Flexible Assistive Robots through AFO-Based Intention Detection

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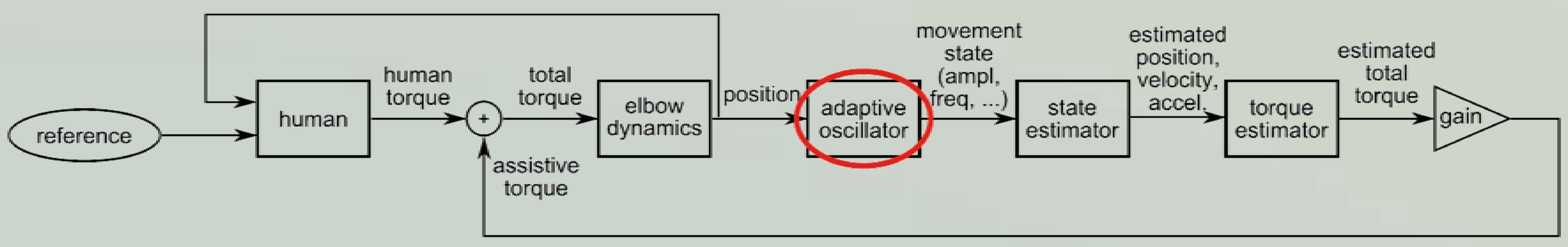
Introduction – Rhythmic Movement Assistance

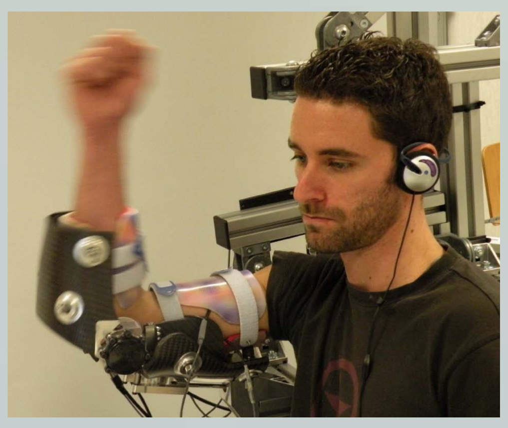
We present a new method for providing robot-mediated assistance during cyclical movements, developed in the framework of the EVRYON project. This method is both trajectory-free, in the sense that it provides assistance to the user irrespective of the performed movement, and requires no other sensing that the assistance robot's own encoders. The approach is based on adaptive oscillators, i.e. mathematical tools that are capable of learning the high level features (frequency, envelope,. . .) of a periodic input signal. Here we present two applications of this method that we recently conducted to validate our approach: A simple sinusoidal movement of the elbow, that we designed as a proof of- concept, and an assisted-walking experiment. In both cases, we collected evidences illustrating that our approach indeed assisted healthy subjects during movement execution. Due to the intrinsic periodicity of daily-life movements involving the lower-limbs, we postulate that our approach holds promise for the design of innovative rehabilitation and assistance protocols for the lower-limb, requiring few to none user-specific calibration.

Single-Joint Rhythmic Movements

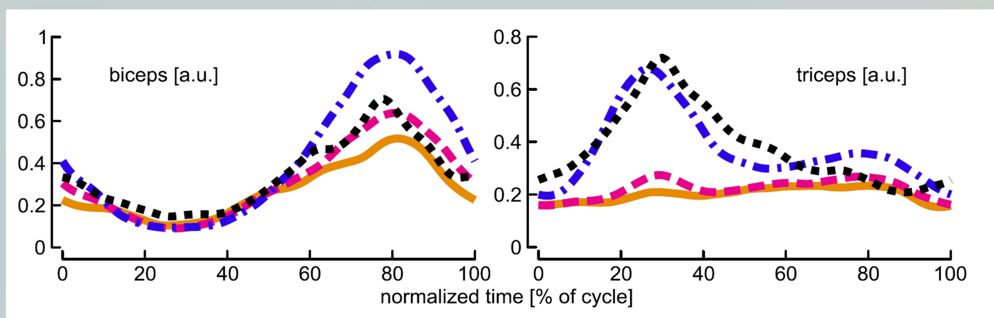


- Upright Elbow Rhythmic movement
- Powered Elbow Exoskeleton **NEUROExos** for assistance
- 8 healthy right-handed participants (age 26-31, weight 51-73)
- Inverse Dynamic Model of elbow + exoskeleton estimated for each subject
- Constant Frequency Trial: 1Hz, Variable Frequency Trial: 0.6-1.4Hz
- Movement Amplitude 40°

Experiment 1: Elbow Motion

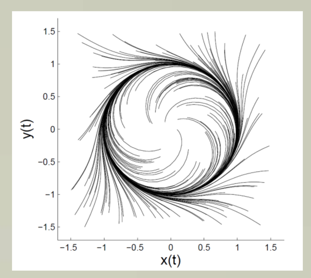


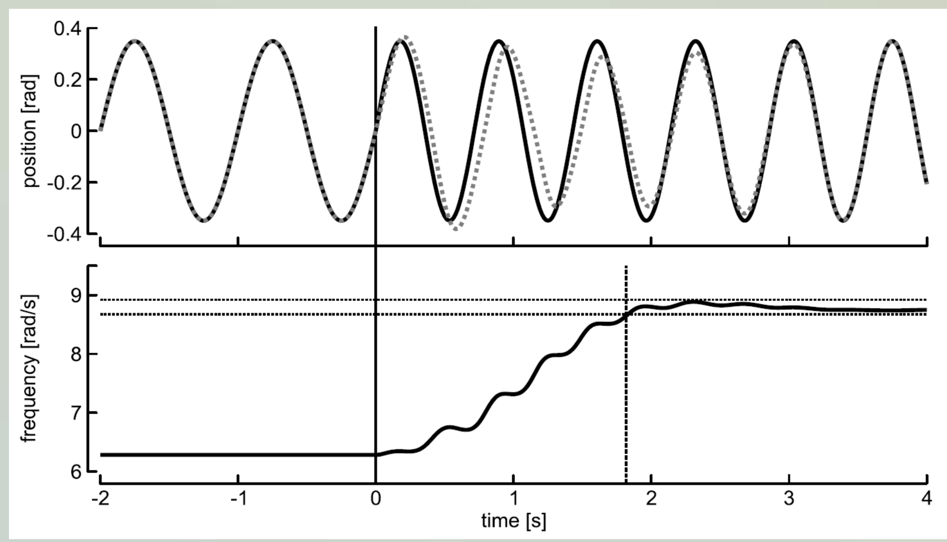
- AFO provide an excellent low-noise, delay-free tracking of the elbow movement
- Marked Decrease in muscular activation envelope
- Assistance does not affect movement controllability by the subject



The Building Block: Adaptive Frequency Oscillator

The adaptive oscillator is a modified Hopf oscillator that can learn the frequency ω (t), amplitude α_1(t) and offset α_0(t) of a quasi-sinusoidal input (t)





Constitutive Equations

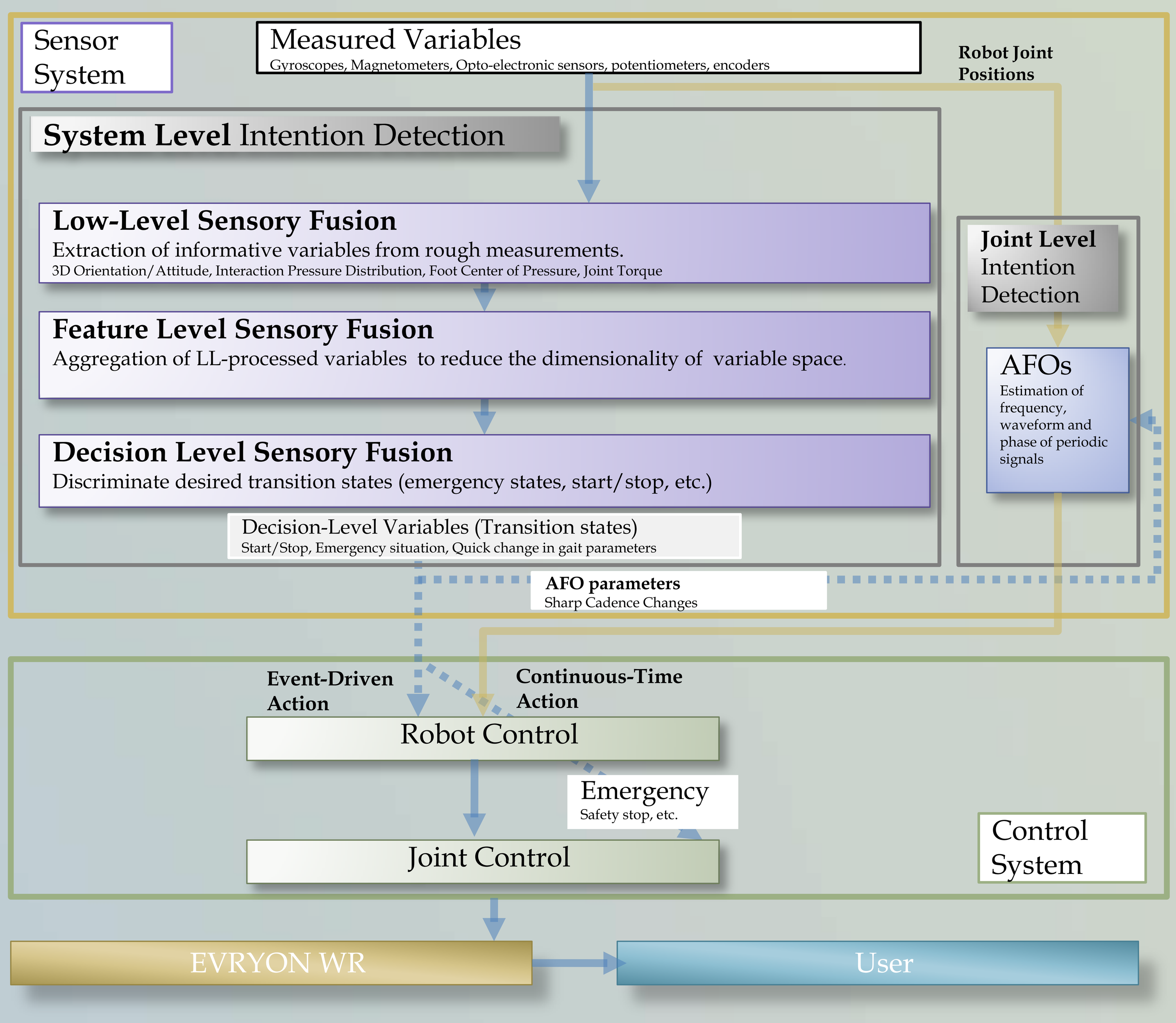
$$\dot{\omega}(t) = f\left(x(t), y(t), F(t)\right)$$
$$\dot{\alpha_0}(t) = \eta F(t)$$
$$\dot{\alpha_1}(t) = \eta x(t) F(t)$$
$$F(t) = \theta(t) - (\alpha_0(t) + \alpha_1(t)x(t))$$

Angular Estimate

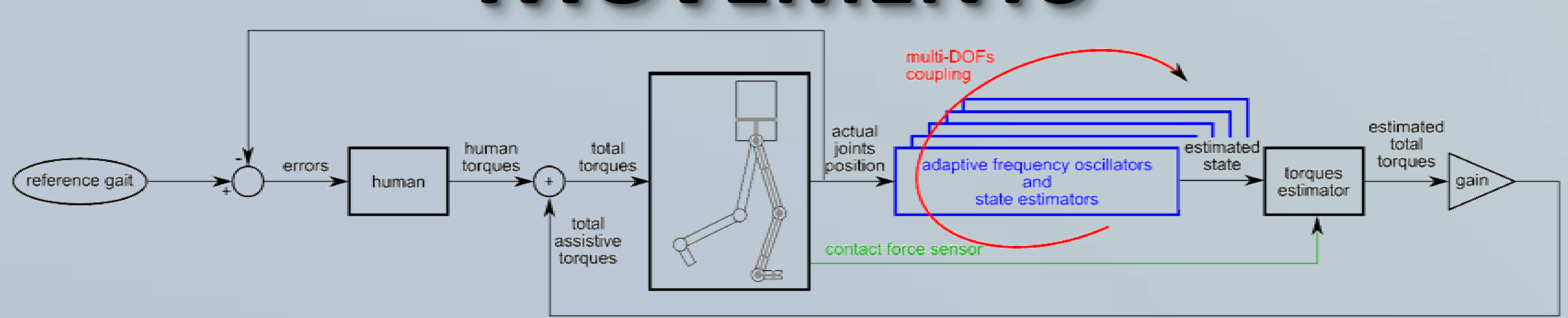
$$\hat{\theta}(t) = \alpha_0(t) + \alpha_1(t)x(t)$$
$$\dot{\hat{\theta}}(t) = \alpha_1(t)\omega(t)y(t)$$
$$\ddot{\hat{\theta}}(t) = -\alpha_1(t)\omega(t)^2 x(t)$$

An Hybrid Rhytmic-Event Driven approach

- Combine rhythmic assistance with event-driven intention detection
- Rhythmic time-driven analysis of joint angles with **AFOs**
- Asynchronous event-driven detection of events with **multiple sensorization**
- **Walking Assistance complemented with START/STOP/Emergency Events**



Multi-Joint Rhythmic Movements



1. Prediction

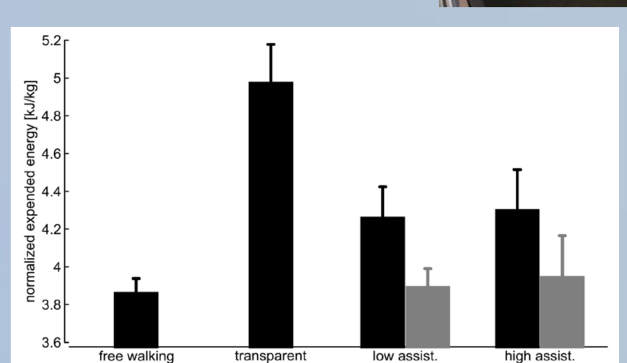
$$\hat{\theta}_\Delta(t) = \hat{\theta}(t+\Delta) = \alpha_1 \sin(\phi + \omega\Delta) + \alpha_0$$

2. Attraction

$$\tau(t) = k_f\left(\hat{\theta}_\Delta(t) - \theta(t)\right) + b_f\left(\dot{\hat{\theta}}_\Delta(t) - \dot{\theta}(t)\right)$$

Experiment 2: Assisted Walking

- AFO tracking for non-sinusoidal signals
- **Model-free Assistance**
- Adaptivity to varying cadence: small time constant (few cycles)
- Reduced energy expenditure during walking



- Assisted Walking Experiment
- **LOPES** lower-limb exoskeleton for assistance
- 9 healthy participants (age 24-28, weight 58-86)
- **No Inverse Dynamic Model**
- **Attraction on Predictor**
- Constant Walk Speed 2.7-4.5 Km/h
- Unconstrained Cadence

References

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