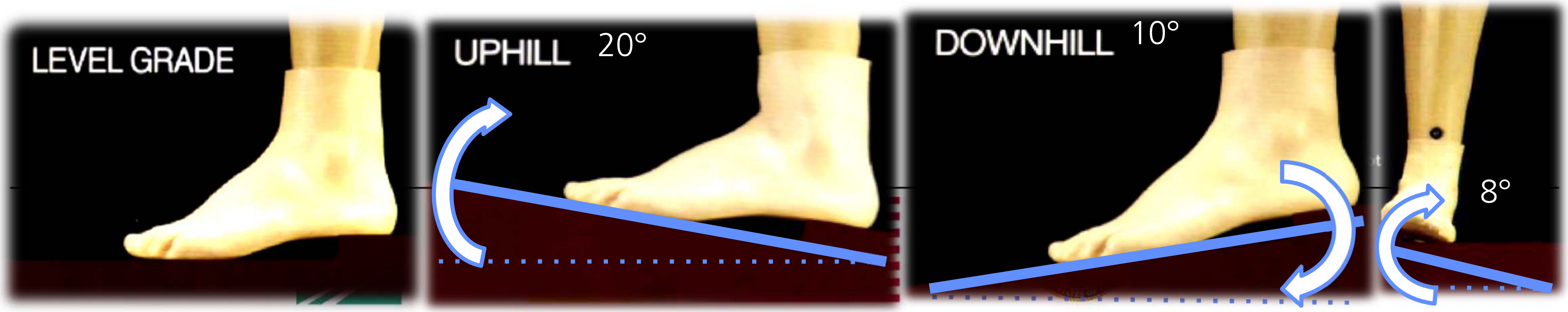




Approach 2: Passive terrain detection for passive terrain adaptation

The Mauch Ankle

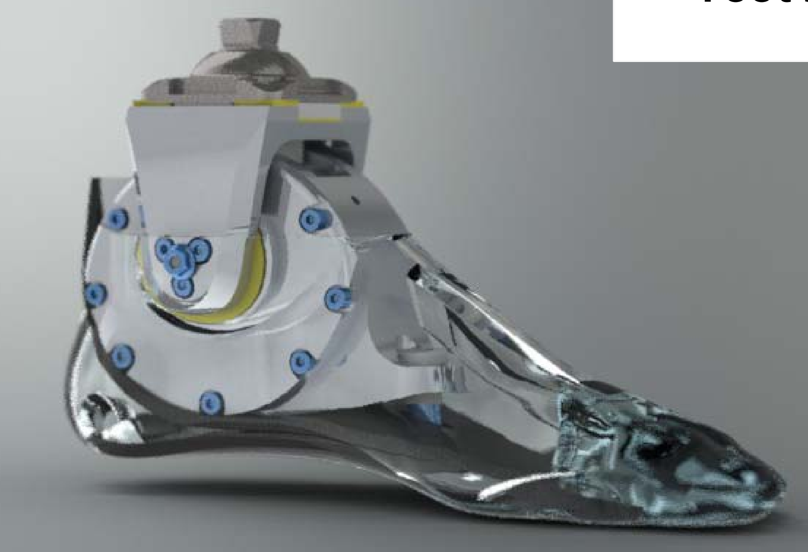
- **Adaption to shoe heel height**
- **Adaption to different terrain**
  - Inclination: 20°
  - Declination: 10°
  - Inversion: 8°
  - Eversion: 0° (restricted)



Approach 2: Passive terrain detection for passive terrain adaptation

Early functional prototype - 2010

- **Build height:** 145 mm
- **Weight:** 1.24 kg
- **Foot size:** 27

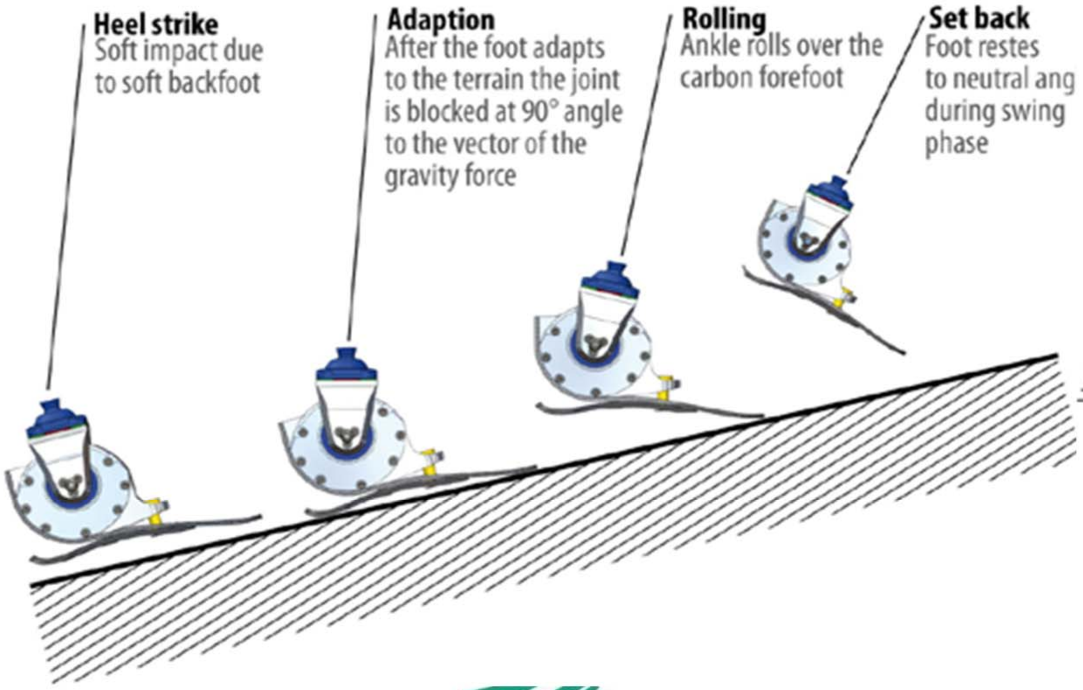


Engineering Felix Starker

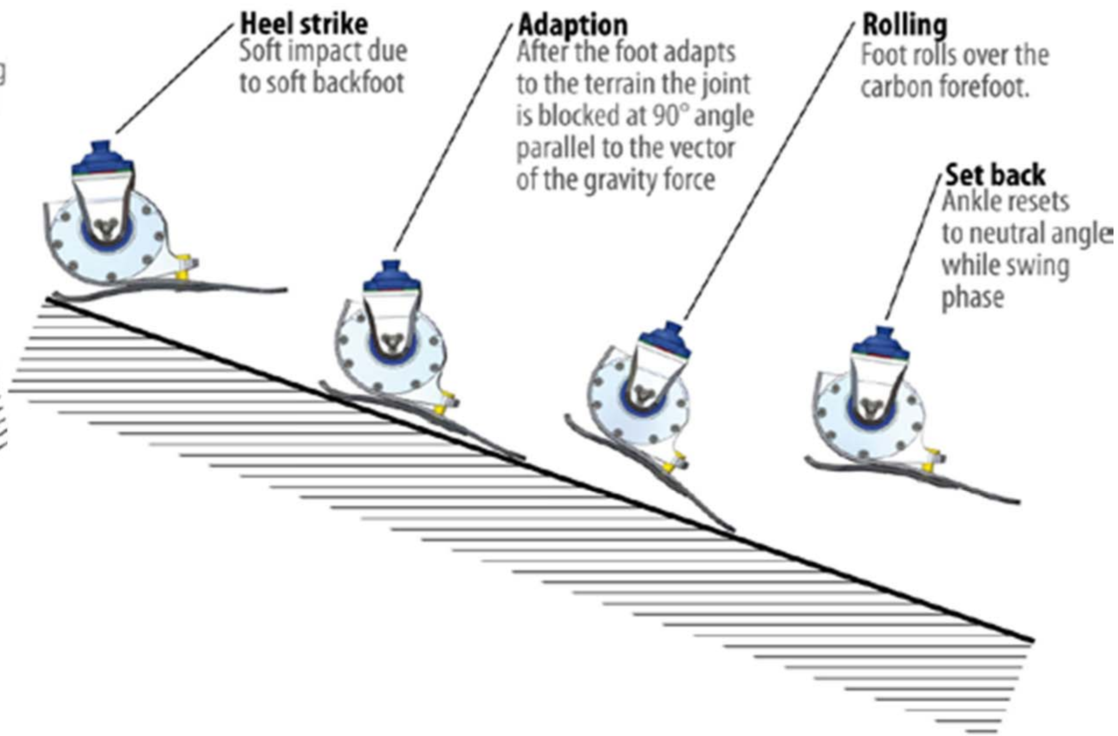
Approach 2: Passive terrain detection for passive terrain adaptation

Adaption to uneven terrain

20° inclination



20° declination



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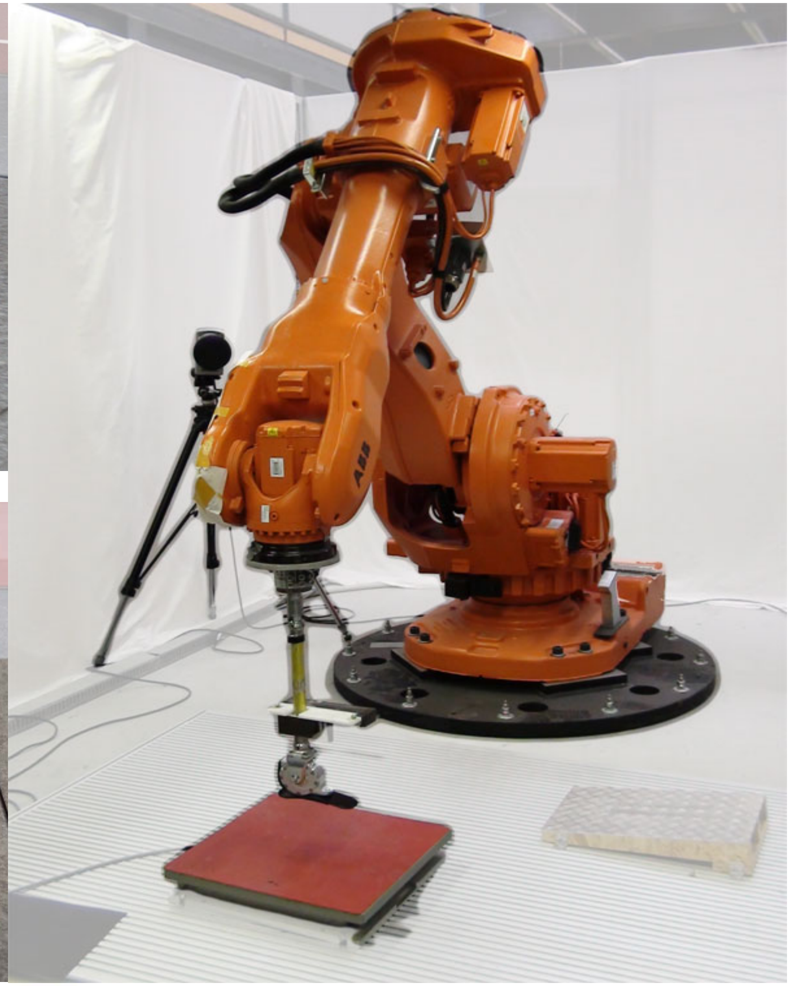
Approach 2: Passive terrain detection for passive terrain adaptation

Early functional prototype – 2010 Evaluation



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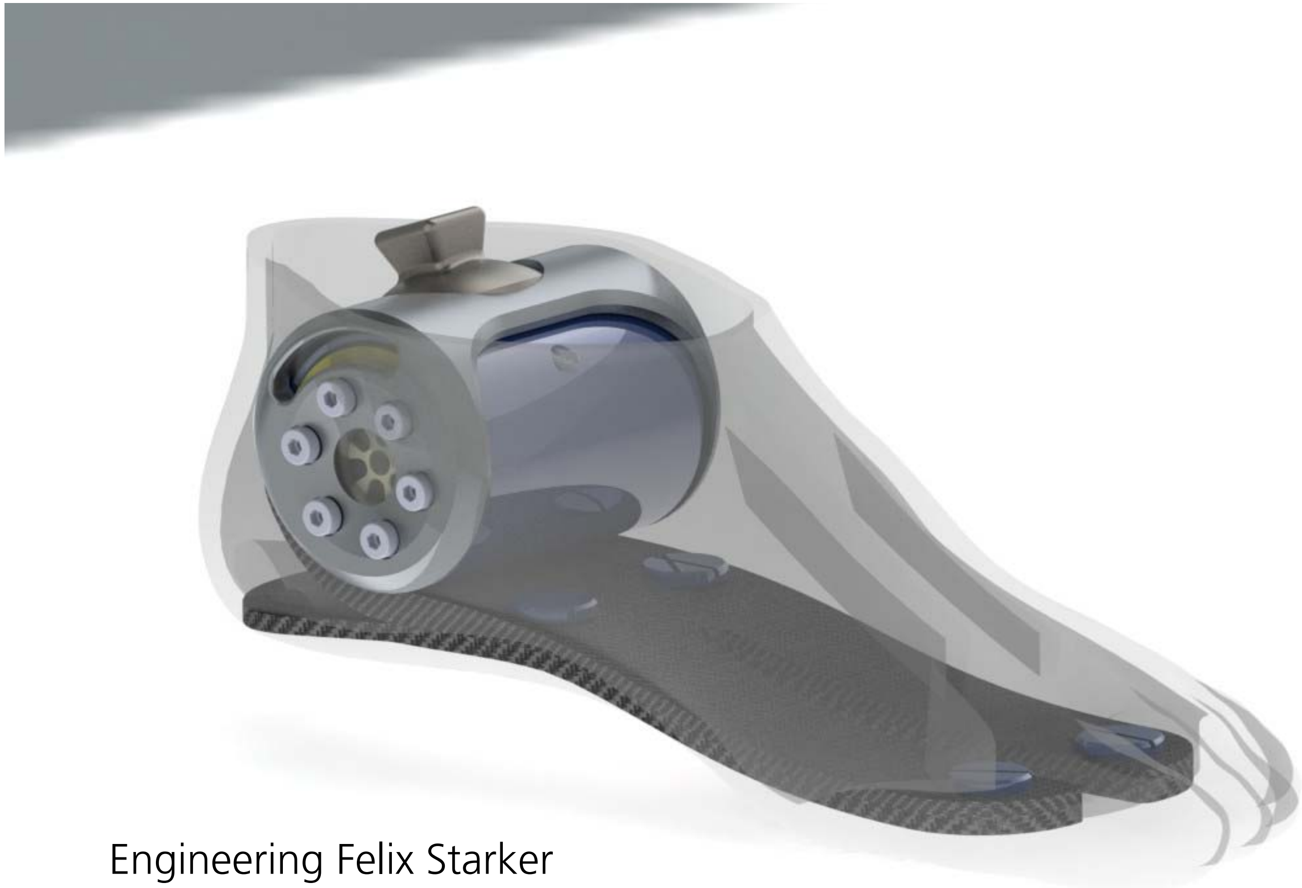
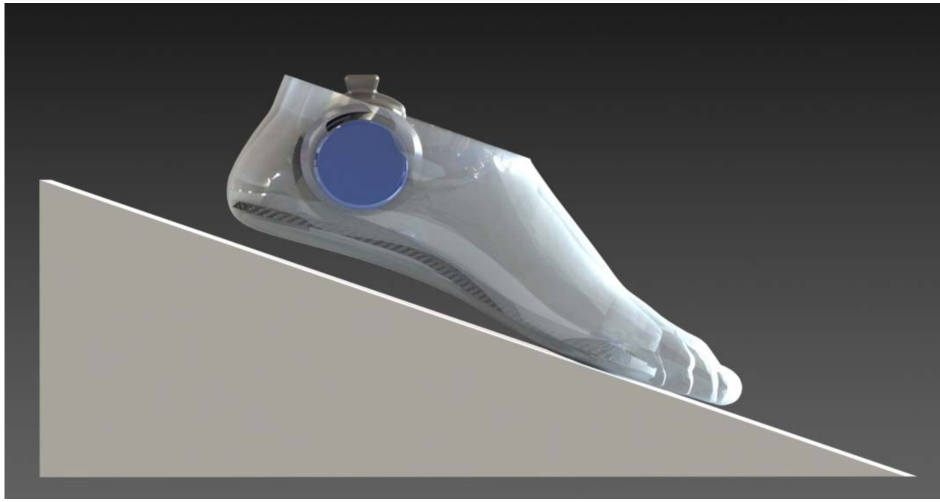
Approach 2: Passive terrain detection for passive terrain adaptation

Prototype 2011



- **Build height:** ~ 100 mm
- **Weight:** ~ 600 g
- **Foot size:** 27



Engineering Felix Starker
Planned Pre-Clinical Tests Andrew Hansen

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Approach 1: Optic terrain detection for active terrain adaptation

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Approach 2: Passive terrain detection for passive terrain adaptation

Basic idea:

EMG and gait sensory based decision

for user control of sagital ankle/ foot plate inclination

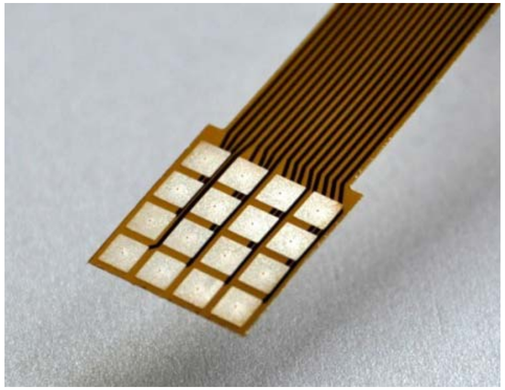
Myo-electrics for lower extremity applications

- Current lower limb prostheses cannot be arbitrarily conrolled by the user
- No biosignal based control feedback yet
- Muscle action based man machine interface
- Based on surface EMG array information
- combined with inertial and pressure sensory for gait phase interpretation

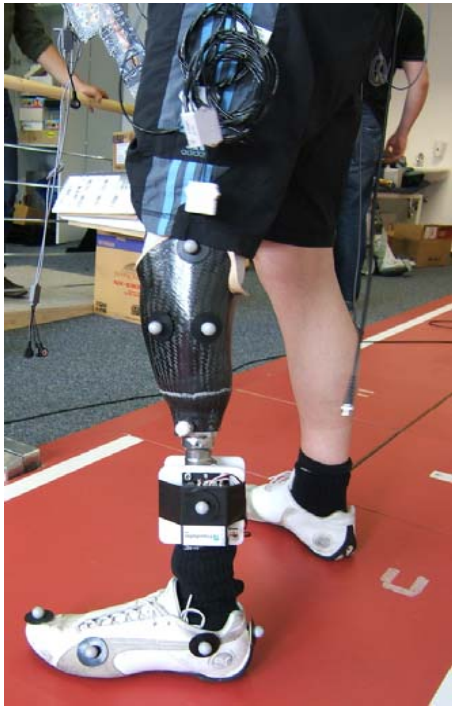
Approach 3: User foot control for active terrain adaptation

Sensory system I: version EMG and pressure

Various sensory arrays versions
4x4 dry EMG array
4x4 pressure sensory array behind the EMG Array



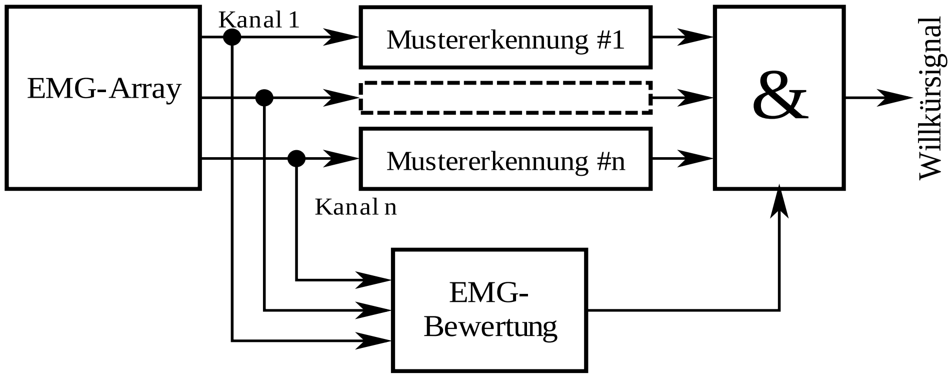
Sensory system II: Inertial tracking and heel pressure for gait phase



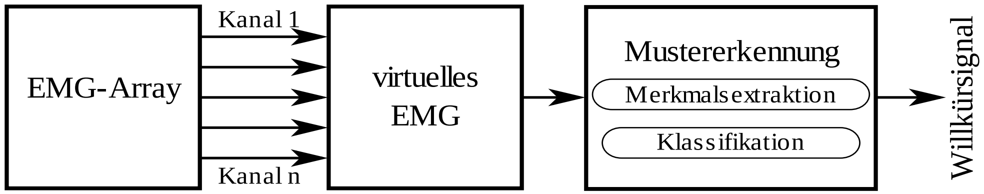
Approach 3: User foot control for active terrain adaptation

Signal Processing

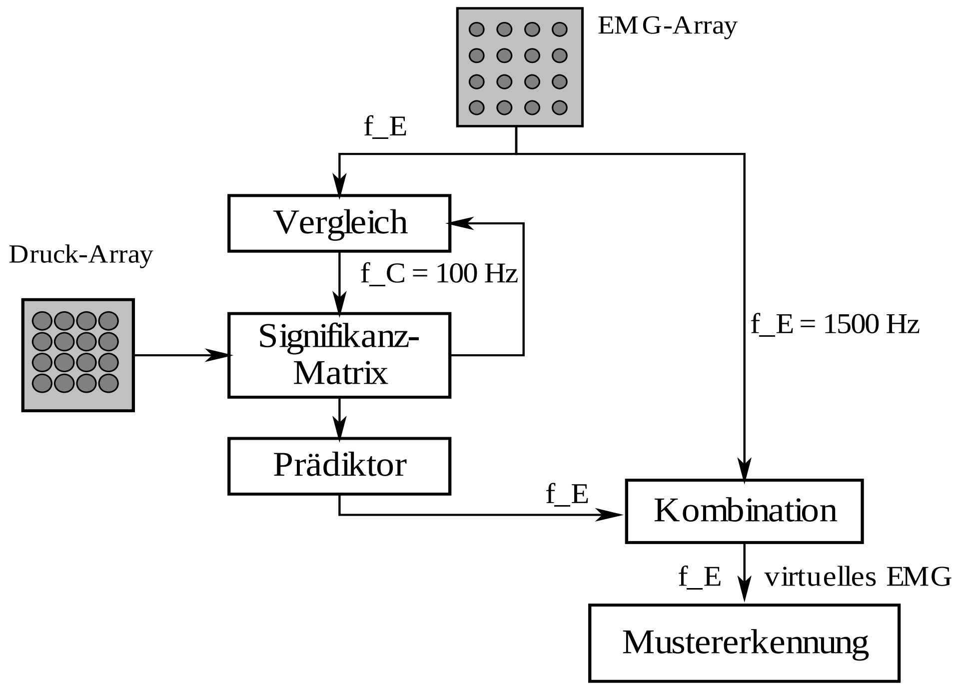
Classic multi sensory approach



Concept „Virtual EMG“



Generation of the „Virtual EMG“



Concept „Virtual EMG“

Engineering Harald von Rosenberg, Fraunhofer IPA 2010

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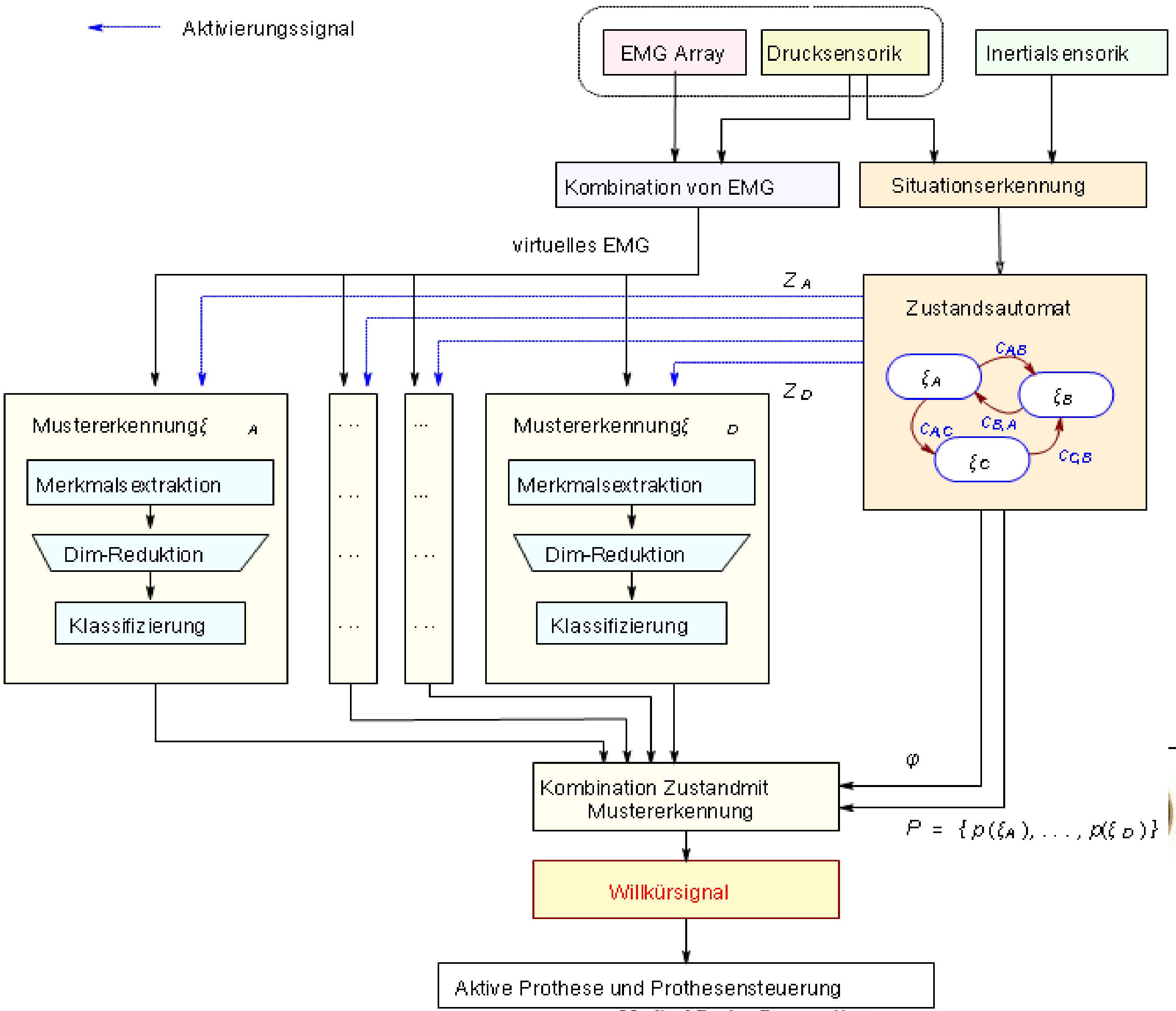
Approach 3: User foot control for active terrain adaptation



Thank you very much for your attention.

Literature

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