CORBYS

Cognitive Control Framework for Robotic Systems

CORBYS: Mobile Robotic Gait Rehabilitation System

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SEVENTH FRAMEWORK PROGRAMME

CORBYS project ID card

EU FP7 ICT Cognitive Systems Large-Scale Integrating Project

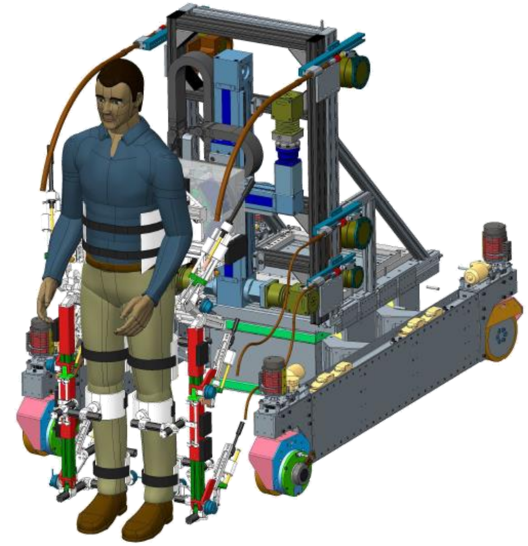
- Area: Cognitive Systems and Robotics (ICT-2009.2.1)
- Project reference: 270219
- Total cost: 8.76 million euro ; EU contribution: 6.1 million euro
- Project start: 1st February 2011; Duration: 48 months
- Consortium: 11 participants from 6 European countries

CORBYS - Objective

- To design, develop and validate an integrated cognitive robot control architecture **to support robot-human co-working with high level cognitive capabilities such as situation-awareness, attention control and goal-setting prioritization**
- Specifically, capability for optimal time-critical control:
  - in take-over/hand-over of goal-setting initiative **between robot and external agent**
  - based on **anticipation of purposeful behaviour of an external agent**
- CORBYS control architecture will be validated within **two challenging demonstrators**:
  - **a novel mobile robot-assisted gait rehabilitation system**
  - an existing autonomous robotic system for investigation of hazardous environment

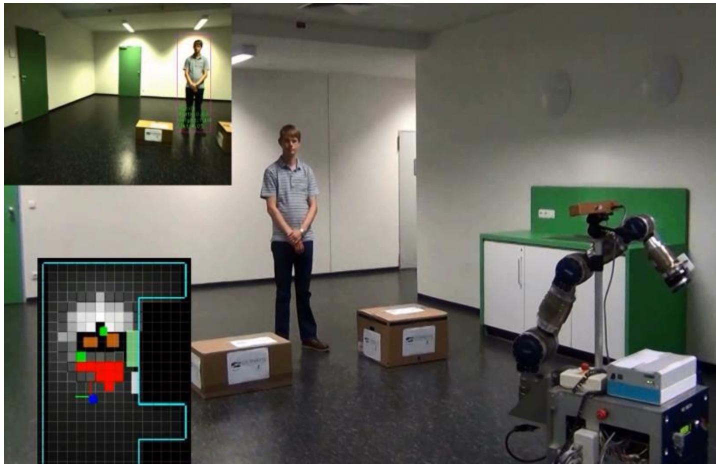
CORBYS Demonstrators

- **Cognitive mobile robotic gait-rehabilitation system to be developed in CORBYS**
  - Combination of a mobile platform and powered orthosis that is attached to the mobile platform
  - Integrates CORBYS cognitive modules
  - Advanced multi-sensor system
  - **Adapts to requirements and abilities of the user**



CAD model of the Demonstrator I

- **Cognitive robotic follower**
  - Follows human co-worker in investigation of environment
  - Preliminary integration of cognitive modules in CORBYS architecture
  - Here: empowerment based robotic (blue) following of human (green)



Scientific and Technical Objectives

CORBYS will extend State-of-the-Art in the following fields:

Sensing systems for assessing dynamic robot environments including humans

Self-awareness as a basis for adaptation of robot behaviour

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Anticipation in the context of a human-robot synergy

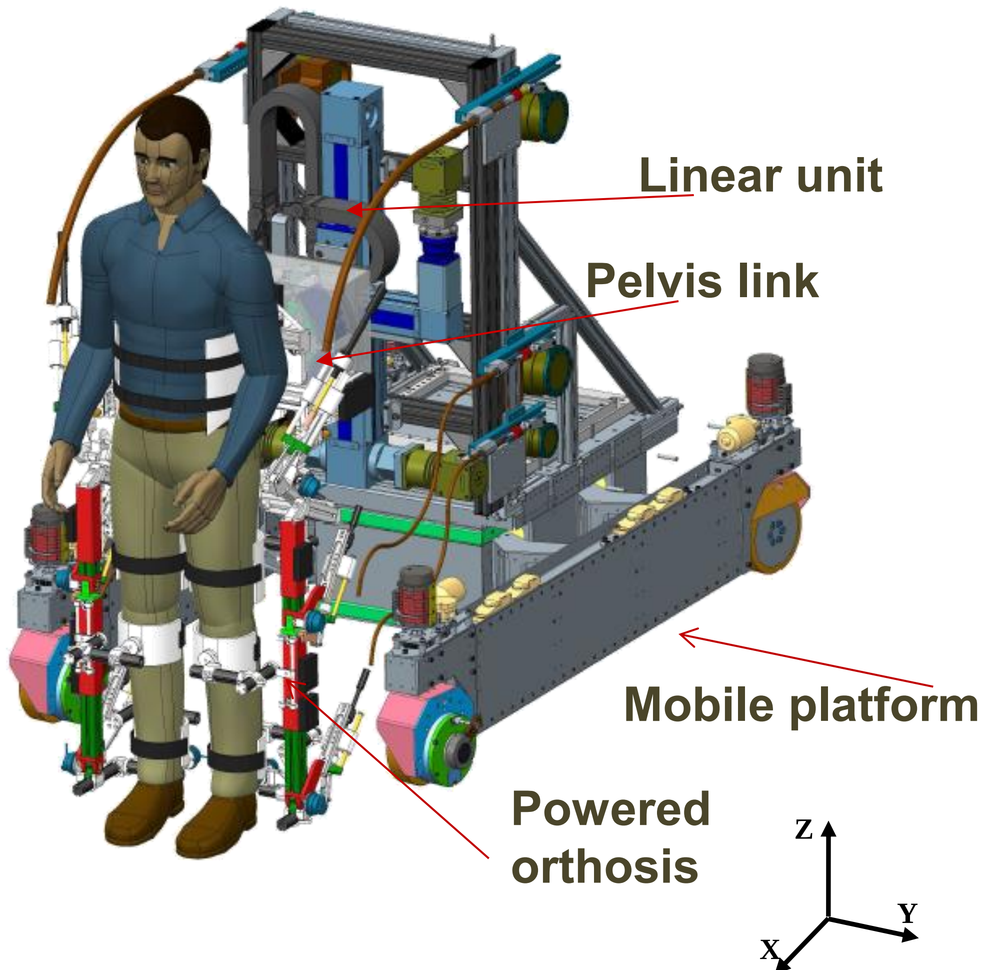
Cognitive robot control

Cognitive mobile robot-assisted gait rehabilitation

Partner	Role in the project
University of Bremen, Germany	Project Coordinator, Cognitive robot control architecture, BCI detection of cognitive processes
The University of Reading, United Kingdom	Situation Assessment Architecture, Evaluation methodology, benchmarking, metrics and procedures, Requirement engineering
University Rehabilitation Institute, Slovenia	Evaluation, clinical tests of subsystems and components, System integration
The University of Hertfordshire, United Kingdom	Self-Organizing Informational Anticipatory Architecture, anticipation of human behaviour and the creation of synergy with this behaviour
Vrije University Brussels, Belgium	Low-level robot control, System integration
Sintef, Norway	System integration and functional testing, Sensor network, Physiological monitoring
Otto Bock Mobility Solutions, Germany	Demonstrator development, design and development of the mobile platform of the CORBYS robot-assisted gait rehabilitation system
Neurological Rehabilitation Center Friedehorst, Germany	Evaluation, End-user requirements and ethical aspects
Bit&Brain Technologies SL, Spain	Sensing systems for assessing dynamic system environments including humans, Brain computer software architecture
SCHUNK, Germany	Design and integration of actuation system, smart and safe actuators, Sub-system conformance testing
Otto Bock Healthcare, Germany	Design and development of the orthotic system of the CORBYS robot-assisted gait rehabilitation system, Demonstration, integration and evaluation

CORBYS: Mobile Robotic Gait Rehabilitation System

Subsystem	Joint/Axis	Actuation
Mobile Platform	Wheel 1..4 (x-axis)	Driving wheels
	Steering 1..4 (z-axis)	Wheel orientation
Linear unit	z-axis	Linear motion to lift or lower patients body
	y-axis	Linear motion to move body sideways
Powered orthosis Left and right legs	Hip	Active extension and flexion
	Hip	Passive adduction/abduction
	Hip	Passive i../e. rotation
	Knee	Active extension and flexion
	Ankle	Active plantarflexion and dorsiflexion
	Ankle	Passive eversion and inversion



16 DOF to enable more natural walking!

System Overview

- 16 Actuated DoF (Mobile Platform, Orthosis, Vertical System)
- >50 sensors – system integrated and human-wearable (force cells, encoders, F/T sensor, current sensors, EEG, EMG, Hart-rate and etc.)
- Functional units / software sub-systems (SOIAA, SAWBB, RTC, BCI, HSS, RTDS)

Technologies used:

- Architecture: Robot Operating System ROS

- Real-time Control: OROCOS

- Algorithm development: MATLAB MathWorks

- Interfaces: EtherCAT EtherCAT

CANOpen CANopen

Ethernet

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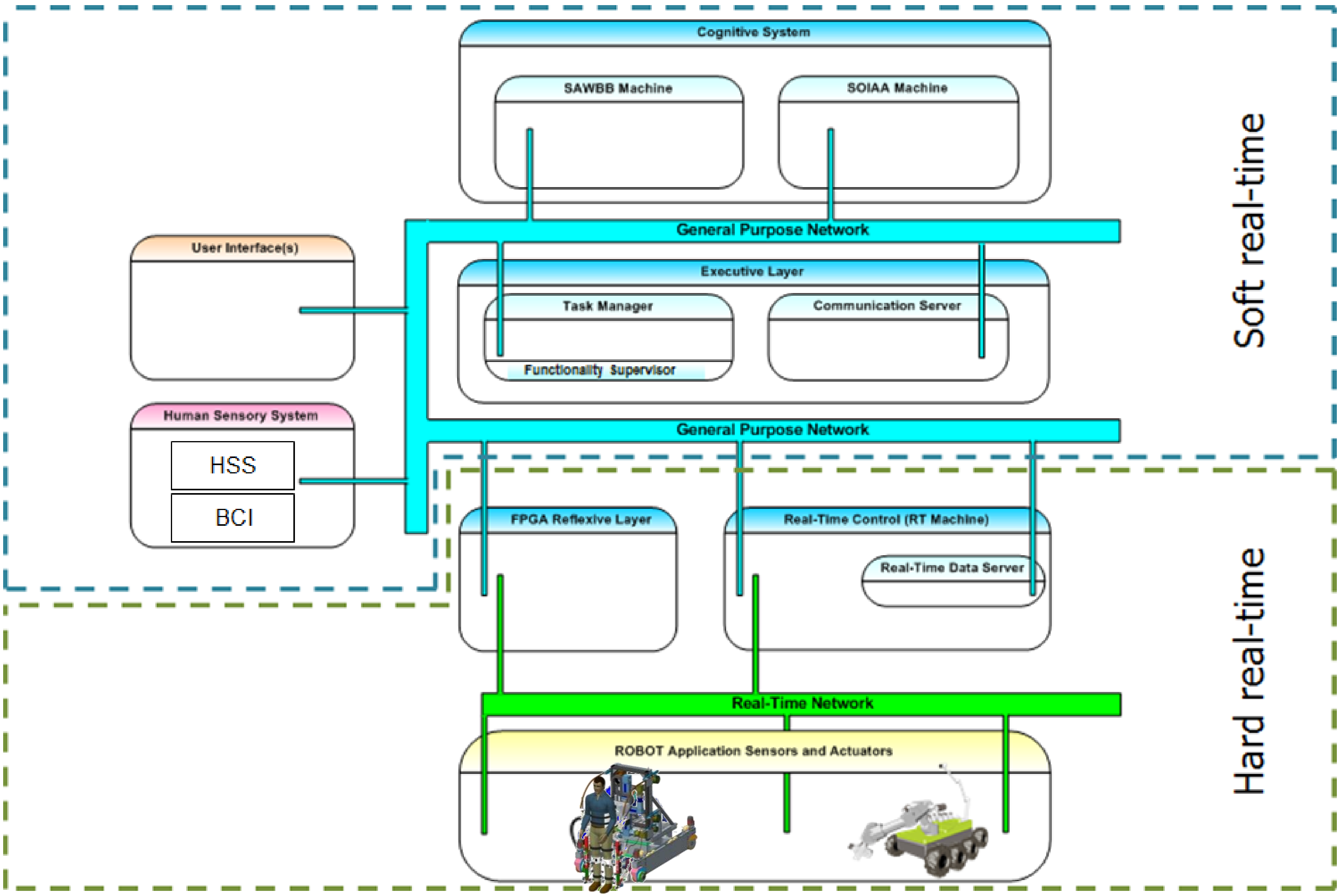
CORBYS architecture overview



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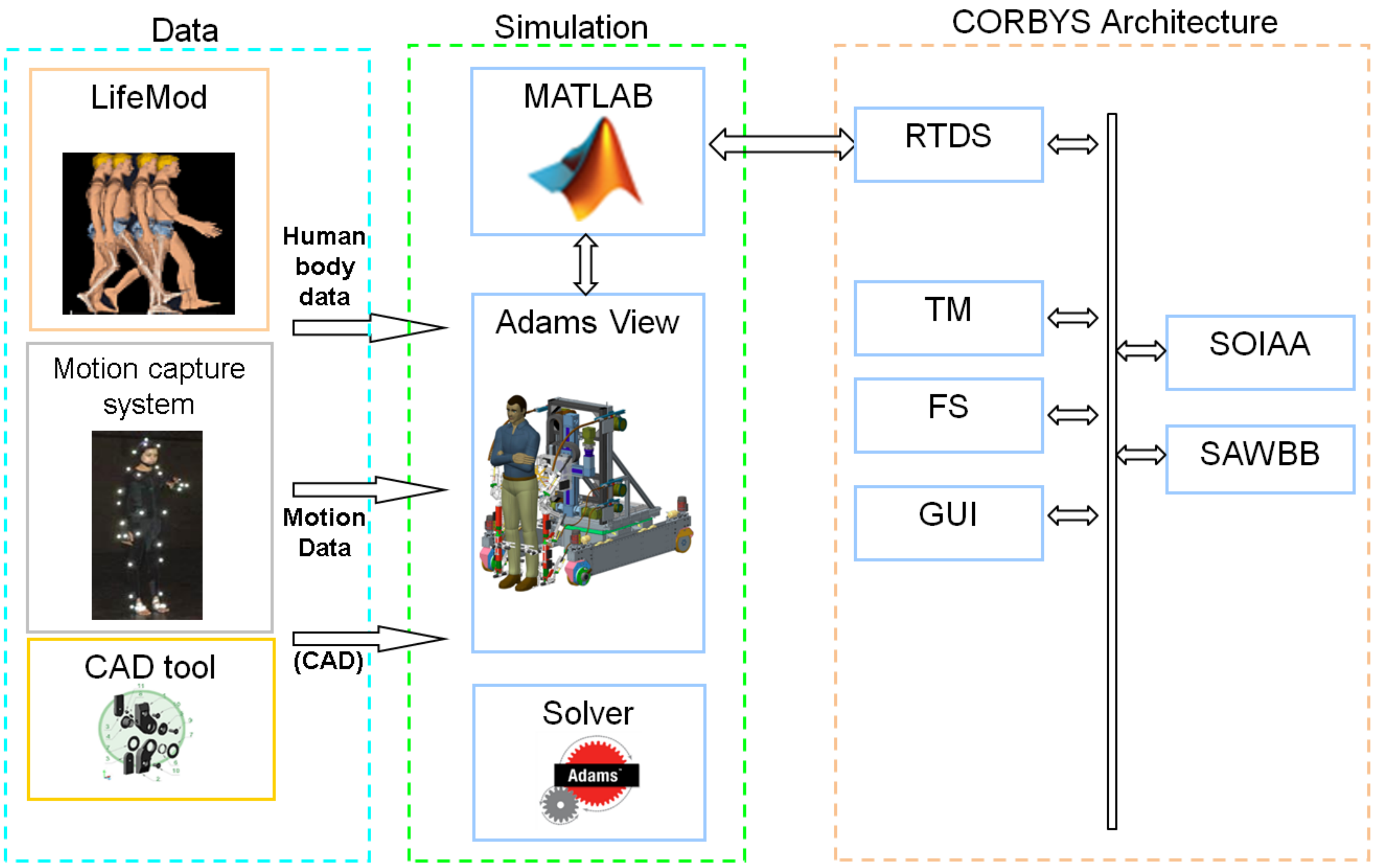
Simulation process overview



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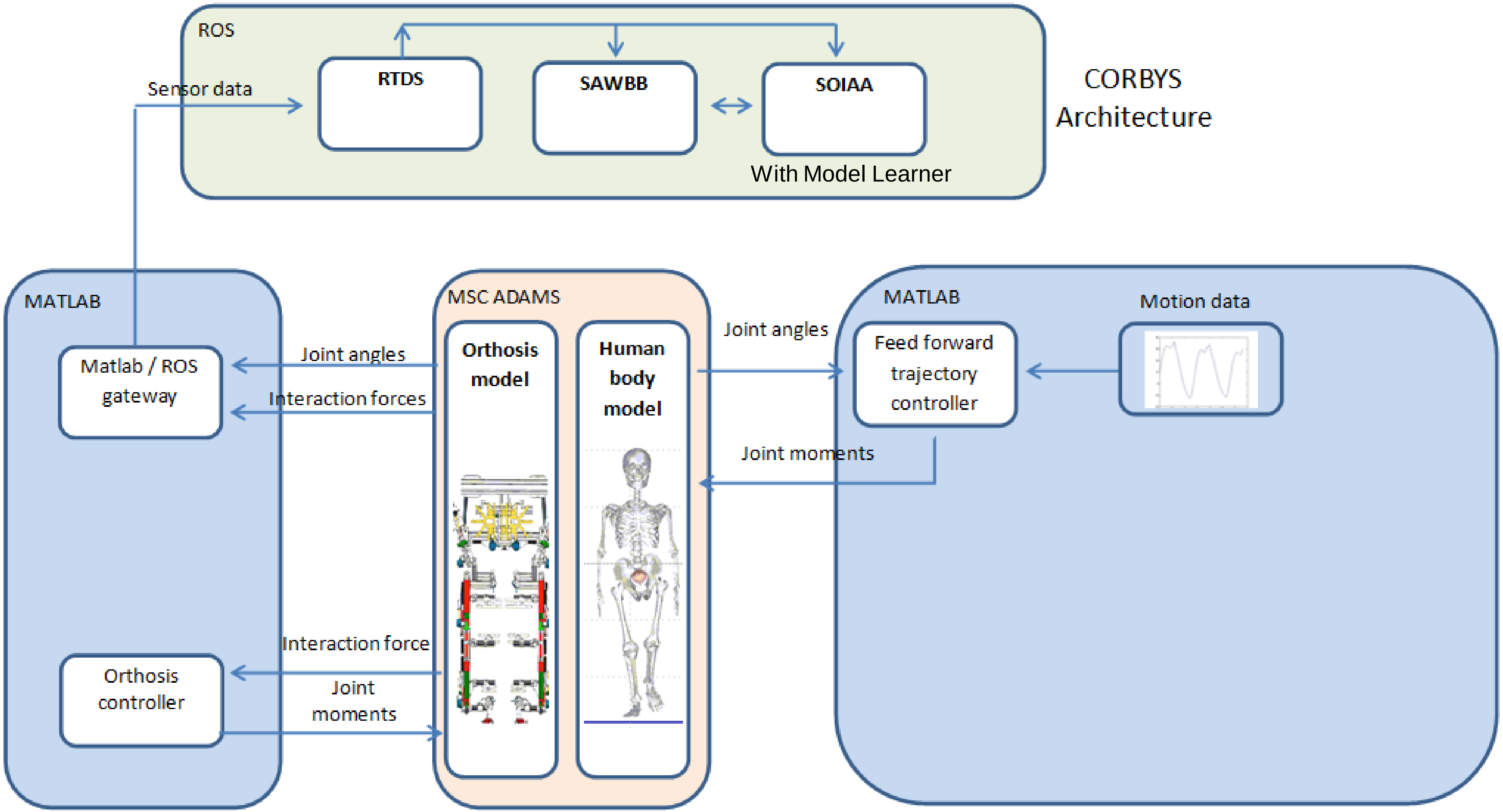
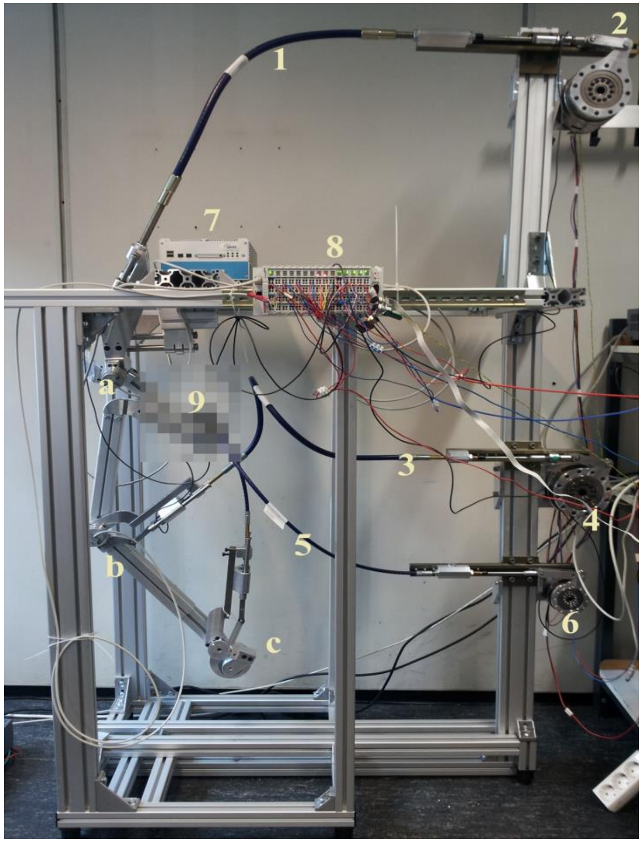
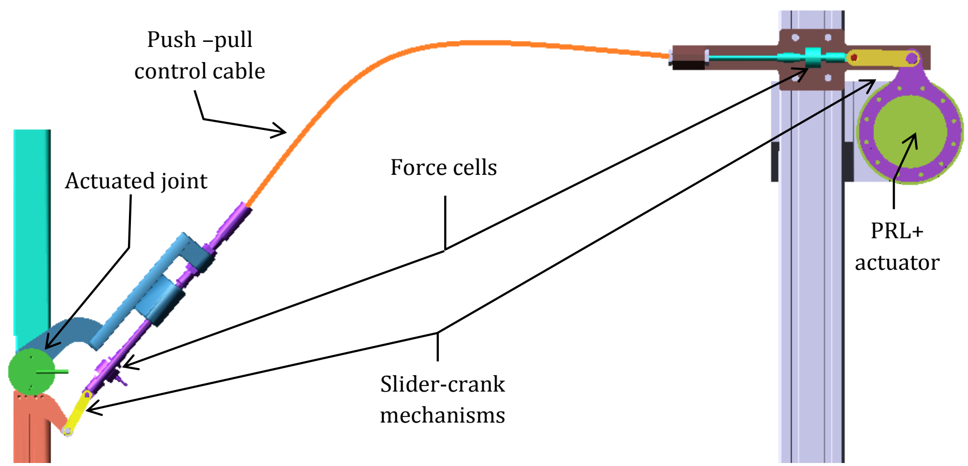
Simulation set-up for CORBYS control architecture



CORBYS orthosis actuation test stand

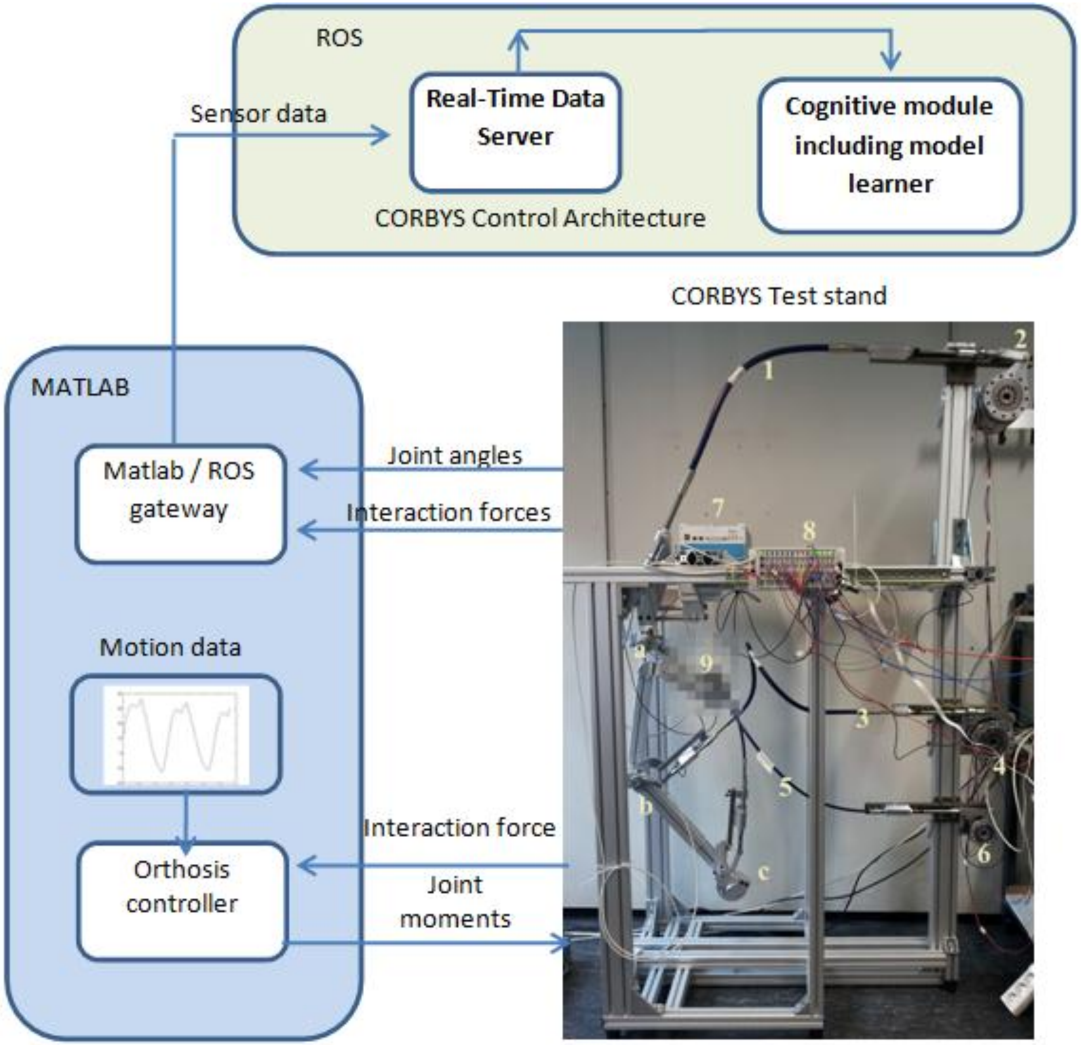


CAD representation of a single joint CORBYS actuation system



2, 4 and 6 – smart actuators of the ankle, hip and knee joint;
1, 3 and 5- the corresponding PPC cables;
7 - the xPC target computer;
8 - the EtherCAT terminal; a, b and c - the hip, knee and ankle joint respectively

Test stand set-up for CORBYS control architecture



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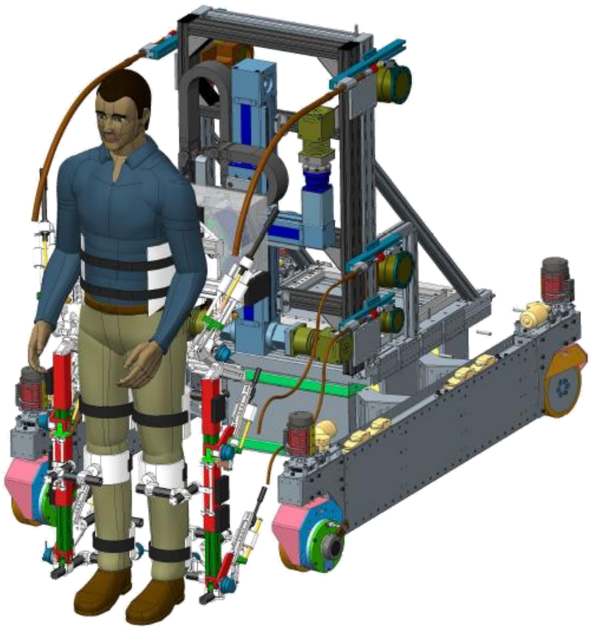
CORBYS cognitive mobile gait rehabilitation system

Operating modes

- Learning
  - treadmill-based walking
  - system learns native gait
  - system learns therapist assisted gait
- Corrective (straight walk mode)
  - over ground walking
  - system provides inputs for corrective actuation
- Parameter based adaptation
  (1st extension of straight walk mode)
  - Cognitive interaction between man and machine:
    detection of patient's intention to stop or to speed up
  - system provides inputs for corrective pattern based on detection
- Adaptive walking
  (2nd extension of straight walk mode)
  - Cognitive interaction between man and machine:
    recognition of patient's intended movement
  - system provides inputs for parameter-based, intra-cycle adaptation



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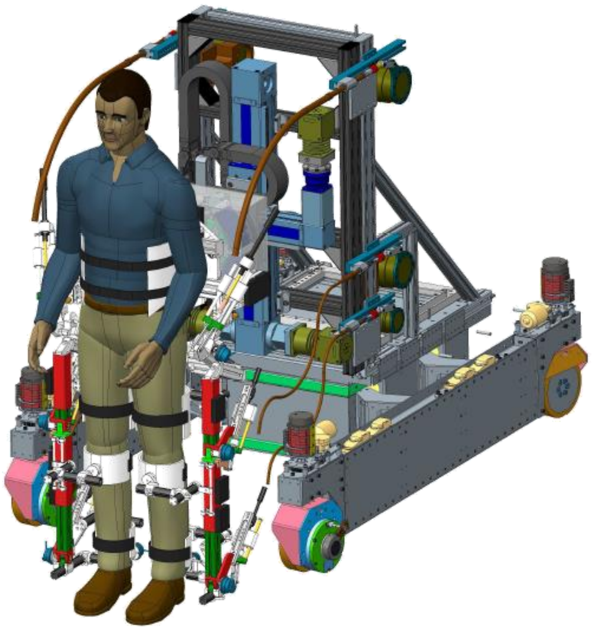

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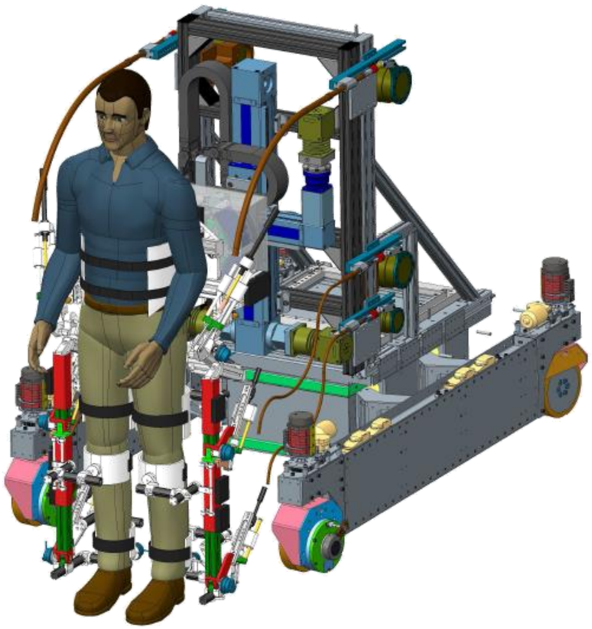

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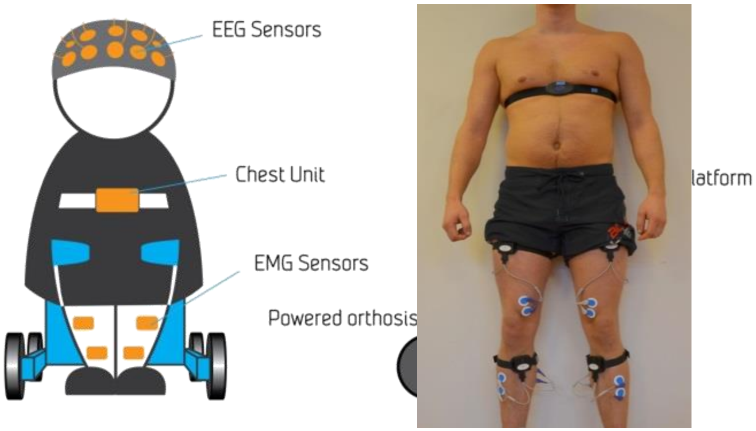
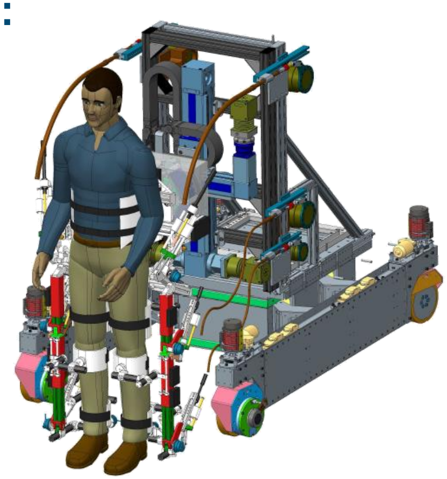
Sensor supported gait learning



Human body wearable sensors

System sensors: encoders, force sensors



SAWBB-situation assessment

SOIAA (anticipation)-gait trajectory generation

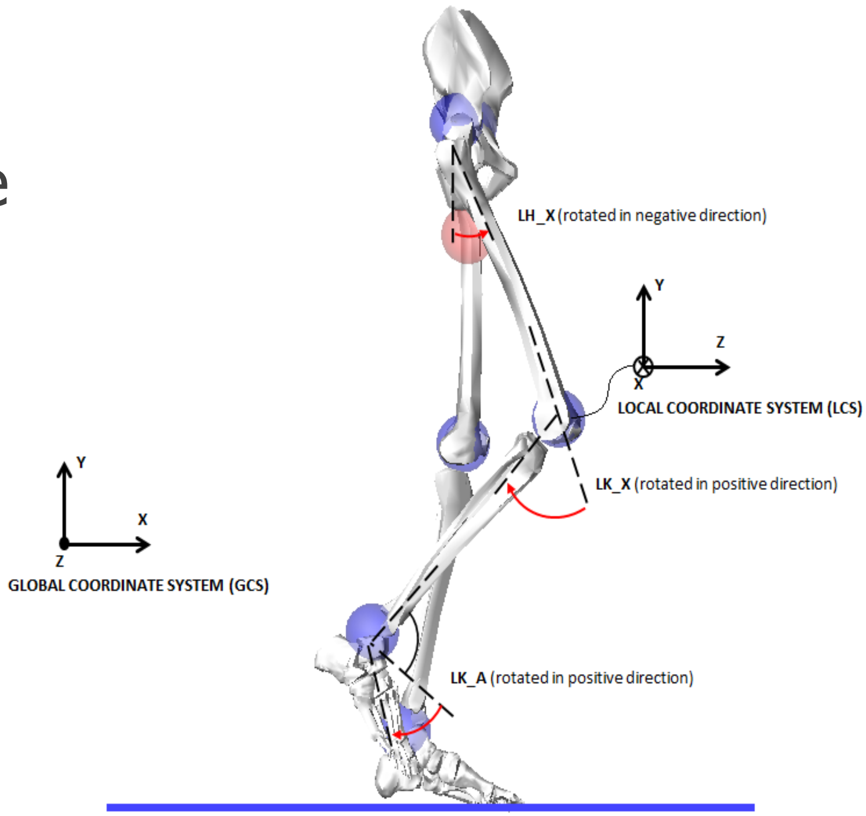
Gait pattern

Assistance level

Real-time robot control

Learning Gait

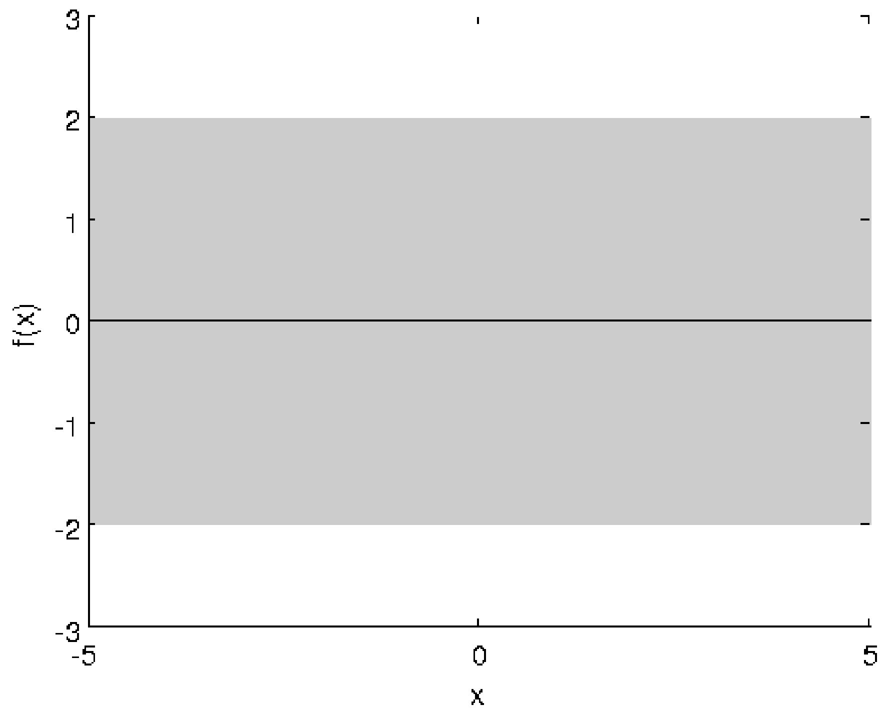
- No two people walk alike. They can be reliably identified by way they place their feet.
- CORBYS gait rehabilitation system will learn each patient's gait.
- CORBYS will seek to mimic the activity of an experienced therapist.



Learning Gait

- What is a suitable machine learning paradigm for a learning gait?
  - Can't be iterative (too slow)
  - It's accuracy can't depend on random initialisation (too unpredictable)
  - It can't have too many parameters to tune (too slow)
- Gaussian Processes meet all of these requirements.
  - State-of-the-art non-parametric Bayesian Regression method
  - Kernel machine
  - Probability distribution over functions
  - Fully specified by Mean and Covariance functions

Intuitive Interpretation of GP Regression



Prior belief about the function

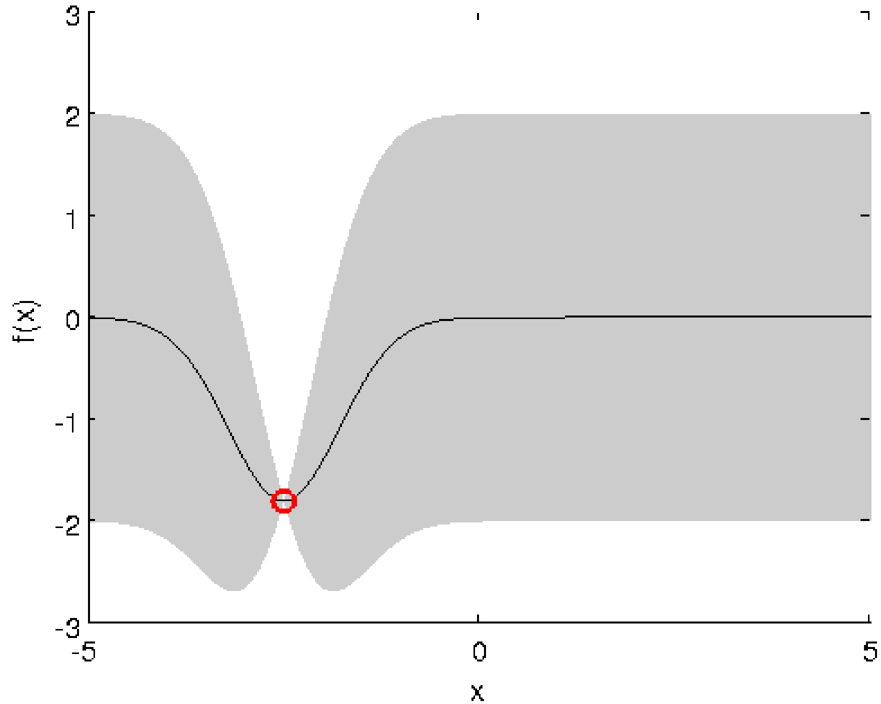
We want to learn gait i.e. how the different joint angles change over time

Predictive (marginal) mean and variance:

$$\mathbb{E}[f(x_*)|\emptyset] = m(x_*) = 0$$

$$\mathbb{V}[f(x_*)|\emptyset] = \sigma^2(x_*) = Cov[f(x_*), f(x_*)] = k(x_*, x_*)$$

Intuitive Interpretation of GP Regression



Each gait sample improves our understanding of a patient's gait

Posterior belief about the function

Predictive (marginal) mean and variance:

$$\mathbb{E}[f(x_*)|\emptyset] = m(x_*) = k(X, x_*)^T k(X, X)^{-1} y$$

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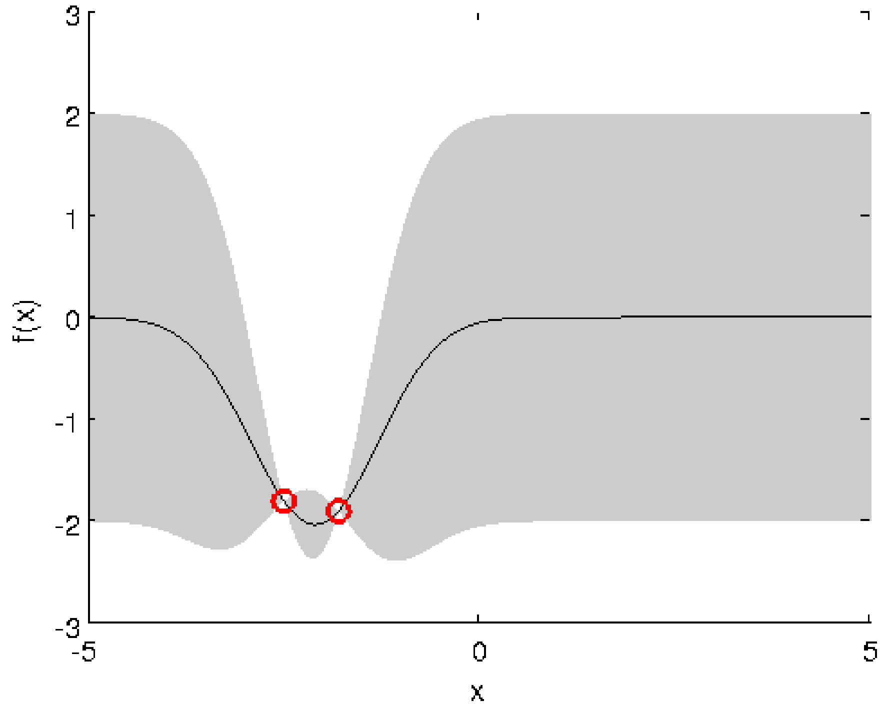

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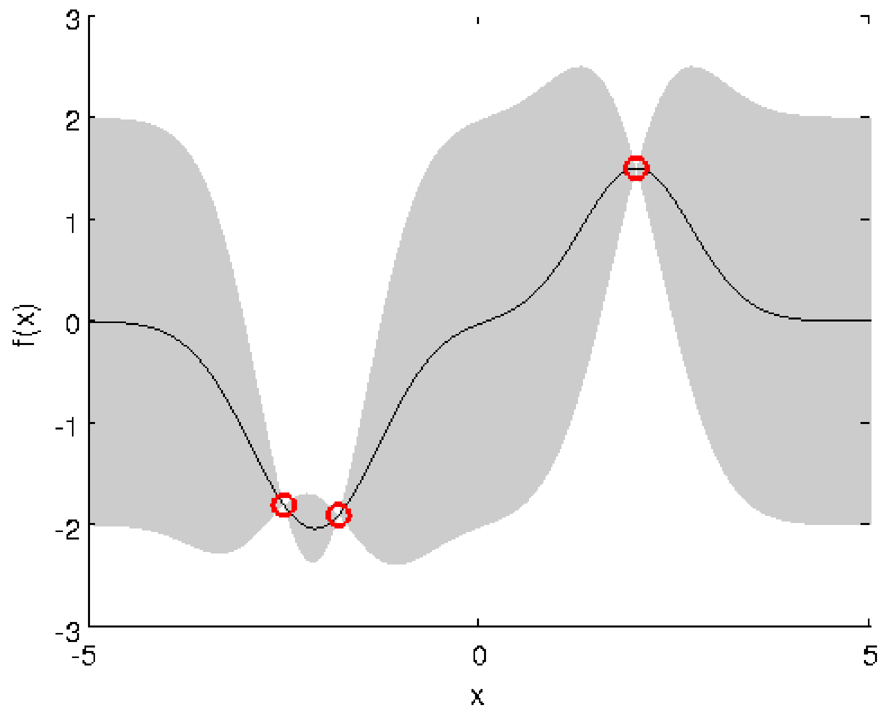

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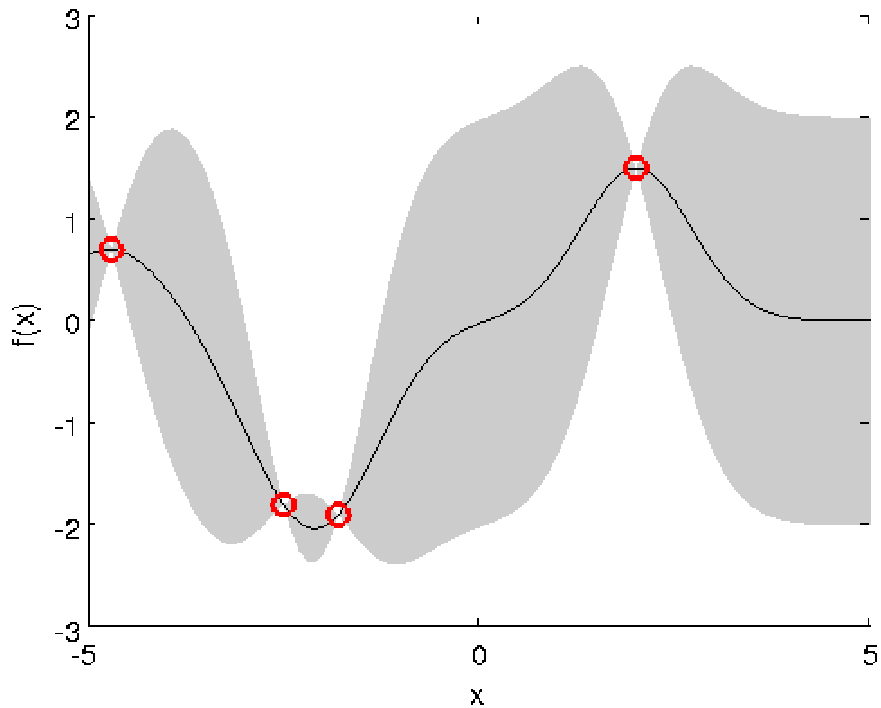

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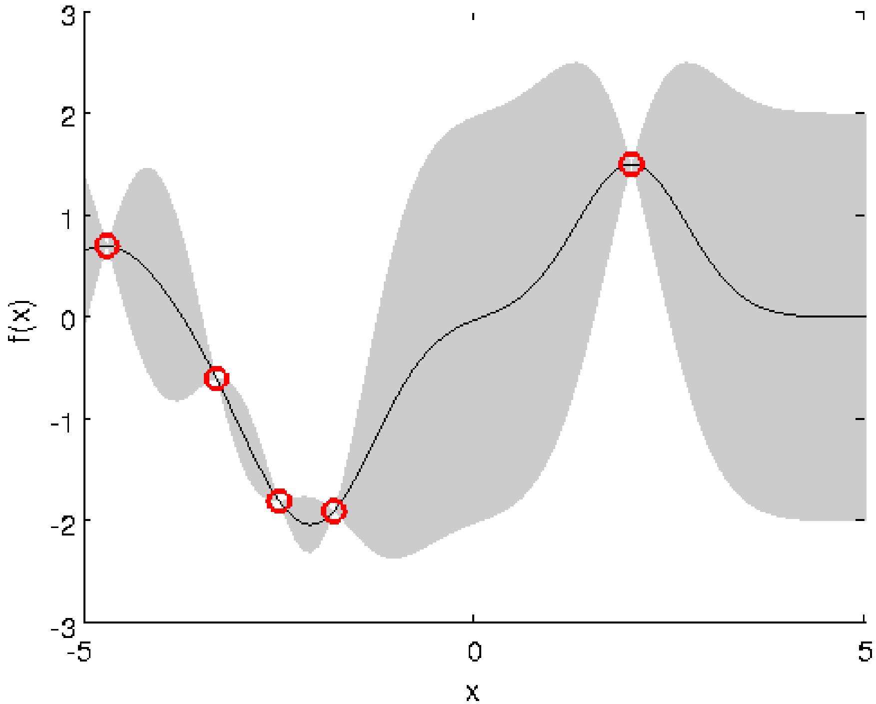

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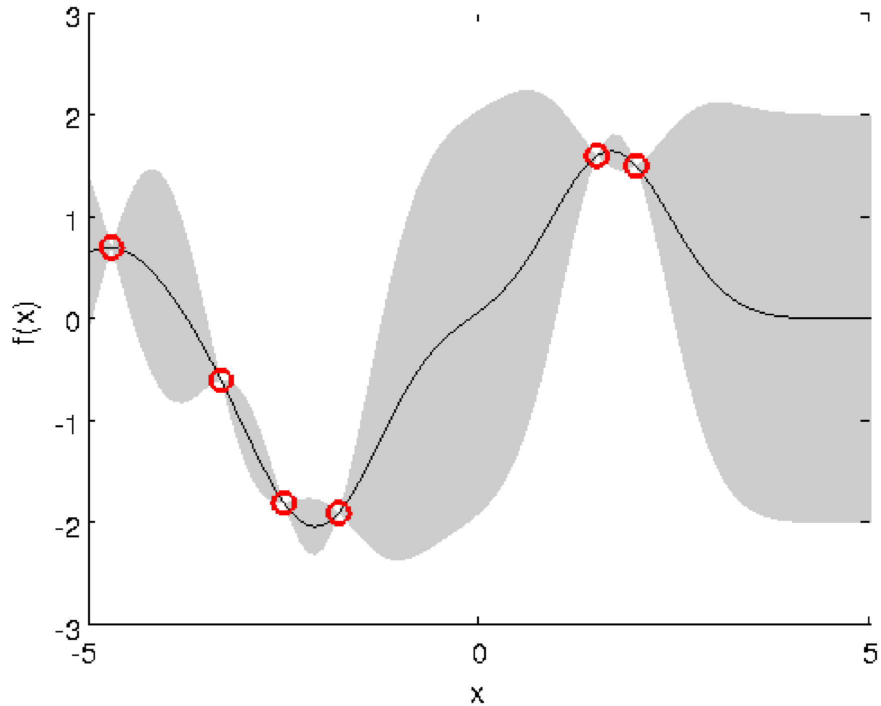

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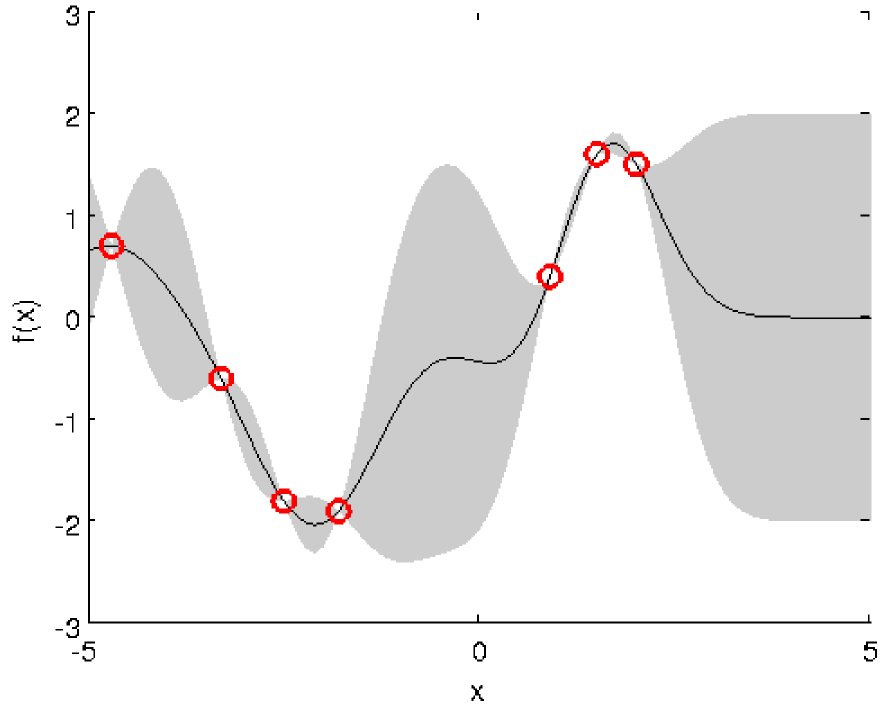

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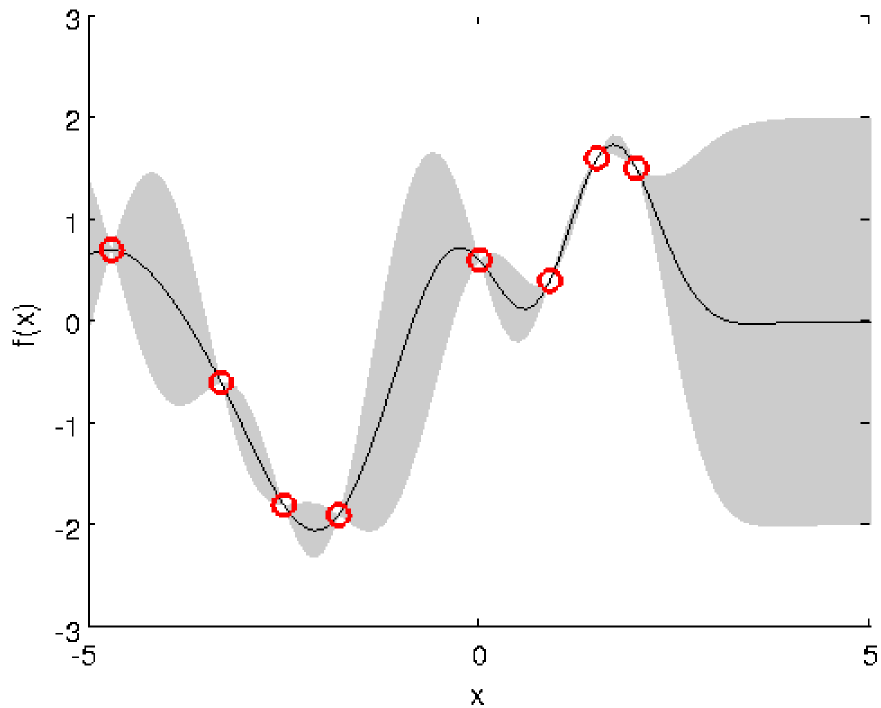

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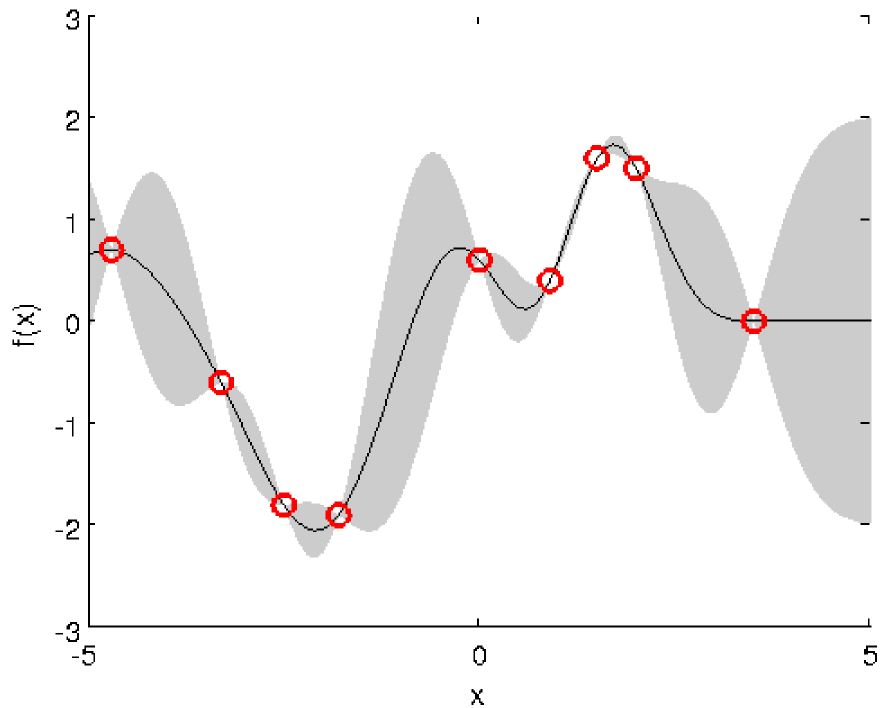

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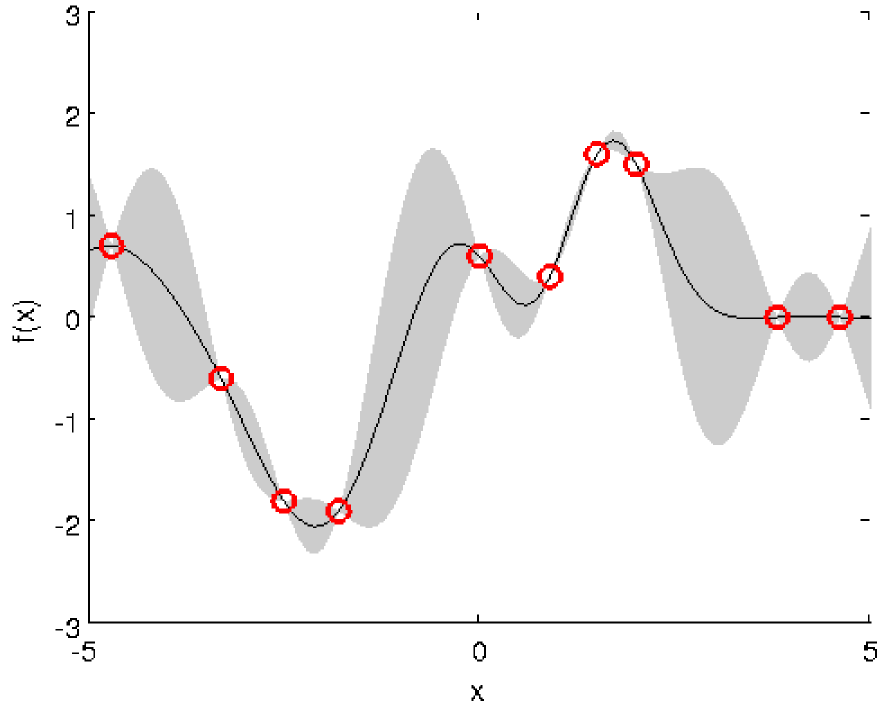

Now the system has learned gait!

Ready to send as set points to low-level control.

Posterior belief about the function

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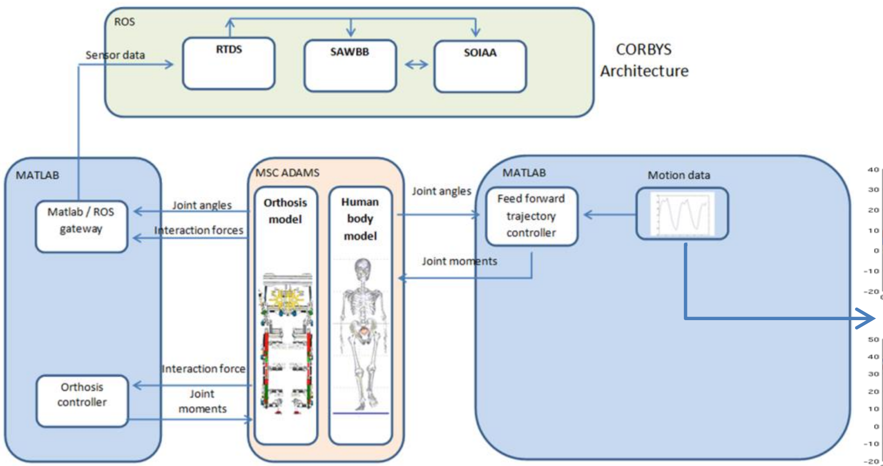
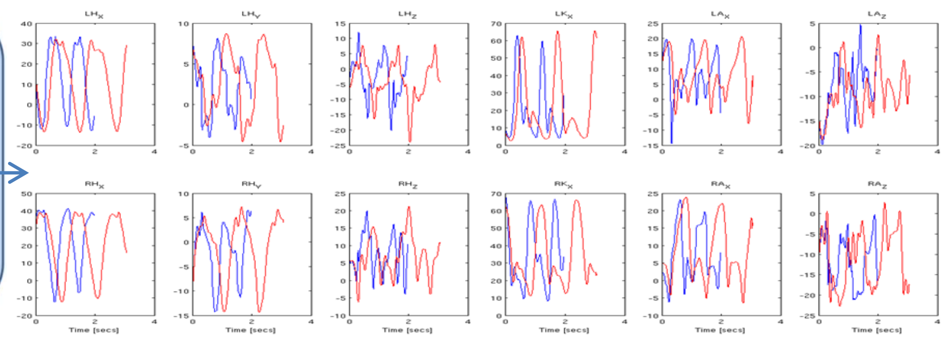
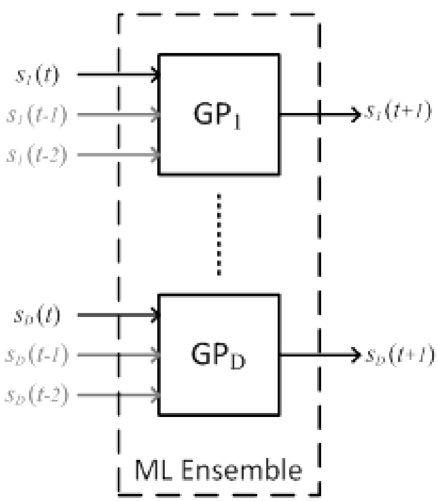
Generalising Gait

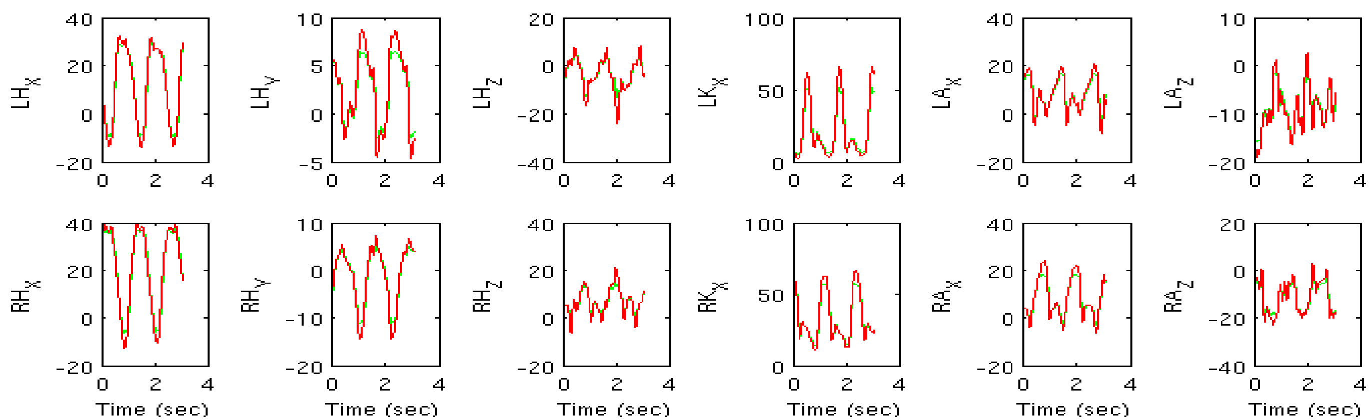


Different walking speeds, and variations in amplitude for the same patient!





Unseen testing results:



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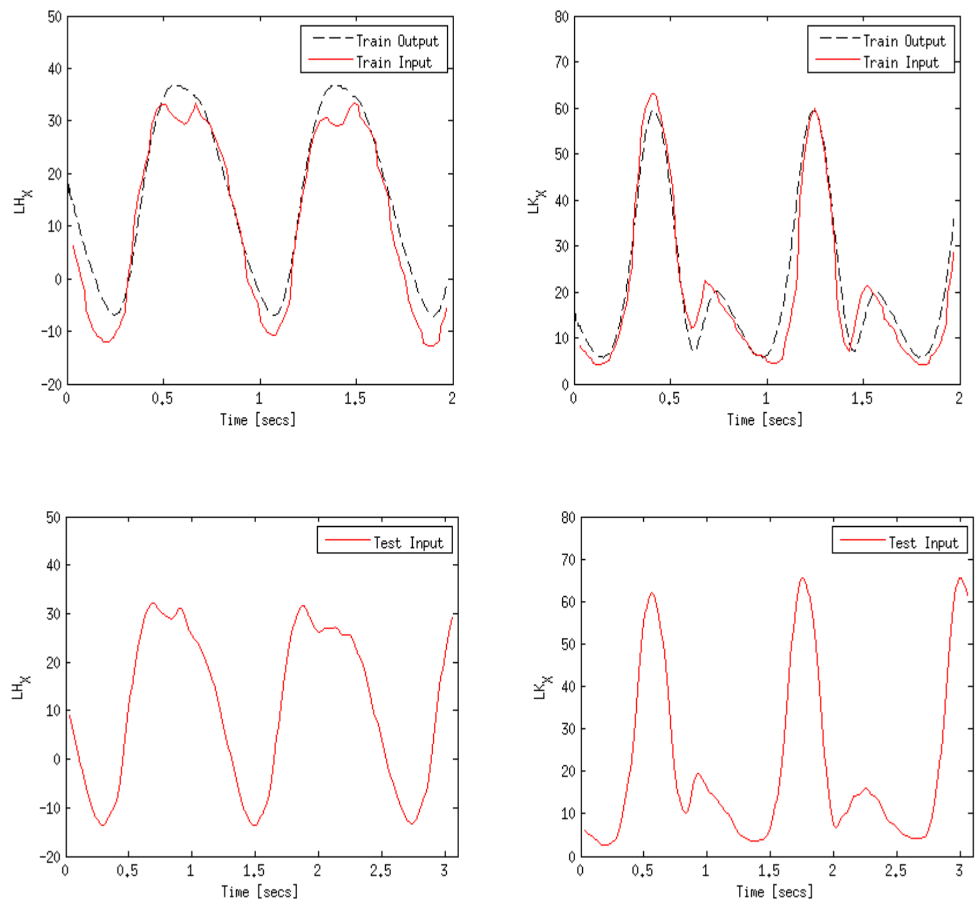
Learning the Therapist-assisted Gait

relationship between native and therapist-assisted gait

- Can the GP methodology be used to adapt native gait in line with therapist assistance?
- Can it do this whilst still generalising for different walking speeds?

LEARNING MODE



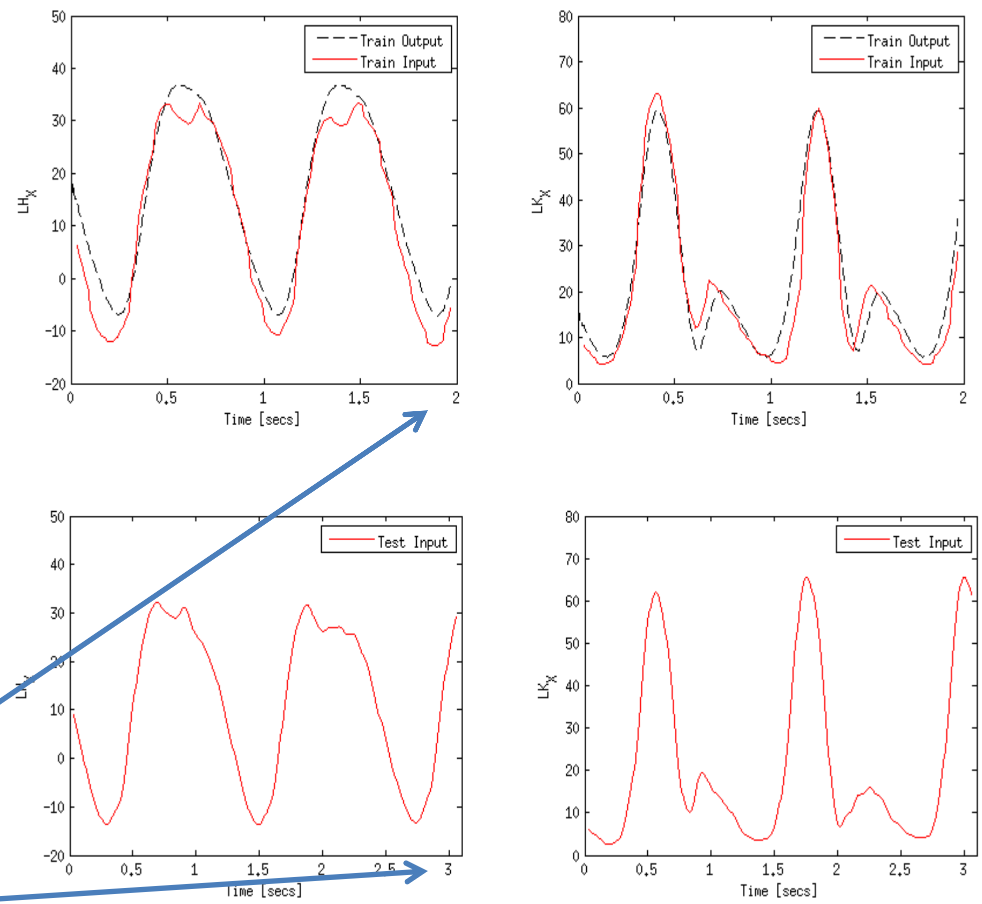
LATER OPERATING MODES

Learning the Therapist-assisted Gait

relationship between native and therapist-assisted gait

- Can the GP methodology be used to adapt native gait in line with what a therapist wants?
- Can it do this whilst still generalising for different walking speeds?

LEARNING MODE



Different walking speeds!

LATER OPERATING MODES

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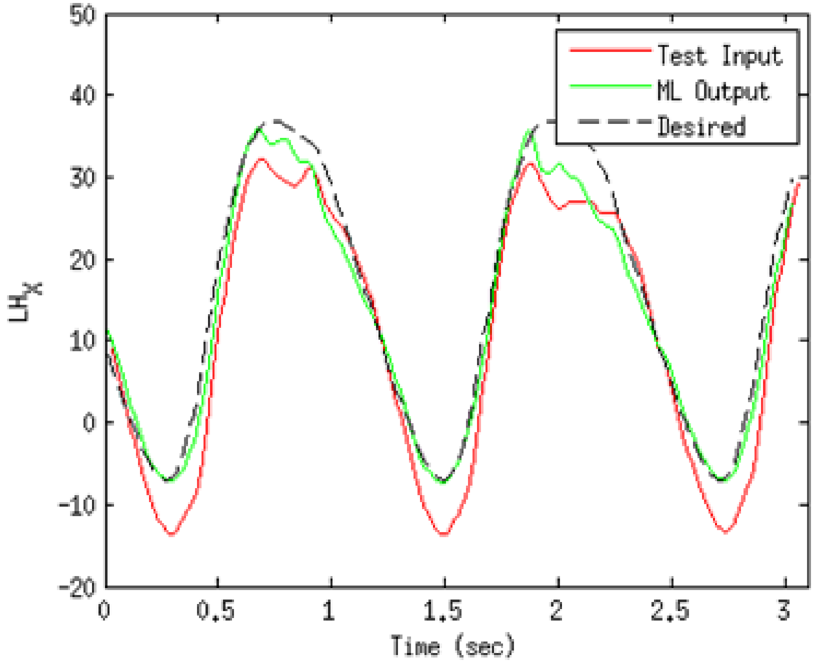

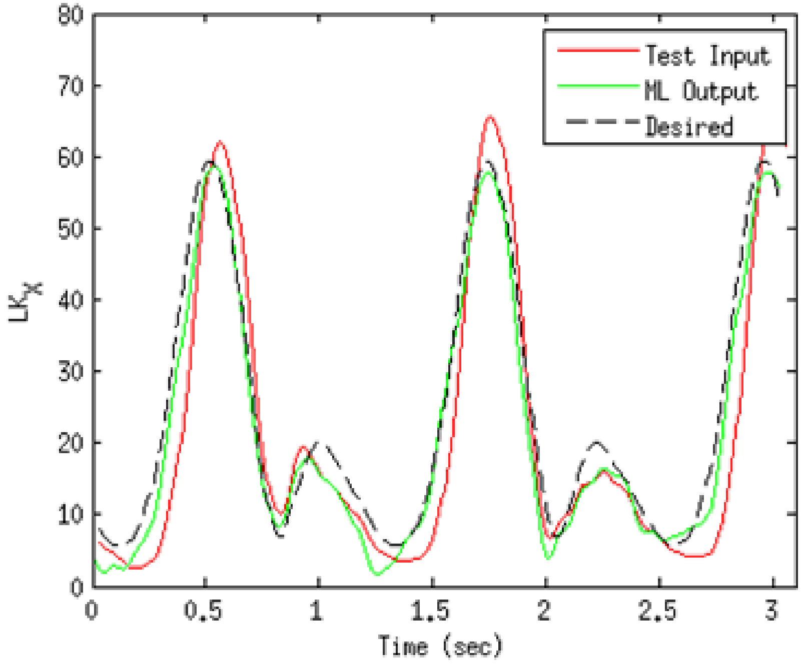

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C. Glackin, C. Salge, M. Greaves, D. Polani, S. Slavnić, D. Ristić-Durrant, A. Leu and Z. Matjačić, "Gait Trajectory Generation using a Gaussian Process-based Model Learner for Powered Orthosis Control," *Robotics and Autonomous Systems* (submitted)

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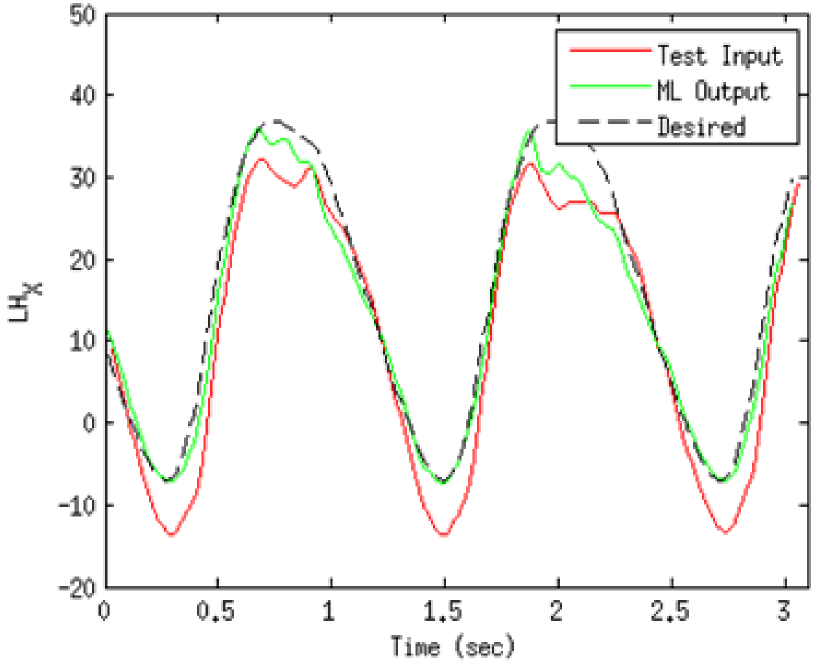

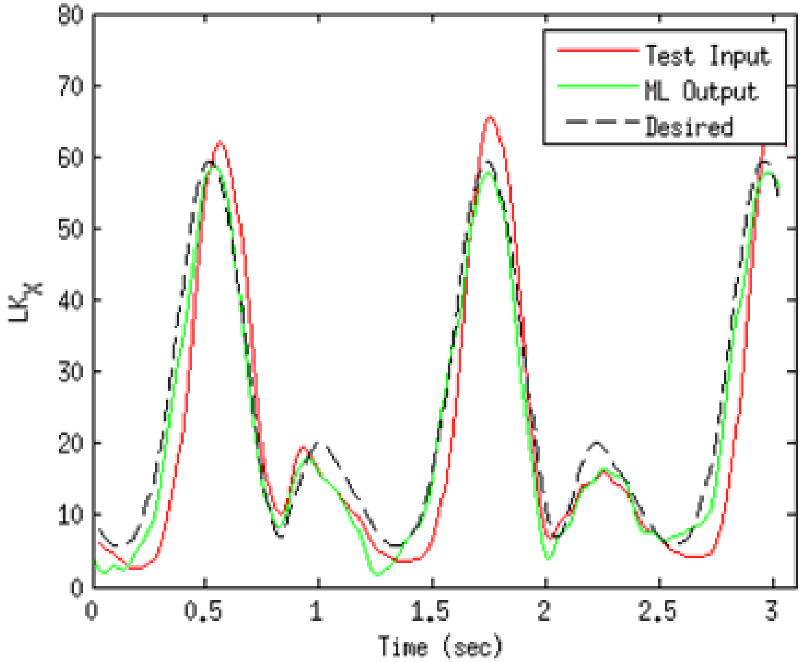

Now we have learned how to generalise the therapist assisted gait!

C. Glackin, C. Salge, M. Greaves, D. Polani, S. Slavnić, D. Ristić-Durrant, A. Leu and Z. Matjačić, "Gait Trajectory Generation using a Gaussian Process-based Model Learner for Powered Orthosis Control," *Robotics and Autonomous Systems* (submitted)

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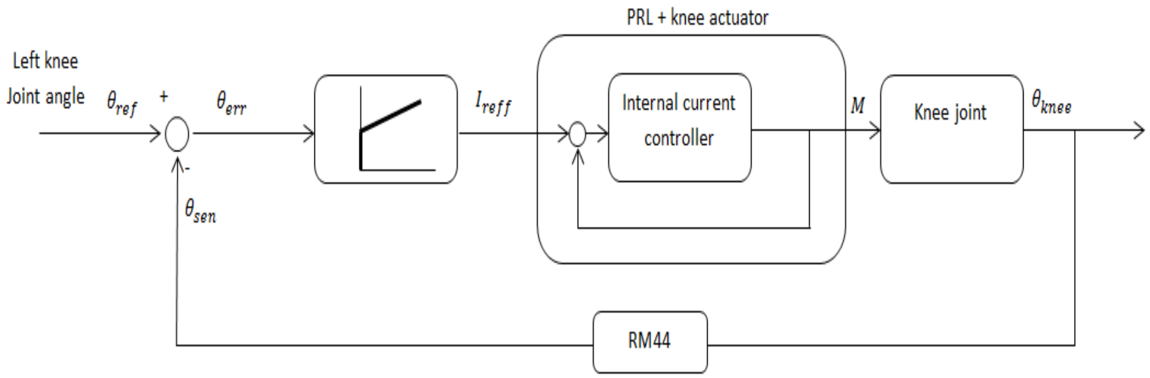
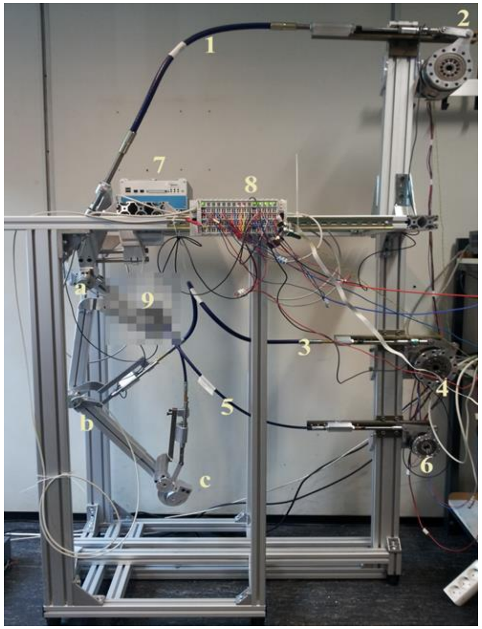
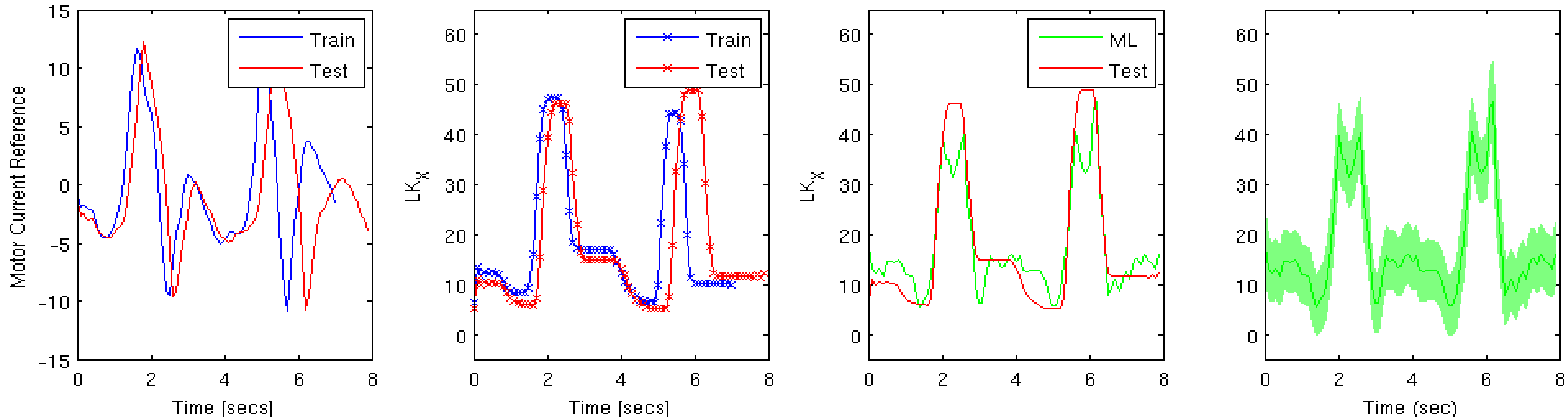
Interfacing the Gait Learner with Control

Relationship between the model learner and control







CORBYS cognitive mobile gait rehabilitation system

- We presented the CORBYS gait rehabilitation system.
- Natural walking requires a good understanding of the complex interactions between human and robot.
- Cognitive modules are necessary to support this complex human-robot interaction.
- The CORBYS system seeks a comprehensive understanding of state-of-the-art technologies necessary to bring such a system to market.

Thank you for your attention!