Terrain Detection & Terrain Adaption in Prosthetic Feet

Design of Medical Devices Conference

April 10 2012, Minneapolis

Fraunhofer IPA Dept. „Orthopedics & Motion Systems“, Stuttgart
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Fraunhofer IPA

Department „Orthopedics + Motion Systems“

Scope of activities

Research & Development

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

Education & Training

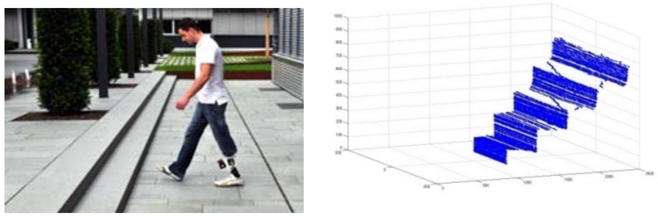
- Lecture „Mechatronics in Orthopedics“, Stuttgart University
- P&O Technology Seminars „Stuttgart Talks“ for CPOs
- Establishment of German P&O association O-PAEDIX

Standard activities

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

Department „Orthopedics + Motion Systems“

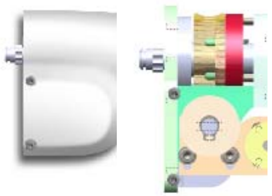
Prosthetics & Orthotics Research Examples



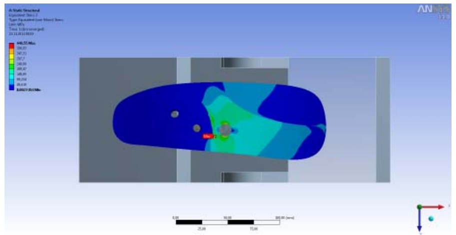
Terrain detection

Activity Monitoring

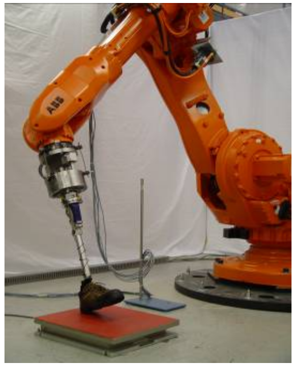
Foot engineering



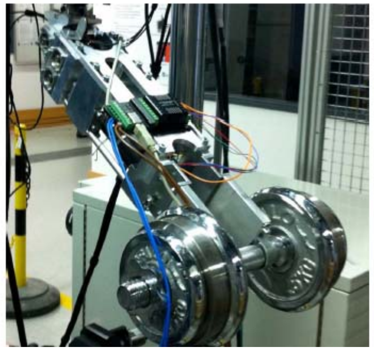
Orthotic Drives



Virtual 22675 testing



Robot Testing



Knee engineering

Rehabilitation Research Cooperation

between

Minneapolis VA Healthcare System & Fraunhofer IPA Stuttgart

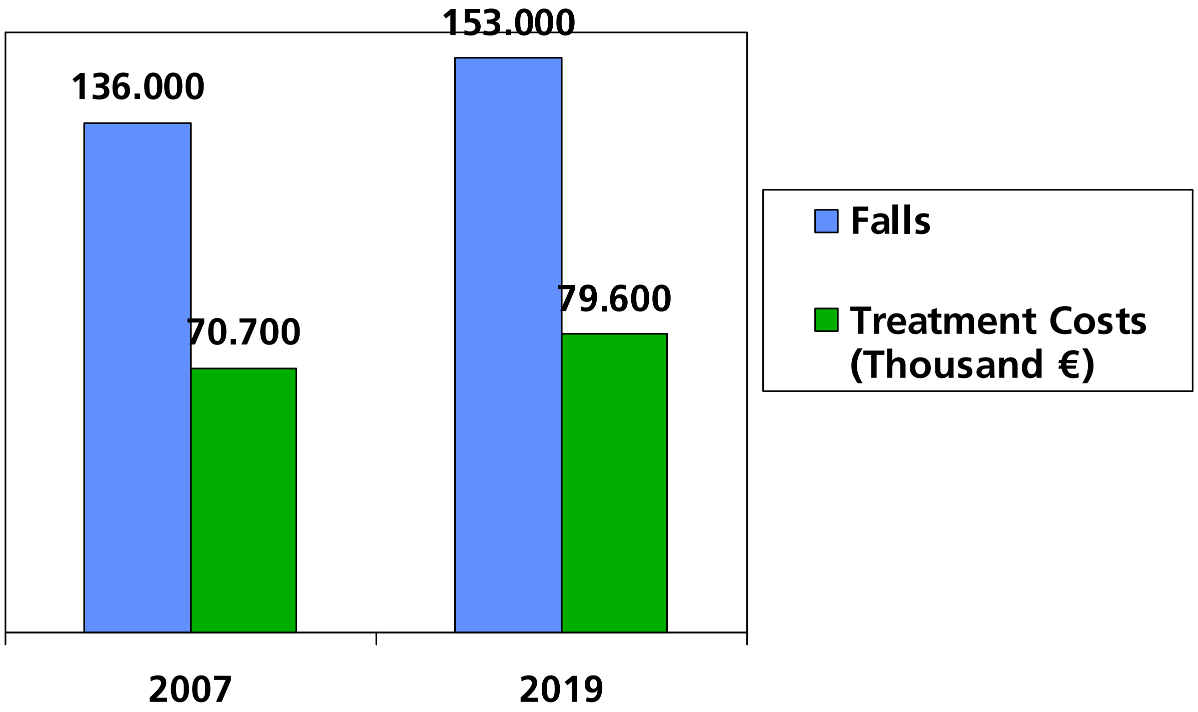
Stuttgart Minneapolis
Rehab Research

A Fraunhofer IPA and Minneapolis Veteran Affairs
Medical Center Cooperation

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)



Overview

Approach 1: Optic terrain detection for active terrain adaption

Approach 2: Passive terrain detection for passive terrain adaption

Approach 3: User foot control for active terrain adaption

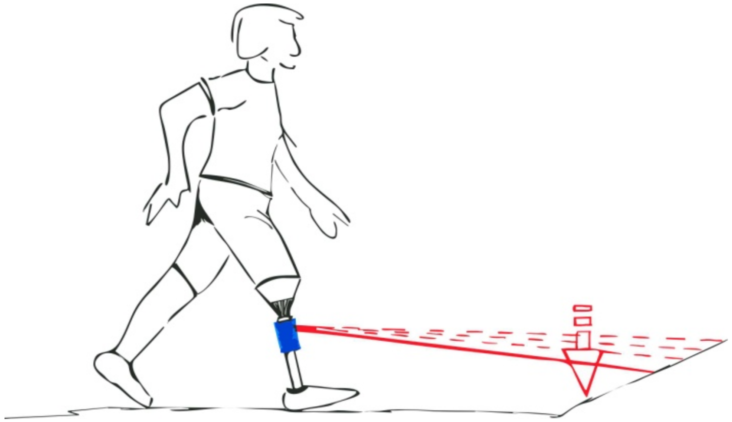
Definition:
„active" stands for drive controlled;
passive stands for a mechanic solution without electronics and drives.

Approach 1: Optic terrain detection for active terrain adaption

Basic idea:

real time obstacle detection

for automatic control of sagital ankle/ foot plate inclination

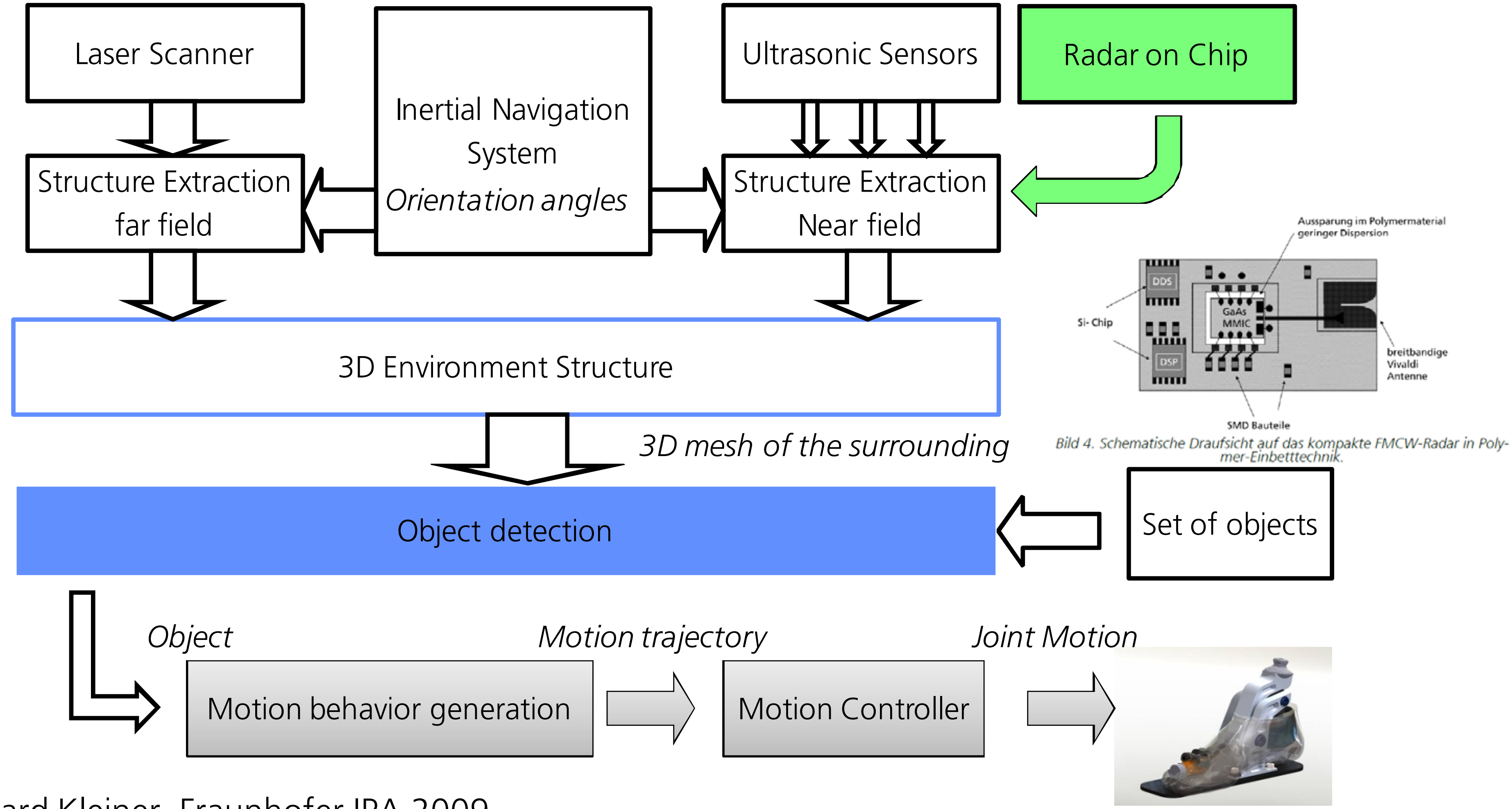


Approach 1: Optic terrain detection for active terrain adaption

- 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 saggital stance phase
- as a control input of an active foot or AFO

Approach 1: Optic terrain detection for active terrain adaption

Control Architecture



foot

Engineering Bernhard Kleiner, Fraunhofer IPA 2009

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

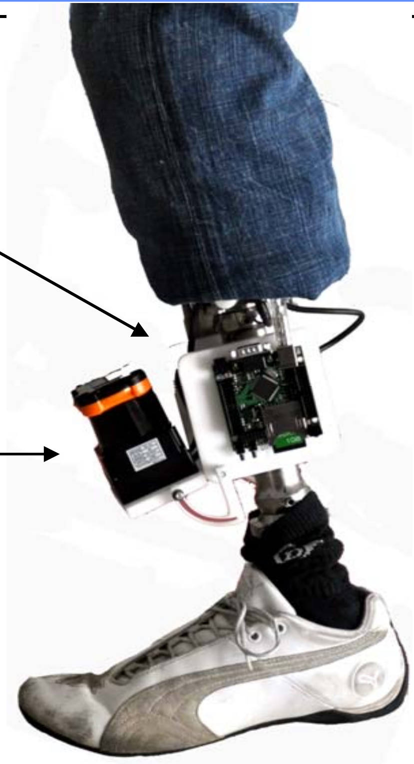
Approach 1: Optic terrain detection for active terrain adaption

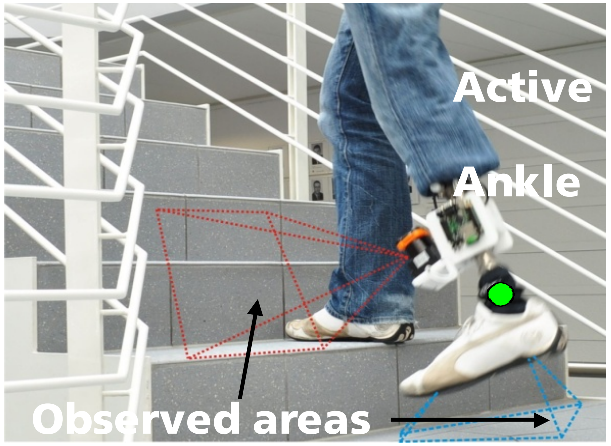
Inertial Measurement System

(Position and Orientation)

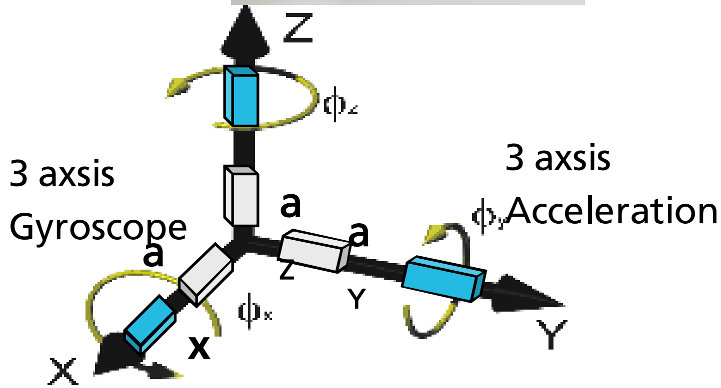
2D Laser Scanner

(270° horizontal scan)

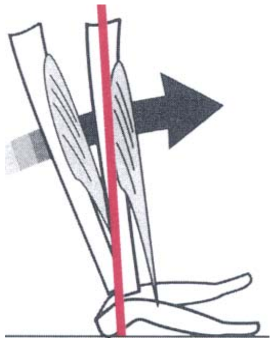


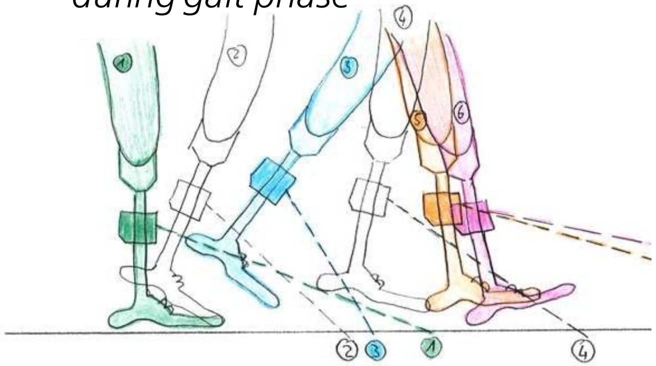


Inertial measurement unit by Fraunhofer IPA



Motion of the sensor unit during gait phase

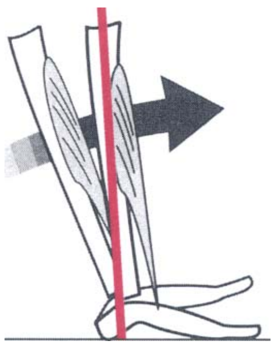




Engineering Bernhard Kleiner, Fraunhofer IPA 2009

Approach 1: Optic terrain detection for active terrain adaption

- 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



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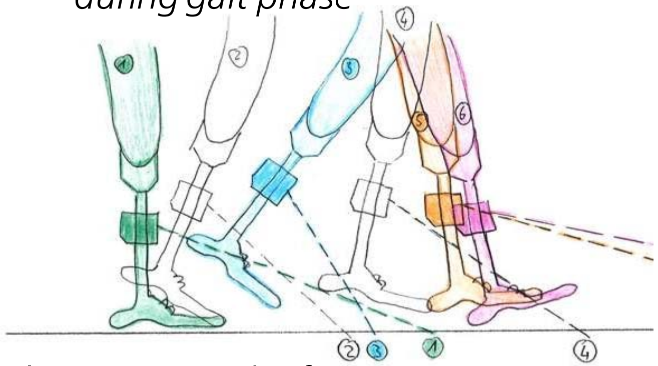
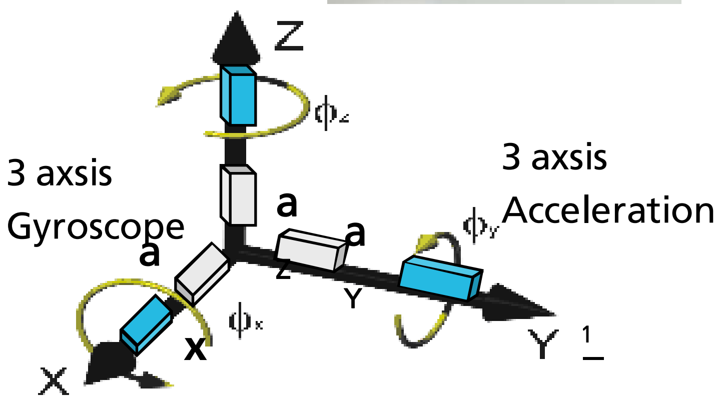


Engineering Bernhard Kleiner, Fraunhofer IPA 2009

Inertial measurement unit by Fraunhofer IPA



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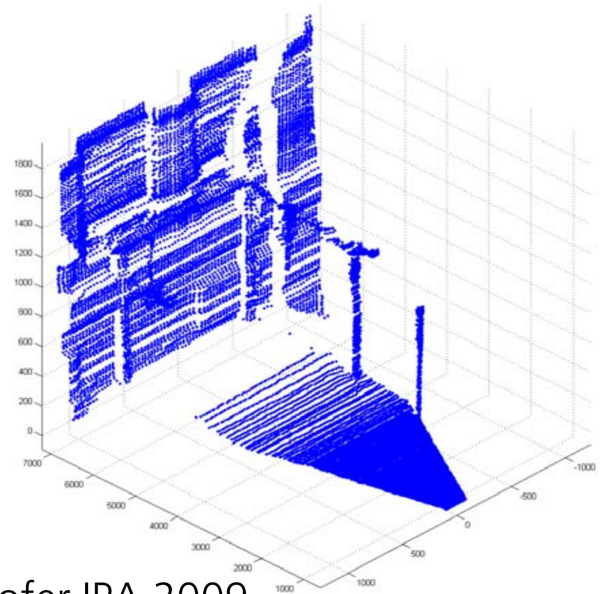
Approach 1: Optic terrain detection for active terrain adaption

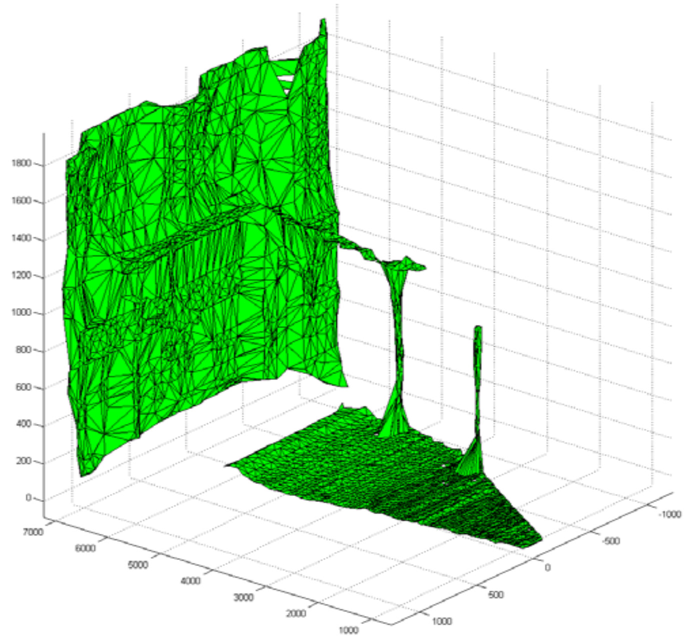
Measurements on ramps

Ramp in the Fraunhofer IPA gait lab

3D point cloud of the measured ramp



Mesh of the measured ramp



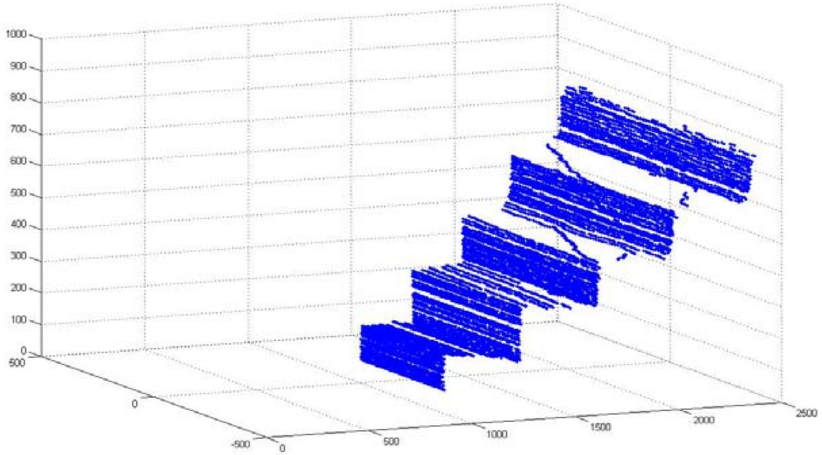
Engineering Bernhard Kleiner, Fraunhofer IPA 2009

Approach 1: Optic terrain detection for active terrain adaption

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

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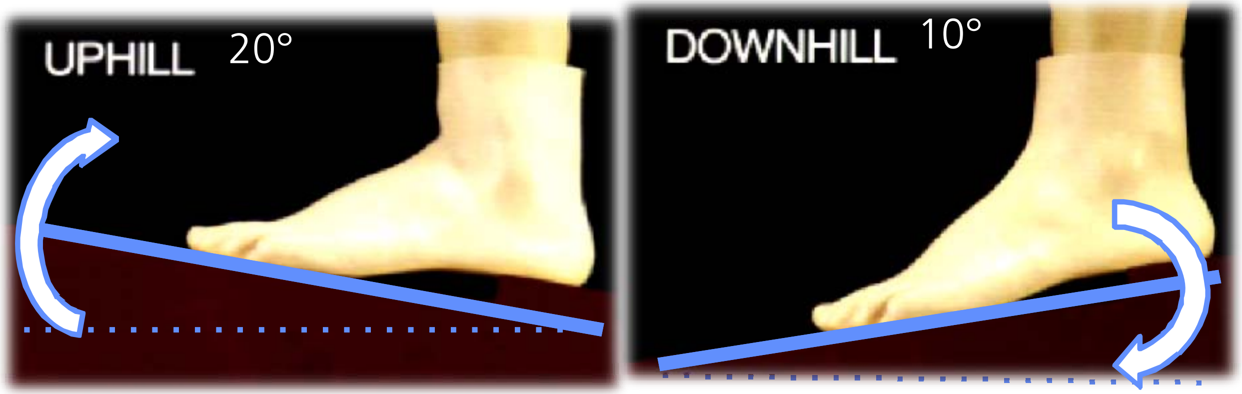
Definition:
„active“ stands for drive controlled;
passive stands for a mechanic solution without electronics and drives.

Approach 2: Passive terrain detection for passive terrain adaption

Basic idea:

real time mechanic detection of vertical foot loading

for passive hydraulic adaption to saggital terrain inclination



Mauch Ankle Product Catalogue Fotos, 1980)

Approach 2: Passive terrain detection for passive terrain adaption

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

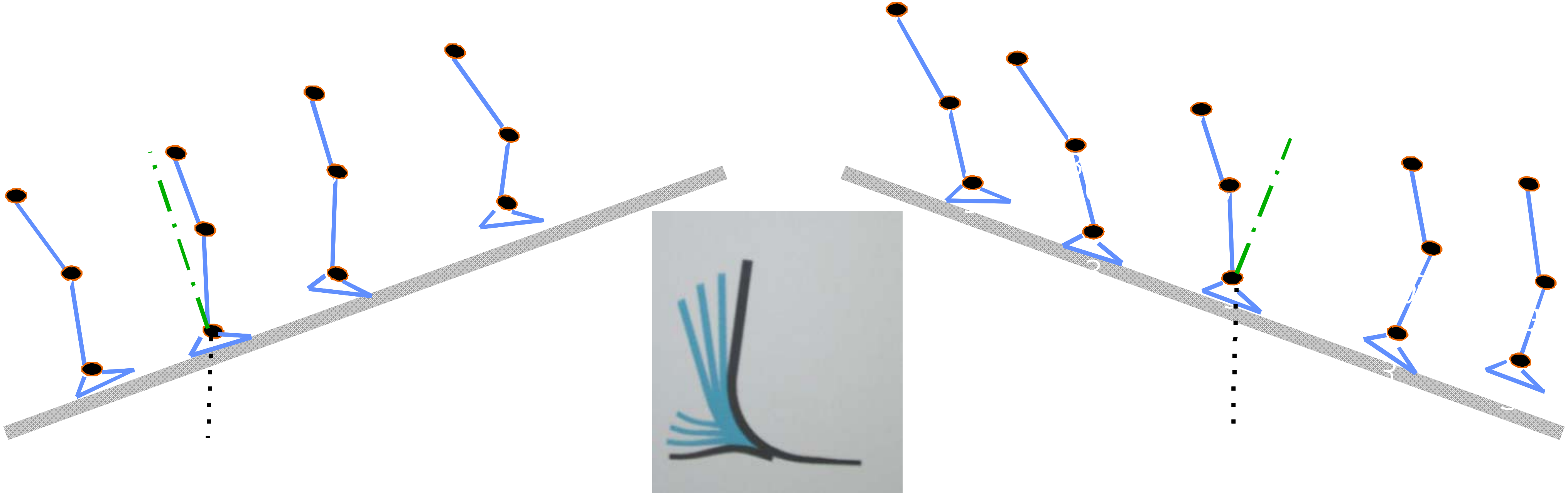
"Patients liked the terrain-adaptive behavior of this foot. Leakage problems led to its withdrawal from the market in the early 80ties"

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

Approach 2: Passive terrain detection for passive terrain adaption

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

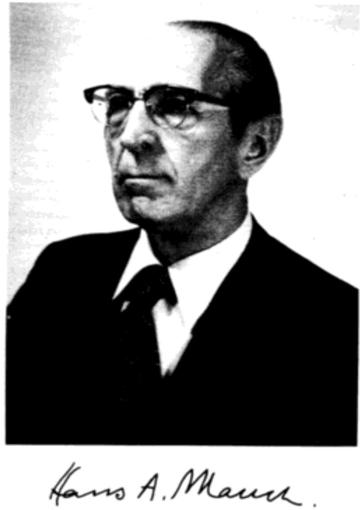


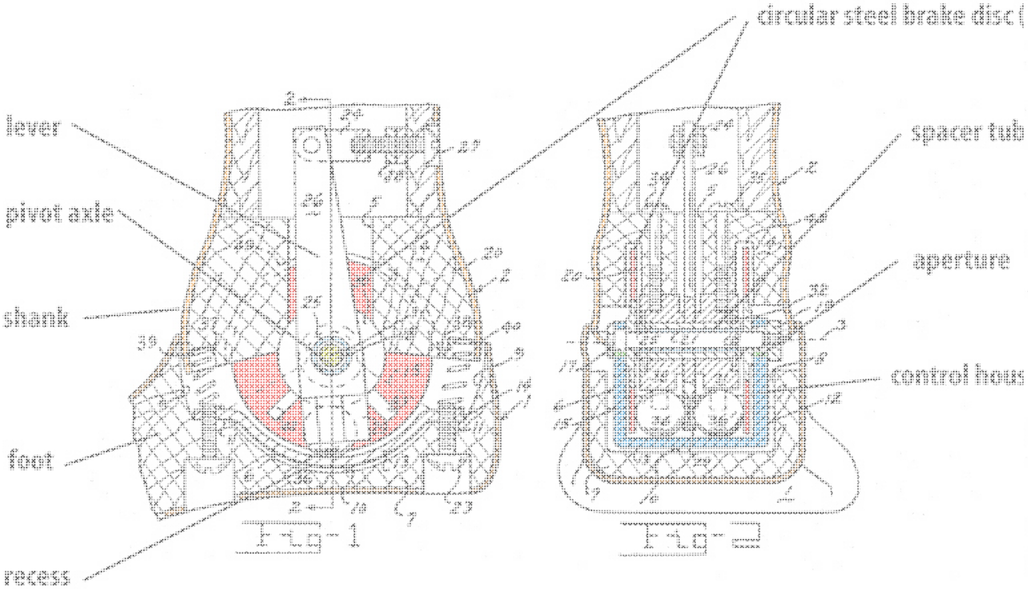
Approach 2: Passive terrain detection for passive terrain adaption

The Mauch Ankle Patent drawings

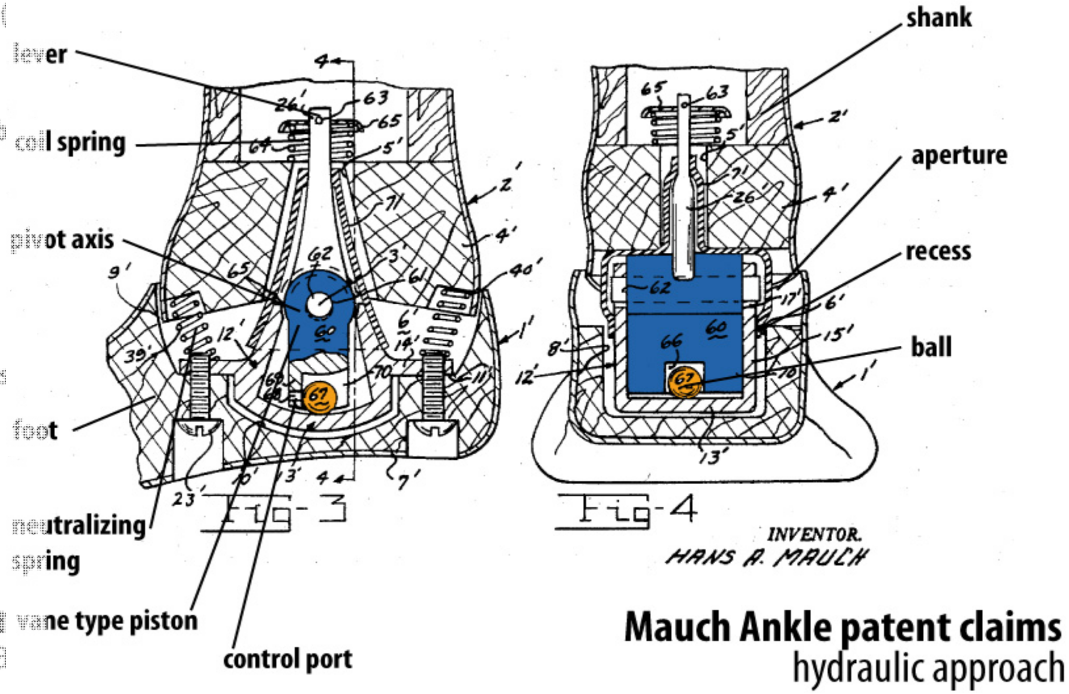
- **Mechanical approach**
  - Disc brake
  - Blocked by 2 balls

- **Hydraulic approach**
  - Piston forms 2 hydraulic chambers
  - Control channel blocked by ball





Mauch Ankle patent clai
mechanical approa



Mauch Ankle patent claims
hydraulic approach

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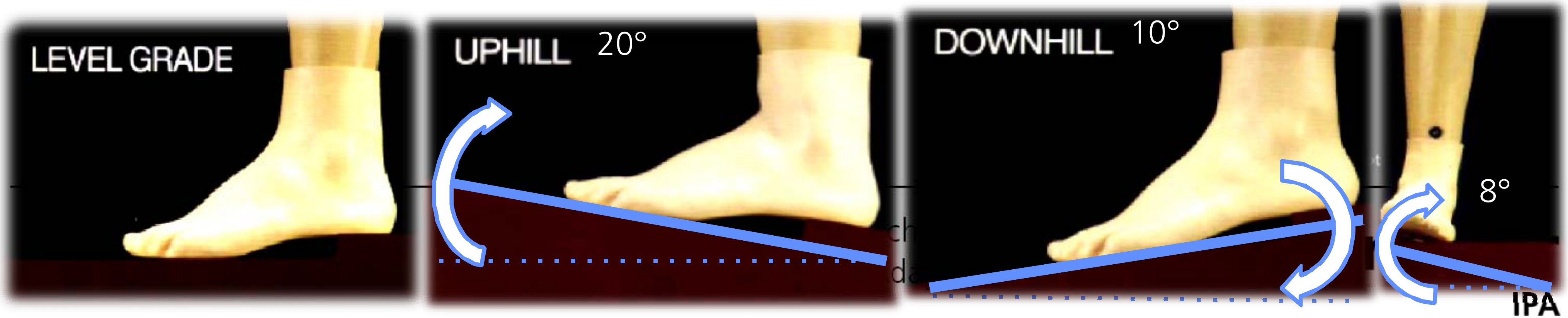
Approach 2: Passive terrain detection for passive terrain adaption

The Mauch Ankle

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



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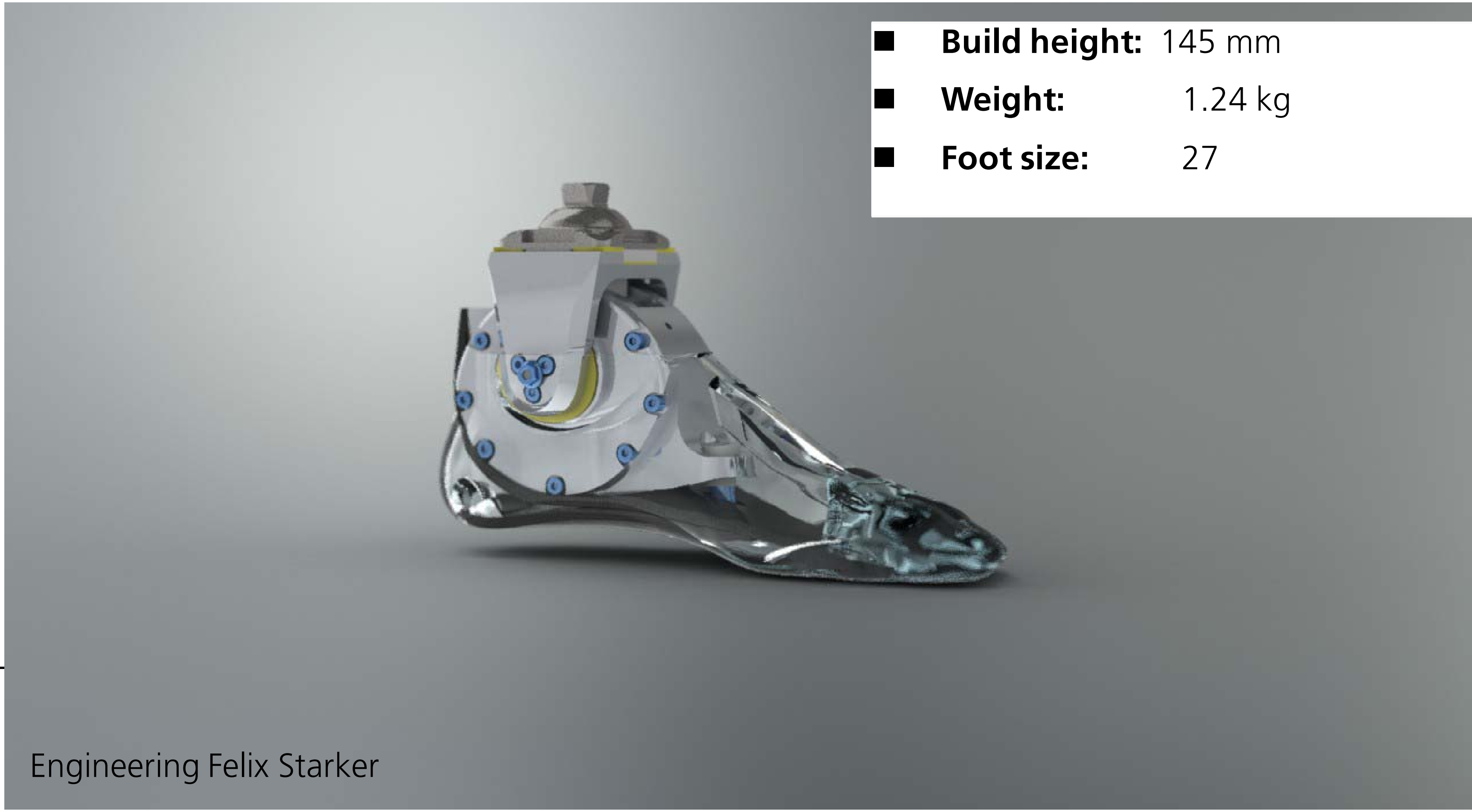
Approach 2: Passive terrain detection for passive terrain adaption

Early functional prototype - 2010

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



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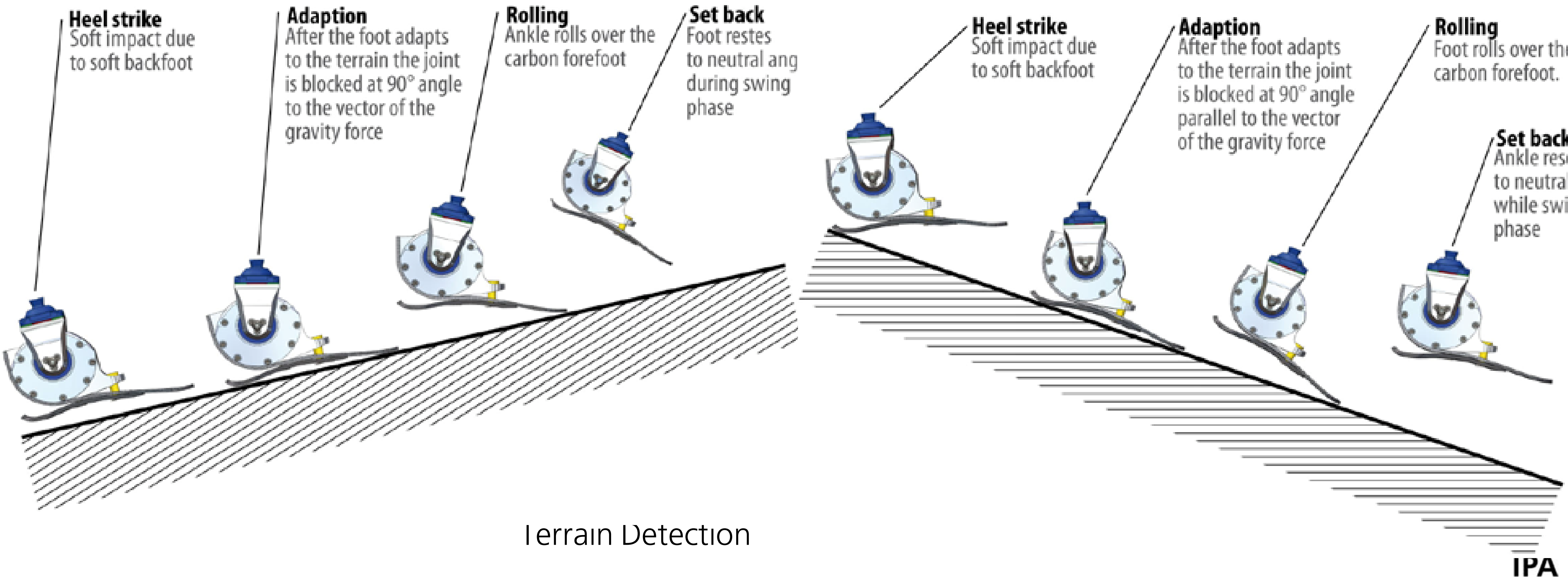
Approach 2: Passive terrain detection for passive terrain adaption

Adaption to uneven terrain

20° inclination

20° declination



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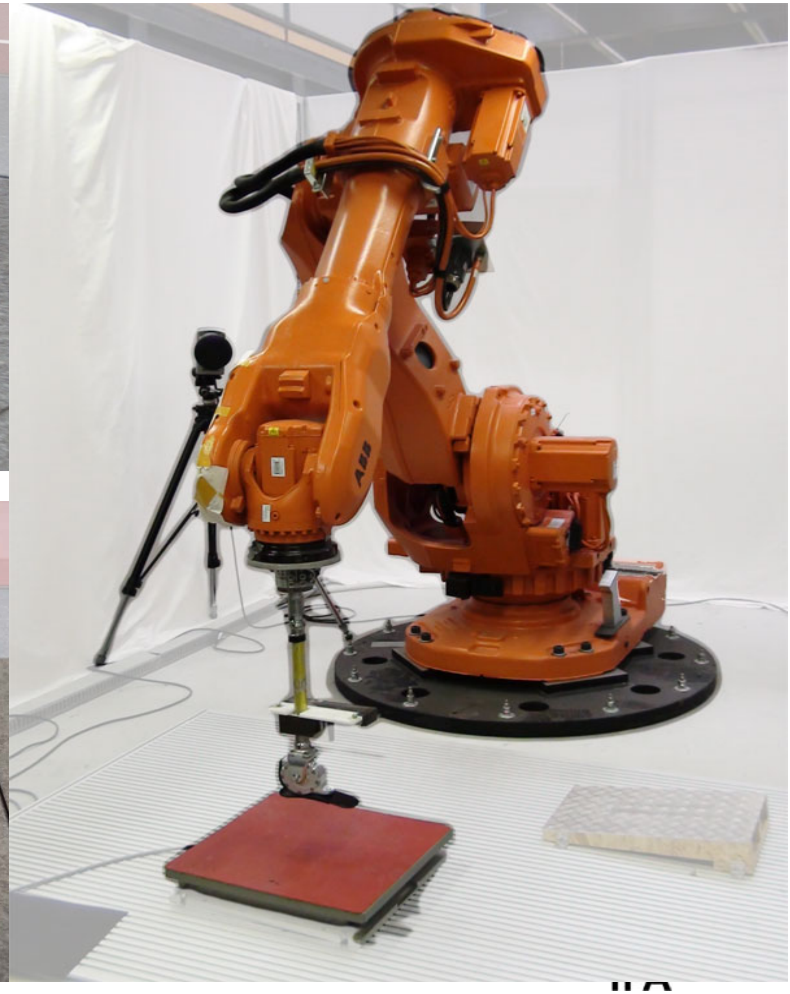
Approach 2: Passive terrain detection for passive terrain adaption

Early functional prototype – 2010 Evaluation



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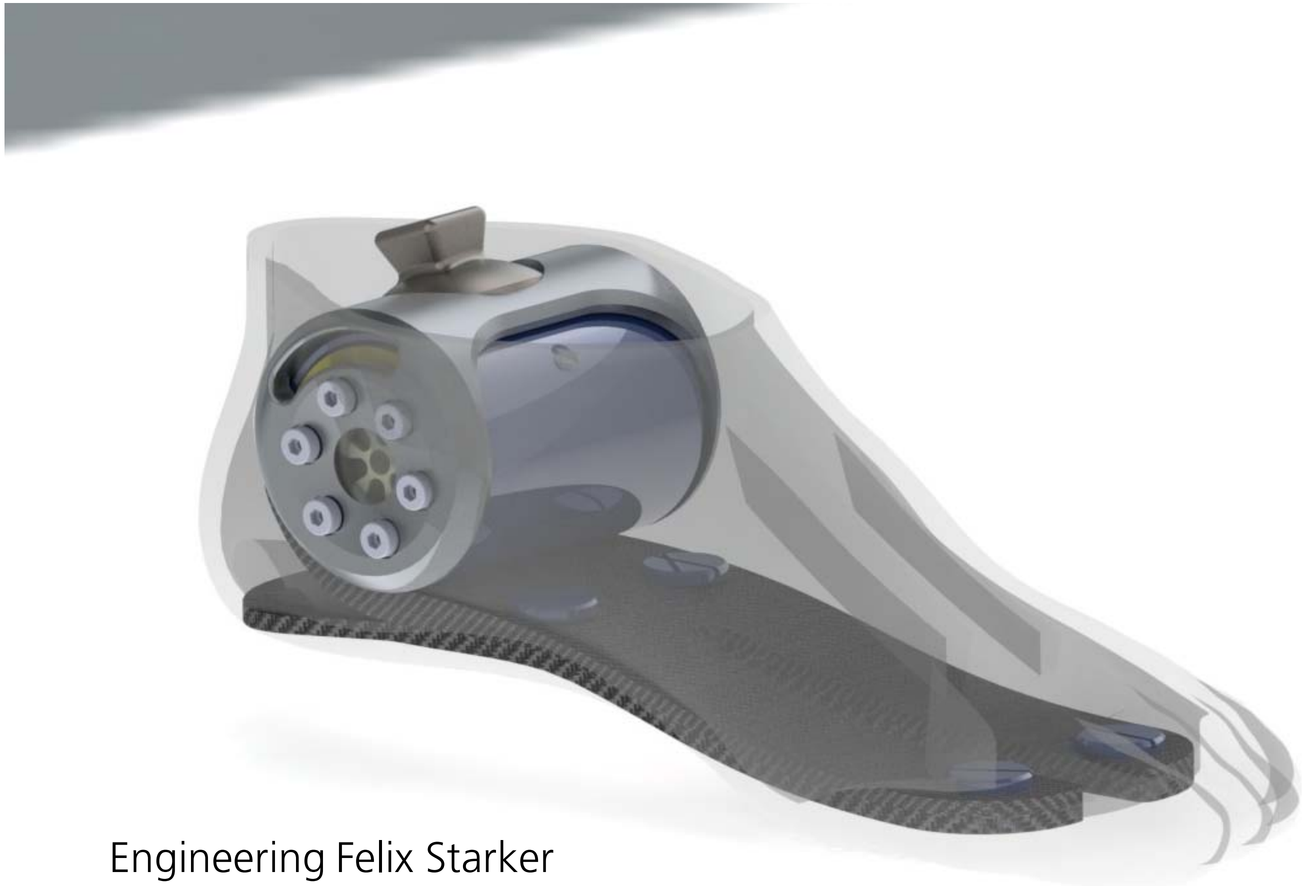
Engineering Felix Starker

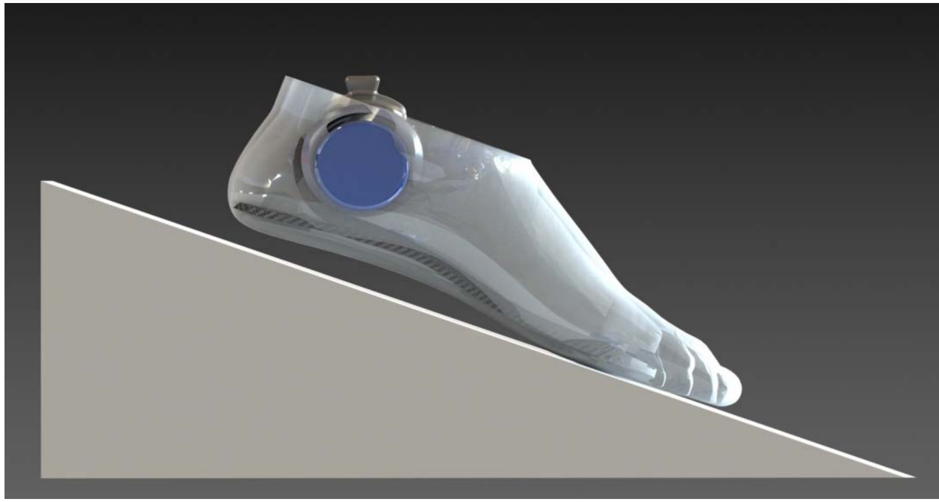
Department of Veterans Affairs

Approach 2: Passive terrain detection for passive terrain adaption

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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Definition:
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passive stands for a mechanic solution without electronics and drives.

Approach 2: Passive terrain detection for passive terrain adaption

Basic idea:

EMG and gait sensory based decission

for user control of sagital ankle/ foot plate inclination

Approach 3: User foot control for active terrain adaption

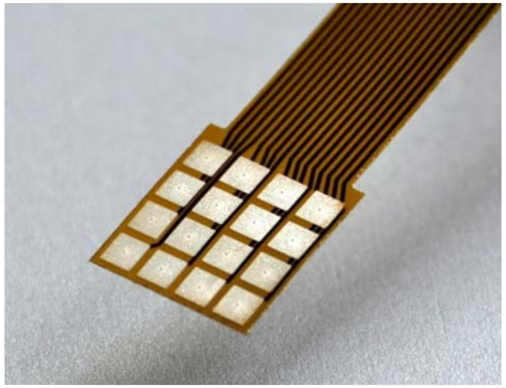
Myo elektrics for the lower extremity

- 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

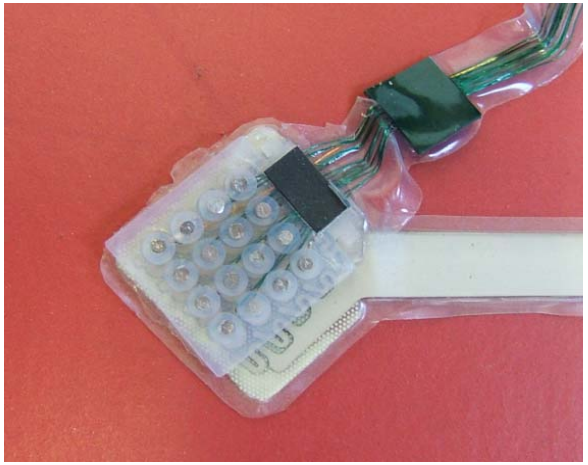
Engineering Harald von Rosenberg, Fraunhofer IPA

Approach 3: User foot control for active terrain adaption

Sensory system I: version EMG and pressure



Various sensory arrays versions
Entwicklung eines Sensor-Arrays zur robusten Detektion von Biosignalen
4x4 dry EMG array
4x4 pressure sensory array behind the EMG Array

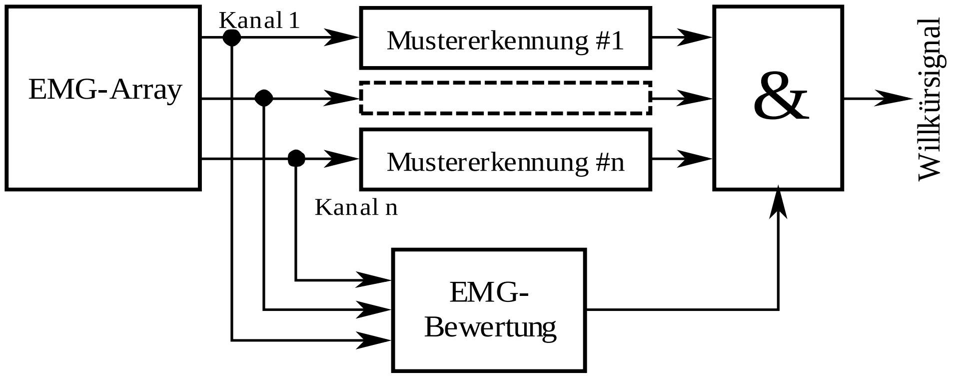


Sensory system II: Inertial tracking and heel pressure for gait phase

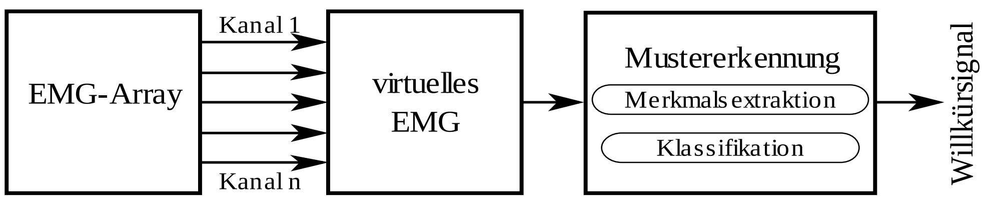
Approach 3: User foot control for active terrain adaption

Signal Processing

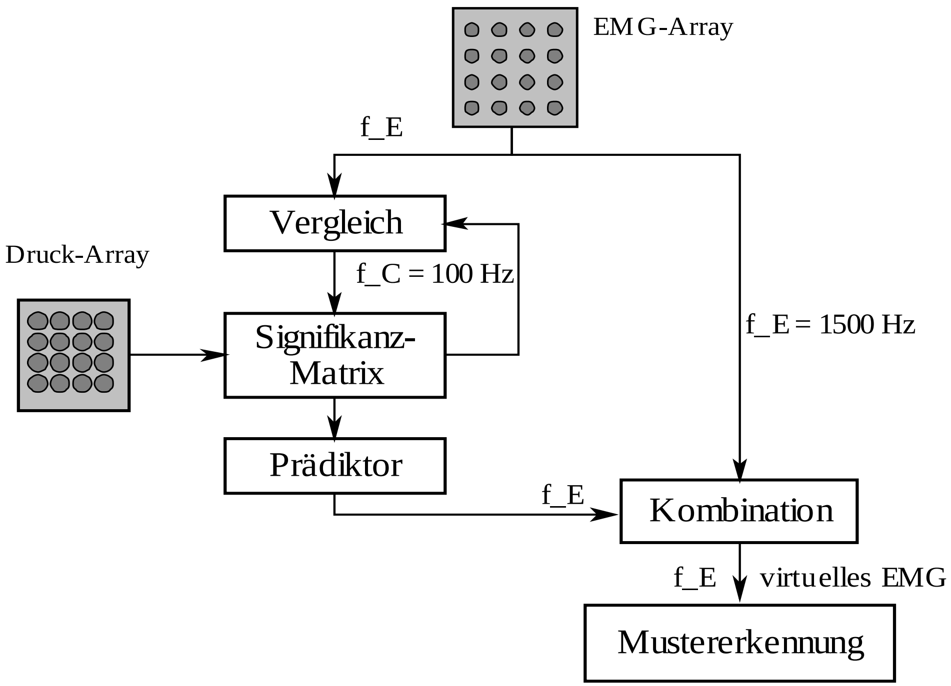
Classic multi sensory approach



Concept „Virtual EMG“



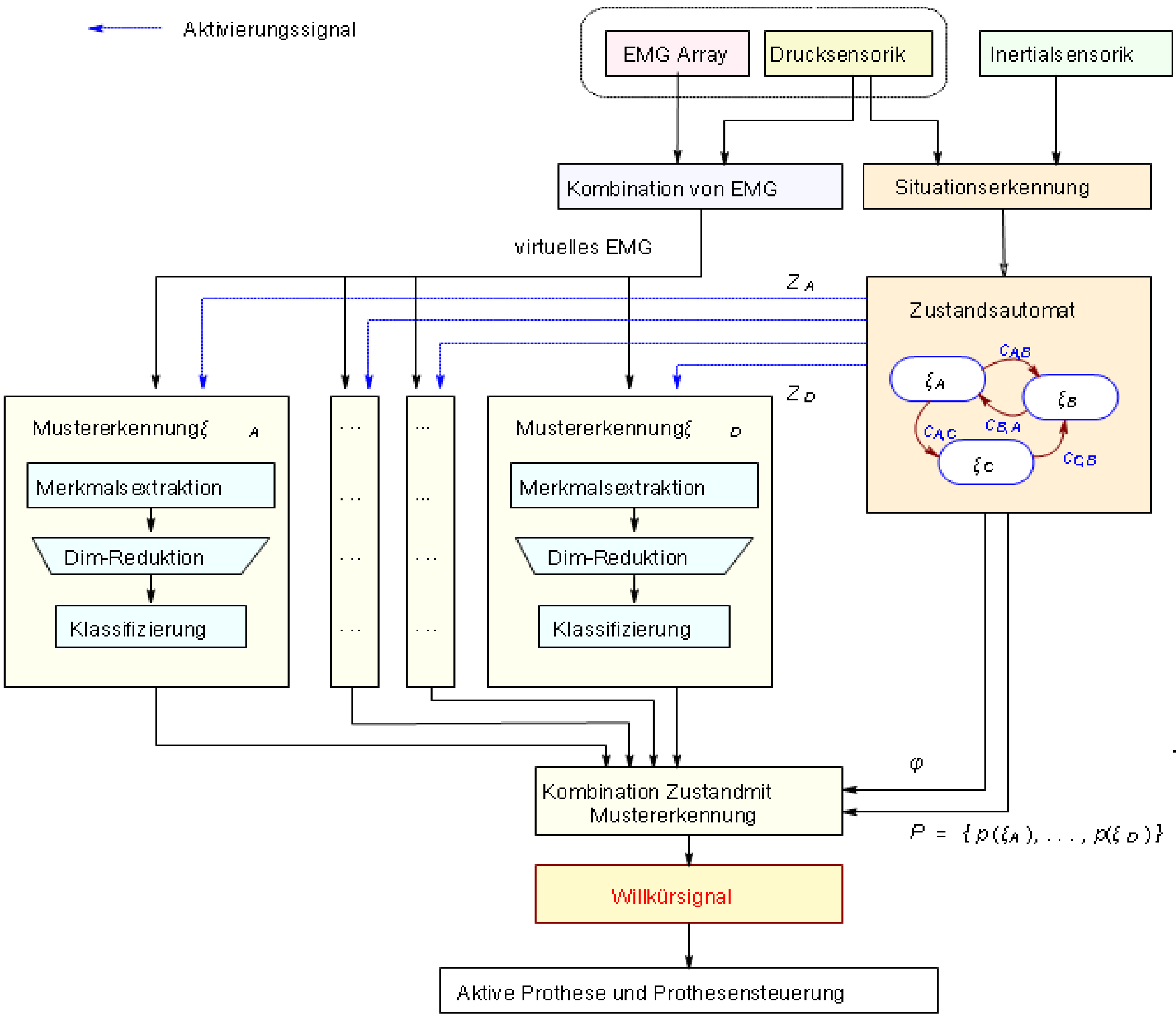
Generation of the „Virtual EMG“



Concept „Virtual EMG“

Engineering Harald von Rosenberg, Fraunhofer IPA 2010

Approach 3: User foot control for active terrain adaption



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Thank you very much for your attention. Meet us in Leipzig May 2012.

Symposium "Enabling technologies for improved walking"

World Congress at ORTHOPÄDIE + REHATECHNIK 2012 in Leipzig, 15th May 2012

Chairs: Dr. Urs Schneider, Dr. Andrew Hansen

Active Approaches

- Dr. Hugh Herr, MIT, Media Lab "The MIT powered ankle drive concept"
- Dr. Tomas Sugar- Arizona State University, Phoenix "The Arizona drive Concept"
- Dr. William Durfee, University Minneapolis, "The Minneapolis Hydraulics approach for P & O applications"
- Bernhard Budaker, Fraunhofer IPA Stuttgart "Towards high efficiency in electric knee drives"

Passive Approaches

- Dr. Andrew Hansen, VAMC Minneapolis – "Passive Terrain Adaption - a Chicago Minneapolis solution"
- Felix Starker, Fraunhofer IPA Stuttgart – "Revision of the Mauch ankle – an old new hydraulic approach"