Emerging directions in Lower Limb Wearable Robots for gait support and augmentation

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Jan Veneman,
Tecnalia Research and Innovation,
Spain

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State of the Art

Key challenges & directions

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Applications of LLWRs

- Healthcare, *rehabilitation training*
- Healthcare, *assistive use*
- Military, Industry, Construction, *load carrying*
- Industry, worker support, *task specific*
- Construction, worker support, *task specific*
- Consumer, *reduction of metabolic cost, increase of range*

Specific intended use determines focus in challenges (not: one design fits all, but task specific design)

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BALANCE

WearRA WEARABLE ROBOTICS ASSOCIATION

Spinal Cord Injury

Ekso Bionics,USA

Indego, USA

ReWalk, Israel

Rex Bionics, NZ

US Bionics,USA

Technaid Exo H2, Spain

IHMC Mina, USA

ExoAtlet, Russia

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BALANCE

WearRA WEARABLE ROBOTICS ASSOCIATION

Assistive/Elderly


Walking Assist Device,Japan


Bodyweight Support Assist, Japan


Power Assist Suit, Japan


Panasonic,Japan


Innophys, Japan


Hexar Systems, Korea


B-temia Keeogo, Canada


X-Ar Equipois Inc. (USA)

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WearRA WEARABLE ROBOTICS ASSOCIATION

Defense

SARCOS, XOS-2, USA

Human Universal Load Carrier, USA

Google, USA

AirLegs Exoskeleton, USA

Harvard/Wyss, USA

Powered Exos, China

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WearRA WEARABLE ROBOTICS ASSOCIATION

Manufacturing and Construction

DAEWOO, Korea

RB3D, France

Cyberdyne, Japan

Fortis, USA

Noonee, Switzerland

Activelink, Japan

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WearRA WEARABLE ROBOTICS ASSOCIATION

Recreation

Passive Ankle, USA

JetPack, USA

Spnkix, USA

Cutch-Spring Knee, USA

Personal Carrier, France

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SoTA Control goals

(a) Propulsion of the body's center of mass, through the stance leg/s (Kazerooni et al. 2005; Blaya and Herr 2004)

(b) Propulsion of the swing leg (Veneman et al. 2005; Banala et al. 2009)

(c) Gravitational support of the extremities (Banala et al. 2006)

(d) Gravitational support to load/body weight carrying (Zoss et al. 2006)

(e) Correcting anomalies of the gait trajectory (Banala et al. 2009; Van Asseldonk et al. 2007)

Overview cited from: Aguirre-Ollinger, 2015

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State of the Art - products

Key challenges & directions

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General LLWR Issues

Most LLWRs are **too heavy**:

- Increase, not reduce metabolic cost
- Large and clunky, impair turning, balance, etc.

Most LLWRs **do not seamlessly interact** with the user

- Impair gait motion
- Use tricks or predefined patterns to work
- Not intuitive to interact with
- Use standard controllers

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Specific Key Challenges

- **Safety and comfort**
  - Fall avoidance
  - Obtrusiveness, long term use, compatibility with use
- **High Level Control and Human Robot Interaction**
  - Control of needed actions (turning, STS, …)
  - Human robot cooperation (shared control)
- **Energy Use**
  - Range of operation
  - Metabolic cost of walking
- **Product Cost**

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Directions in R&D

- **Human robot interaction in control**
  - Impedance/force control
  - Transparency control
  - Shared control of movement / interaction with HMC
- **Ergonomics and design**
  - Alignment of joints and movement
  - Soft design (exosuit)
- **Balance and posture control**
  - Detection of loss of balance
  - Corrective actions

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Directions in R&D

- **Systems energetics**
  - Recovery of dissipated energy (elastic, electric)
  - Integration in gait cycle dynamics
  - Minimalistic design
- **Component design; sensors, actuators, attachments, modularity, energy optimization**
  - Accurate motion and force sensing
  - Power to weight ratio
  - Low impedance actuation
  - Personalization, modularity, 3D printing

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(Some)Key European Projects

Active or recently active cross Europe consortium R&D projects publicly funded

AXO-SUIT, http://www.axo-suit.eu/
BALANCE, http://www.balance-fp7.eu/
BIOMOT, http://www.biomotproject.eu/
CORBYS, http://www.corbys.eu/
CYBERLEGs, http://www.cyberlegs.eu/
EXO-LEGS, http://www.exo-legs.org/
ROBO-MATE, http://www.robo-mate.eu/
SYMBITRON, https://www.symbitron.eu/

www.openaire.eu

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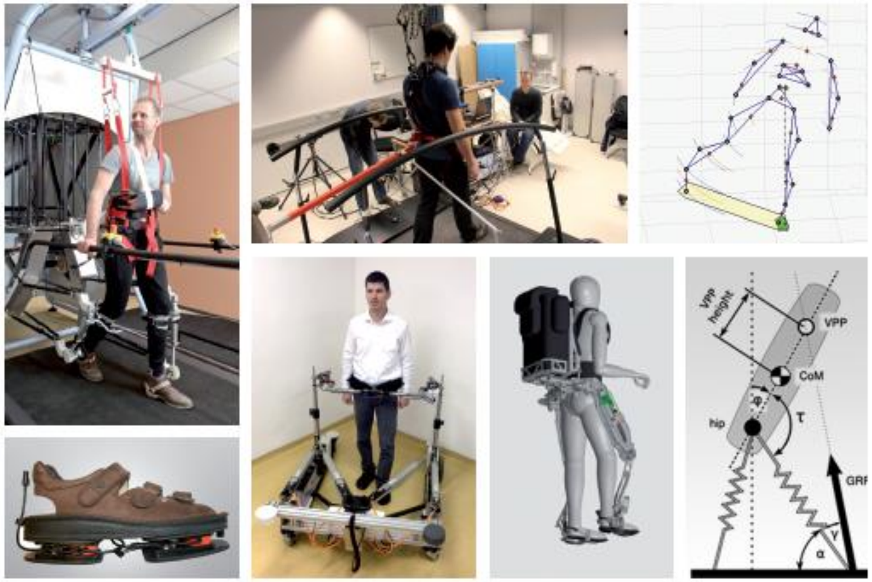
Balance Augmentation in Locomotion, through Anticipative, Natural and Cooperative control of Exoskeletons.



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BALANCE

INTRODUCTION

Science

Hardware

Control

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Primary Goal

Use exoskeletons to augment **postural balance performance** in standing and walking for assistance and training

→irregular incidences (not the regular cycle)

→research, identify limitations

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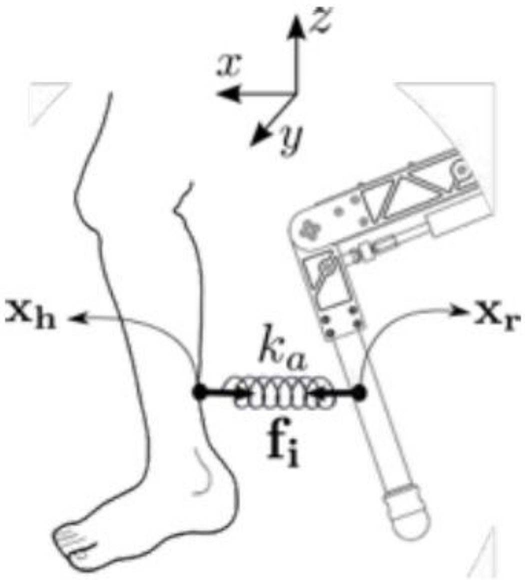
Secondary Goals

- Study balance strategies in humans
  - Foot placement
  - Stiffness adjustment
  - Healthy vs. brain trauma
- Model balance strategies of humans
- Equip an exoskeleton with adequate structure, actuators and sensors
- Develop cooperative exoskeleton control
- Assess and evaluate performance



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State of the art

Cyberdyne HAL:
on the user

Ekso Bionics:
by crutches

Rex Bionics:
slow and conservative

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INTRO

Science


Hardware

Control

Balance control

1. Experiments to understand human balance control
   - Standing; treadmill and over ground walking; turning;
   - Healthy versus impaired
   - Different perturbations:
     - Pelvic pushes
     - Vertical floor (missed step)
2. Model balancing strategies of humans, focus on FPS
3. Use strategies/models as basis for cooperative exoskeleton control

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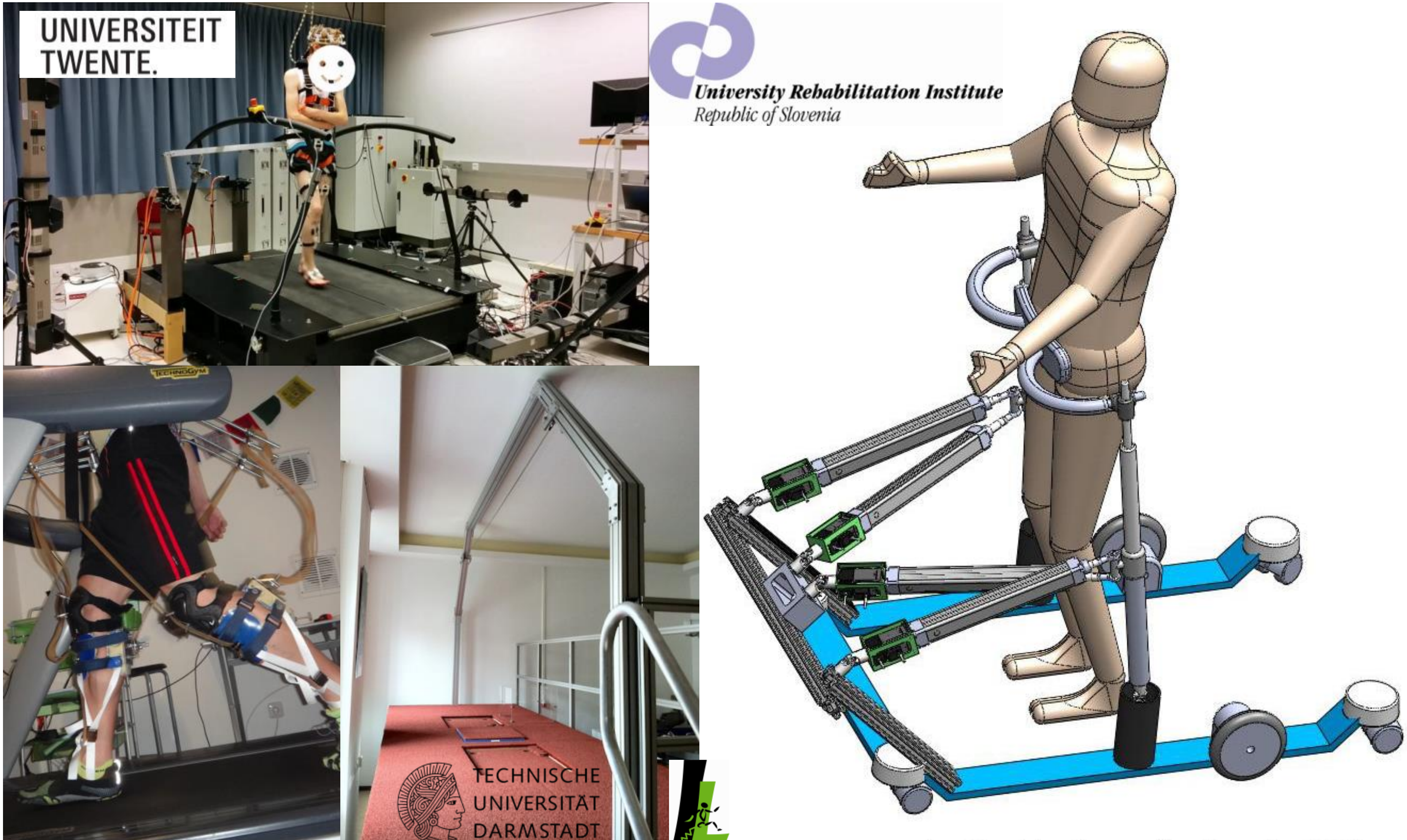

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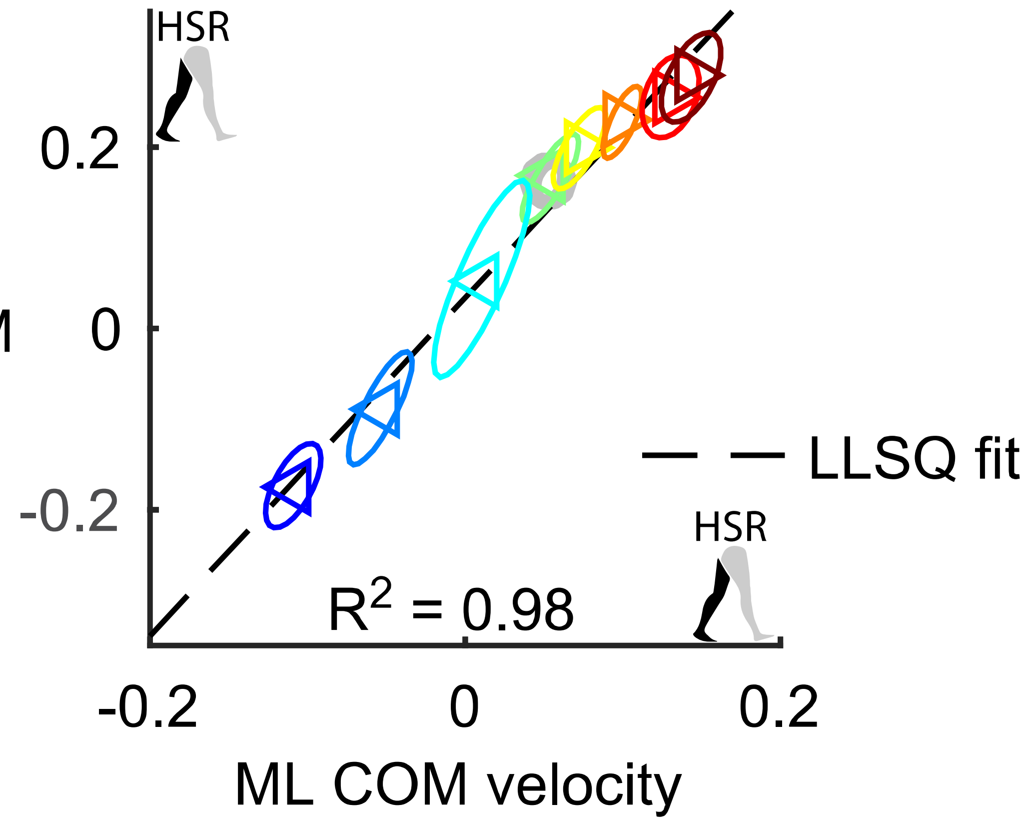
Mediolateral foot positioning is linearly related to Center of Mass velocity



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INTRO

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New hardware platform


Hercule Hv3

Development of EMY-dev : a lower leg exoskeleton with high **mobility**, high **transparency** and high **dynamics**, dedicated to the evaluation of balance control strategies

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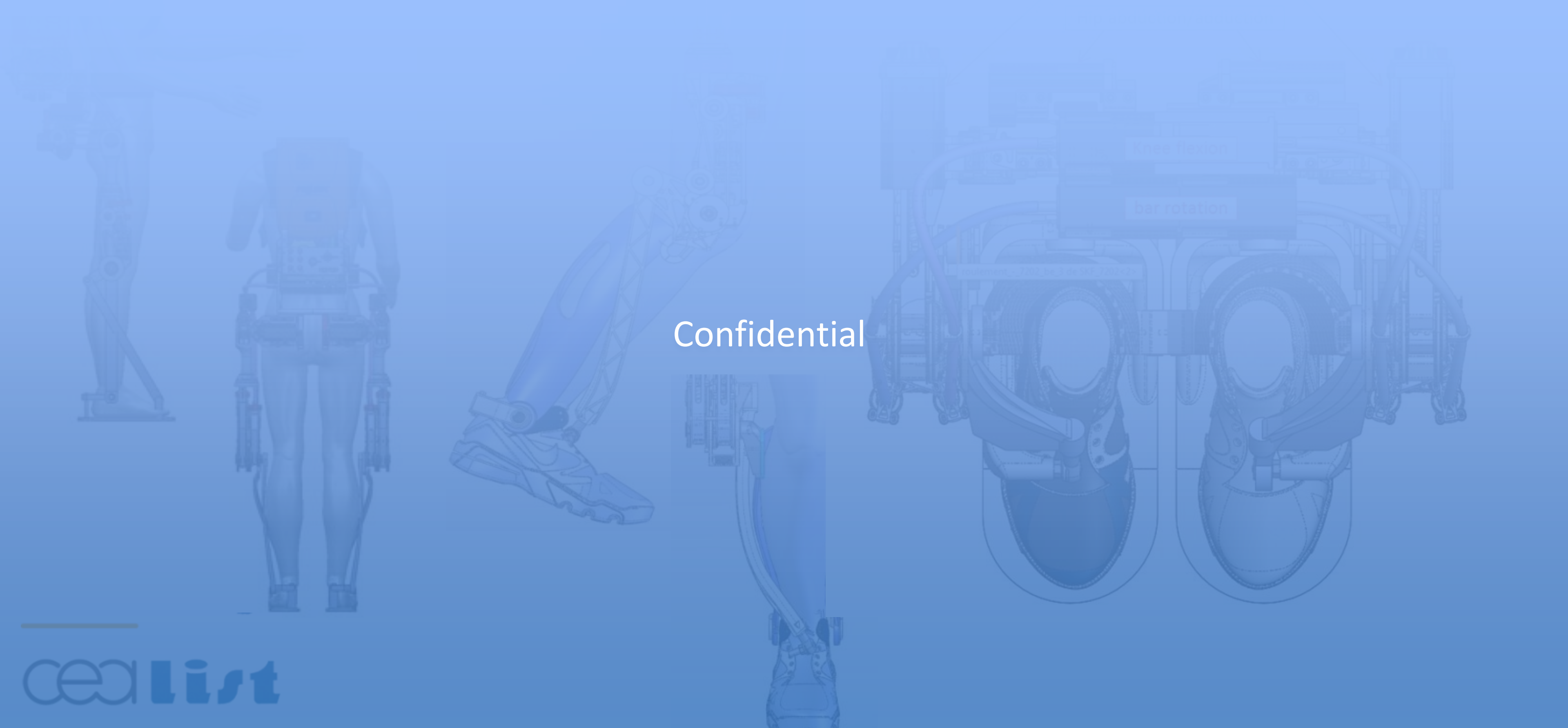
New hardware platform



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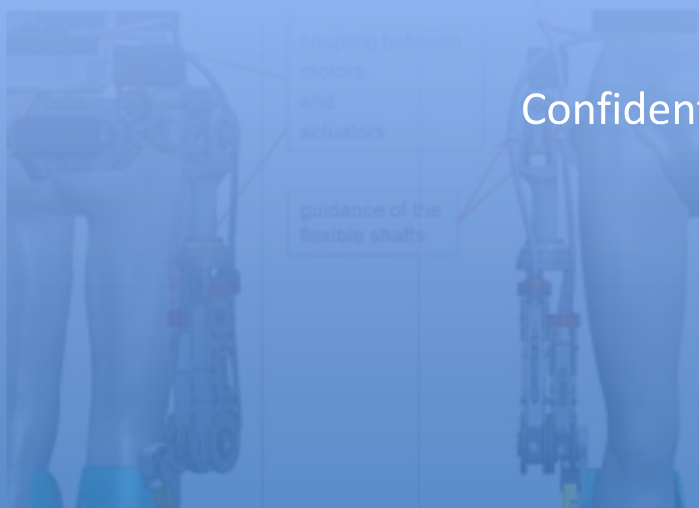
Actuation Technology

- Low friction
- High efficiency
- Torque control without torque sensor

Ball-screw and cable actuator



Remote actuation through flexible shafts

Confidential

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Joint specifications

- Same motors for each actuated joint. Adjustment via reduction ratio.
- Proximal joints (Hip a/a and f/e) : priority given to torque
- Distal joints (knee and ankle) : priority given to speed

Joint Name	Hip abduction/ adduction	Hip flexion/ extension	Hip inter/ external rotation	Knee flexion/ extension	Ankle flexion/ extension	Ankle supination/ pronation
Type	*Active*	*Active*	*Lockable passive*	*Active*	*Active*	*Lockable Passive*
Amplitude	*-15°/+15°*	*-120°/+20°*	*-30°/+60°*	*0°/+130°*	*-30°/+30°*	*-20°/+20°*
Reduction ratio	*100,98*	*100,98*	-	*49,37*	*49,37*	-
Nominal torque	*90,9 Nm*	*90,9 Nm*	-	*44,4 Nm*	*44,4 Nm*	-
Max torque	*205,8 Nm*	*205,8 Nm*	-	*100,6 Nm*	*100,6 Nm*	-
Max speed	*3,2 rd/s*	*3,2 rd/s*	-	*6,5 rd/s*	*6,5 rd/s*	-

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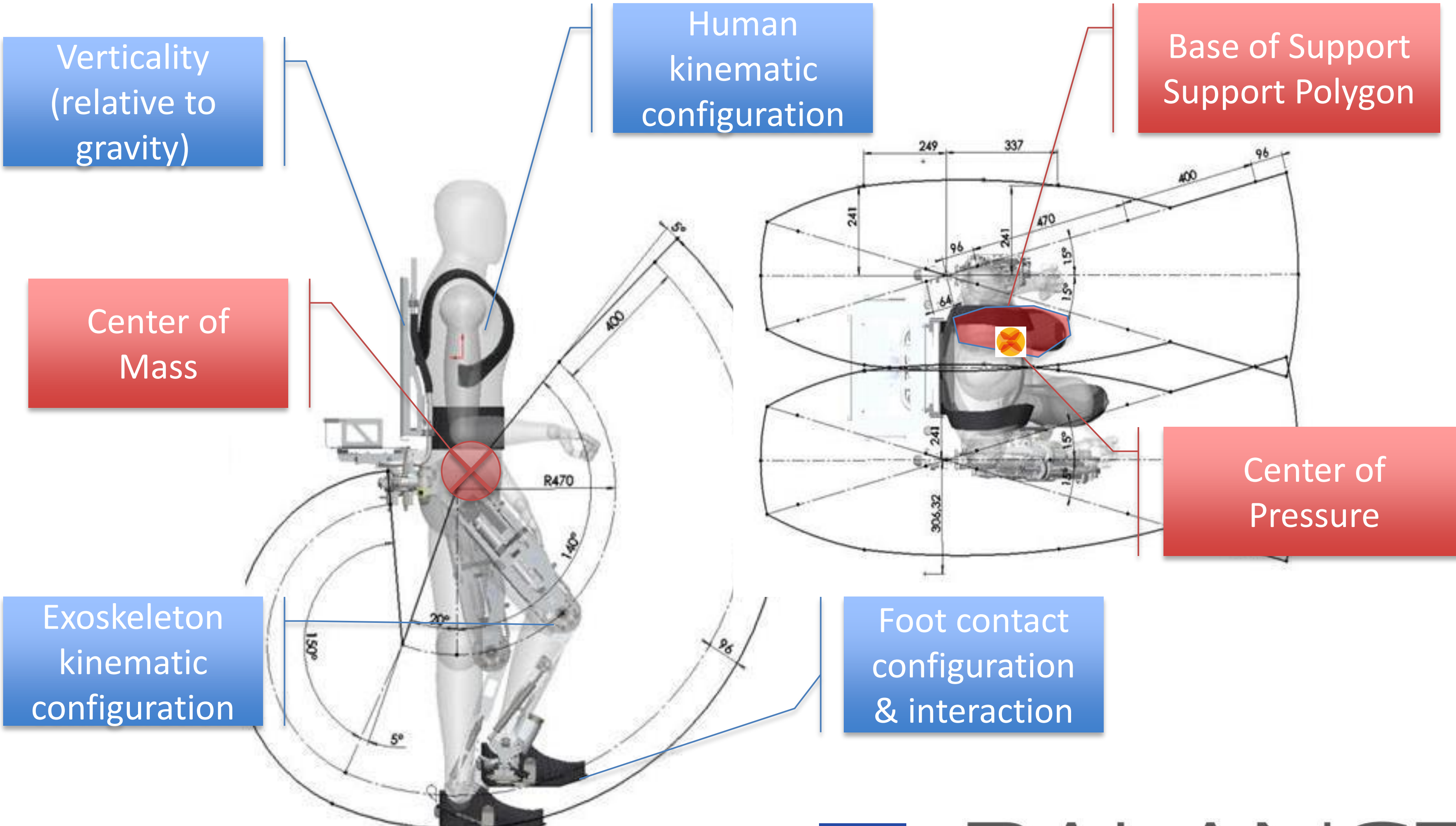
Adequate hardware and sensing environment



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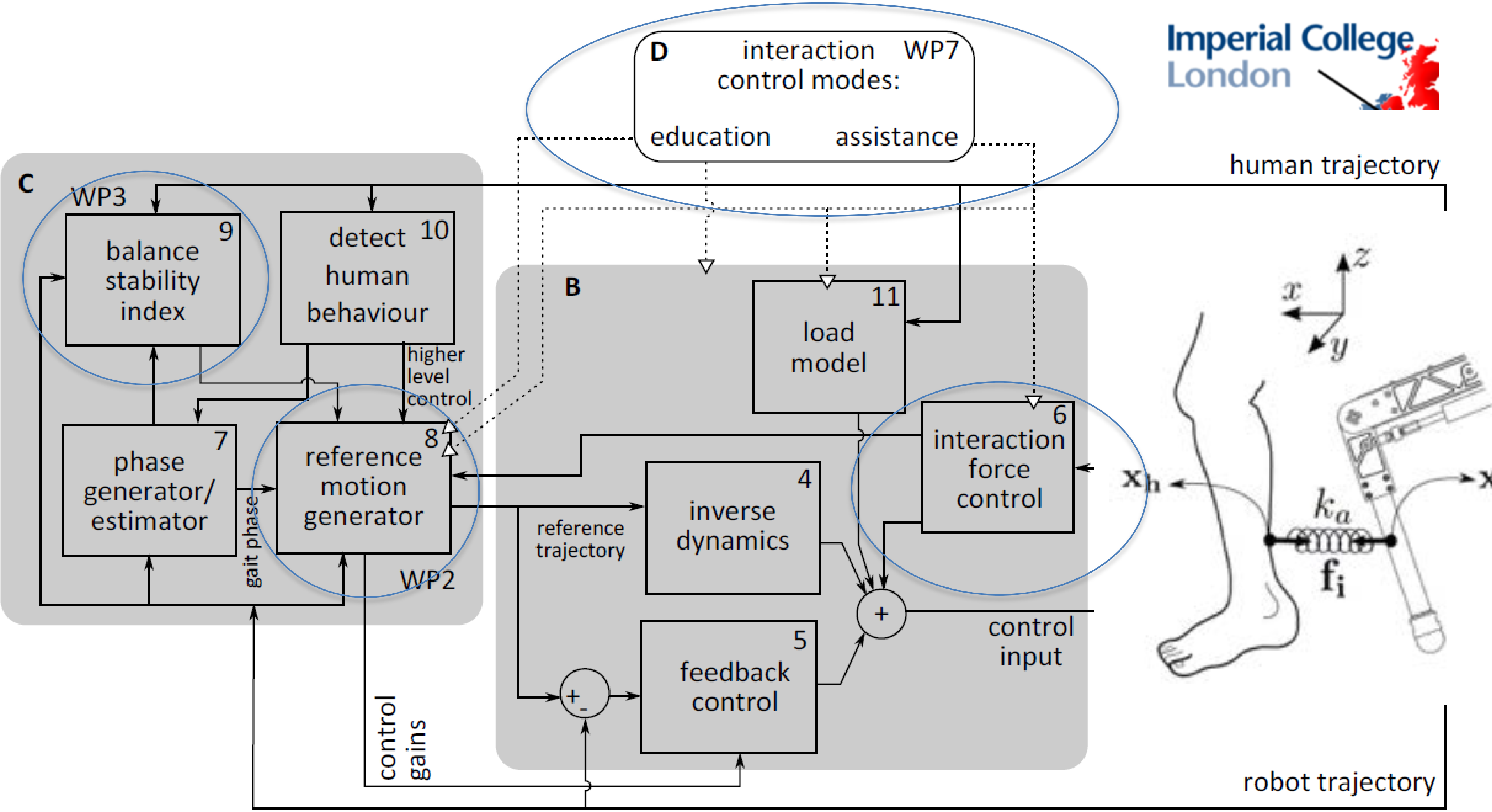
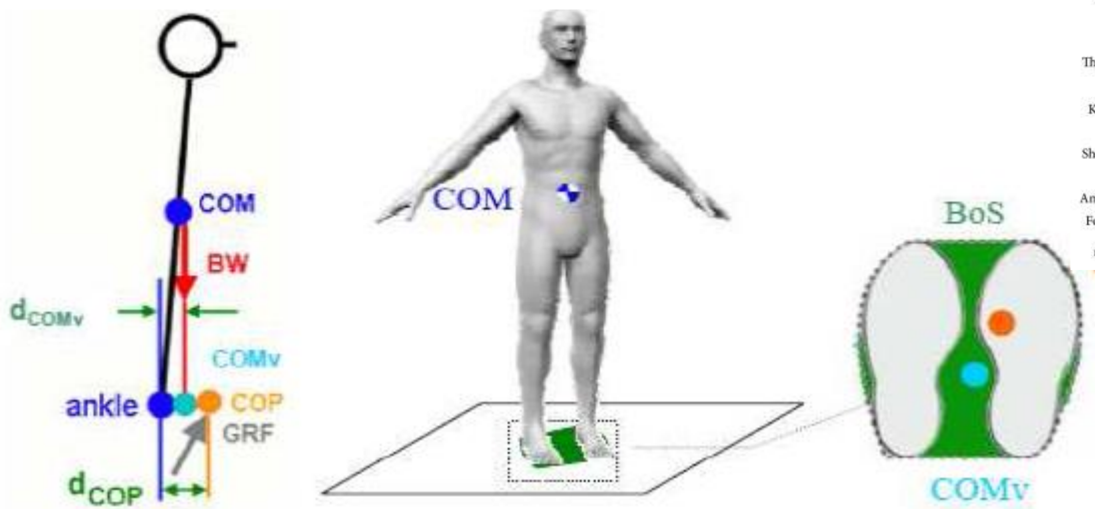
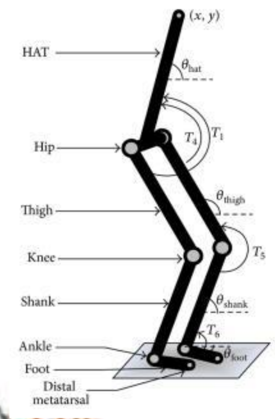
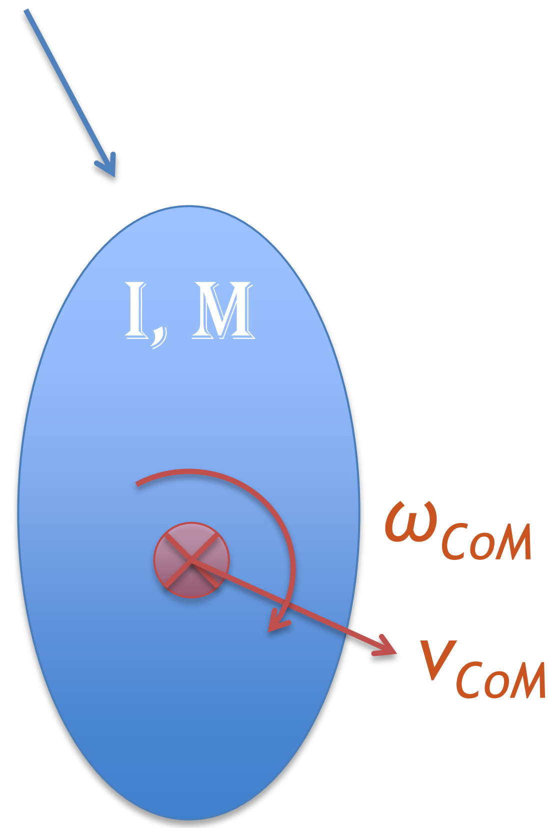

D
interaction control modes:
WP7
education
assistance
human trajectory
C
WP3
9
balance stability index
10
detect human behaviour
higher level control
7
phase generator/ estimator
gait phase
8
reference motion generator
WP2
control gains
B
11
load model
6
interaction force control
4
inverse dynamics
reference trajectory
5
feedback control
control input
x_h
k_a
f_i
robot trajectory

Sense, and quantify the quality of postural balance,

define a STABILITY INDEX.







Centroidal dynamics

CoM – CoP - BoS

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Preliminary validation

LOPES II Gait Rehabilitation Robot &
MVN Wearable IMU based mocap

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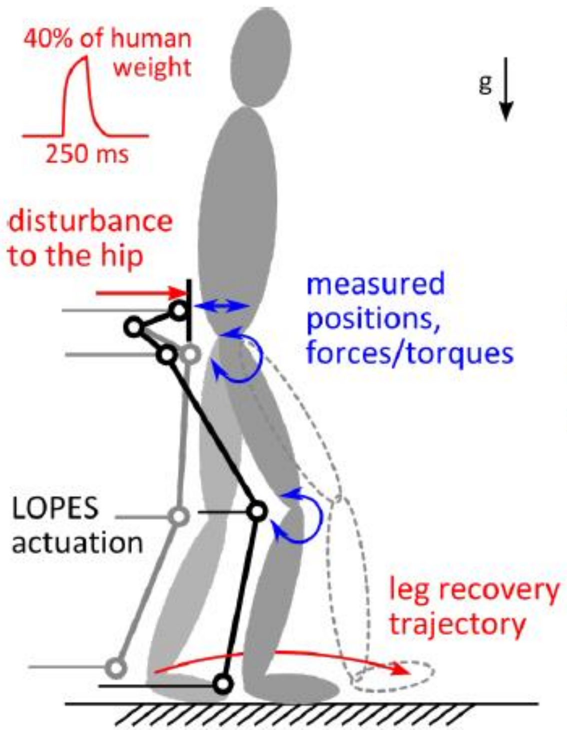
Initial balance recovery experiments

- Pelvis is perturbed by force
- Foot placement recovery trajectory is recorded
- PD-control is used to re-play the recorded trajectories with low or high gains



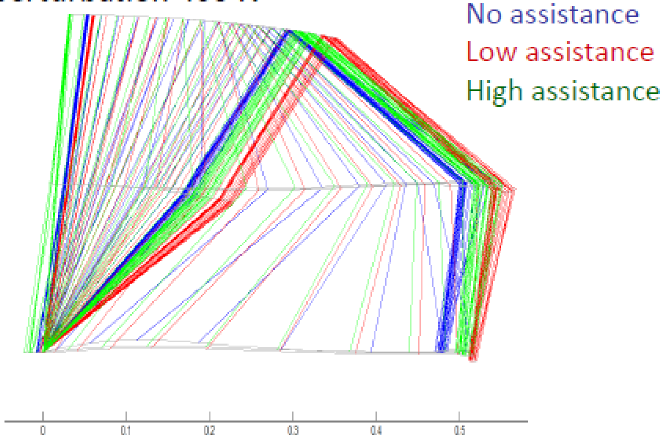
perturbation forces: 40% and 50% of subject weight

Test at Twente University

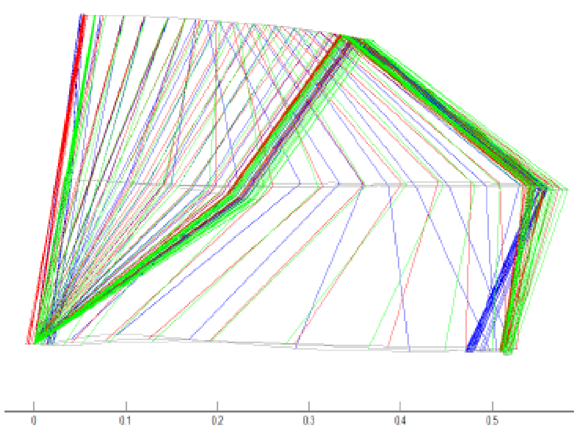
Preliminary results - recovery trajectory

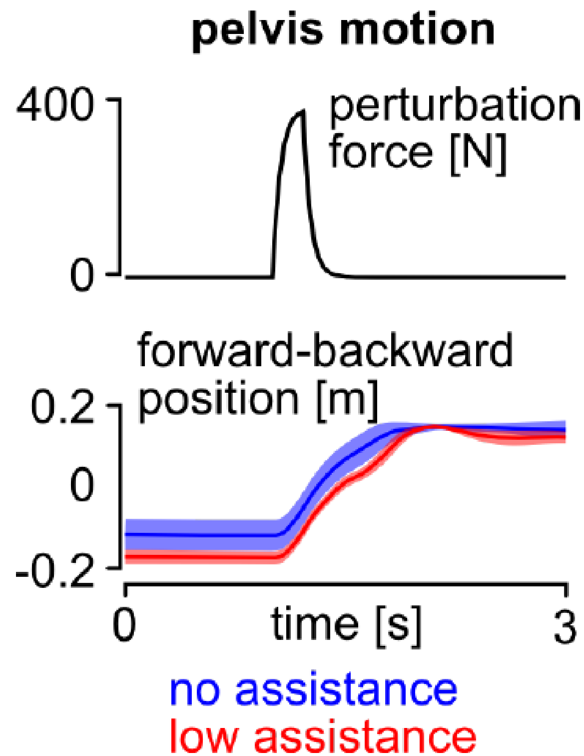
Imperial College London

perturbation 400 N



perturbation 450 N





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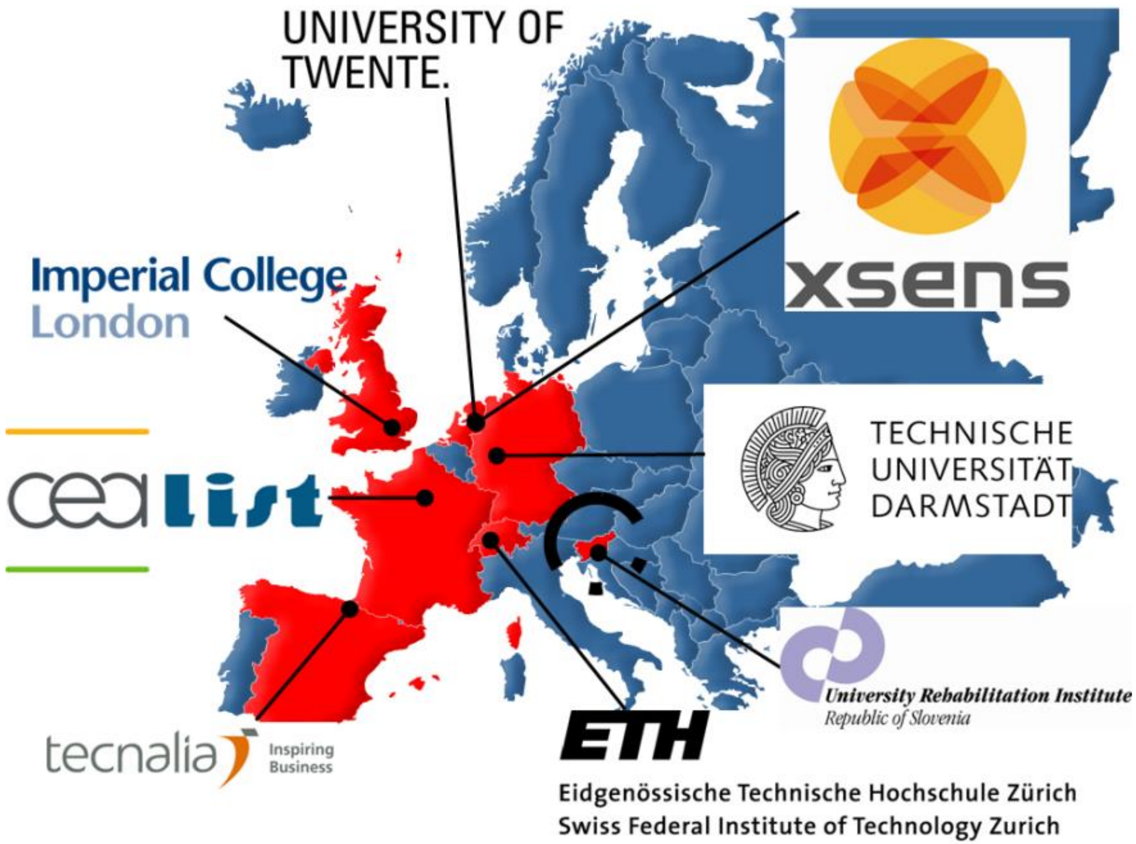
Consortium



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Web: balance-fp7.eu

EU FP7 funded: 2013-2017

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