Towards ergonomically enhanced robotic co-workers

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AFIA Journée Robotique et IA

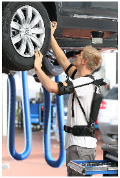
Interactions : Humains, Robots, Environnement

Collaborative robotics: A physical assistance for complex tasks

Robot
- Weight compensation
- Strength amplification
- Guidance via virtual paths

Human
- Technical expertise
- Decision
- Adaptability

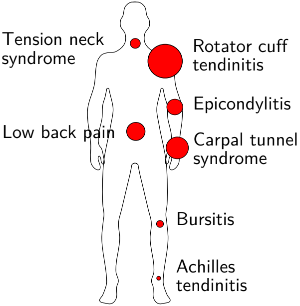
Physical Human-Robot Collaboration

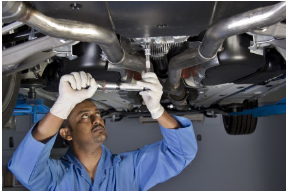


Work-related musculoskeletal disorders: A major health issue

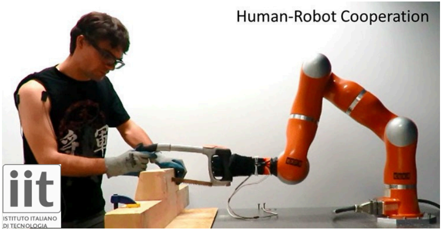
- Over 50 % of industrial workers worldwide
- 1st occupational disease in Europe
- Direct cost in France: > 830M€ a year
- Global cost in the US: $\simeq$ \$50B a year

- Biomechanical risk factors: **posture**, **effort**, static work, repetitive work





Human-robot collaboration is growing fast in multiple domains



How to design and control robots so that the physical collaboration is efficient, comfortable, and intuitive?

Maximizing the benefit provided by a collaborative robot

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   [Maurice *et al.*, Int. J. of Industrial Ergonomics, 2017]

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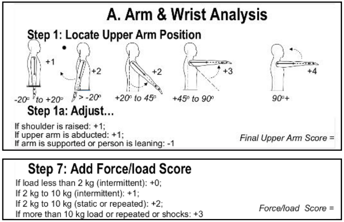
Standards ergonomics assessment tools are ill-adapted for cobotics

Ergonomics worksheets

- Global level of risk
- Task-specific: no robot



A. Arm & Wrist Analysis

Step 1: Locate Upper Arm Position

Step 1a: Adjust...

If shoulder is raised: +1;
If upper arm is abducted: +1;
If arm is supported or person is leaning: -1

Final Upper Arm Score =

Step 7: Add Force/load Score

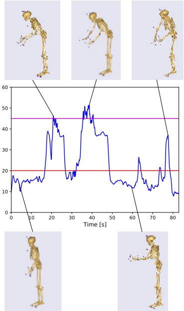
If load less than 2 kg (intermittent): +0;
If 2 kg to 10 kg (intermittent): +1;
If 2 kg to 10 kg (static or repeated): +2;
If more than 10 kg load or repeated or shocks: +3

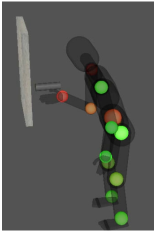
Force/load Score =

Standing (and walking)				Kneeling or crouching		
1			Standing & walking in alteration, standing with support	12		Upright
2			Standing, no body support (for other restrictions see Extra Points)	13		Bent forward
3		a	Bent forward (20-60°)	14		Elbow at / above shoulder level
		b	with suitable support			
4		a	Strongly bent forward (>60°)			
		b	with suitable support			

Biomechanical / physiological measures

- Generic
- Numerous local indicators





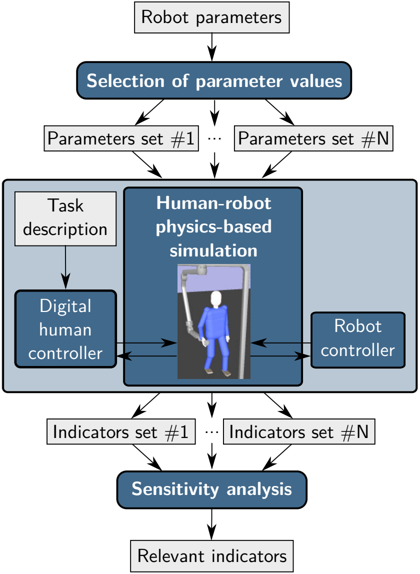
Selecting task-specific indicators for ergonomics comparison of cobots

Sensitivity analysis

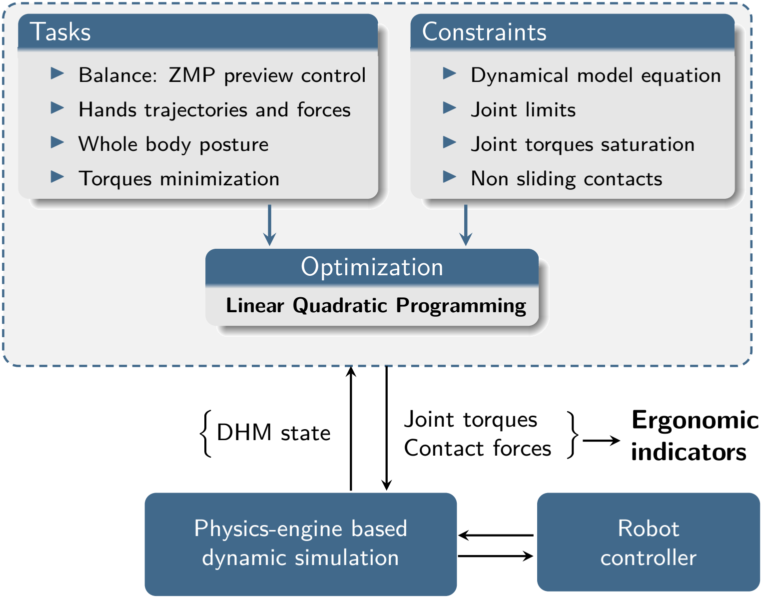
- Relevant indicators are the ones that vary the most

Physics-based human-robot simulation

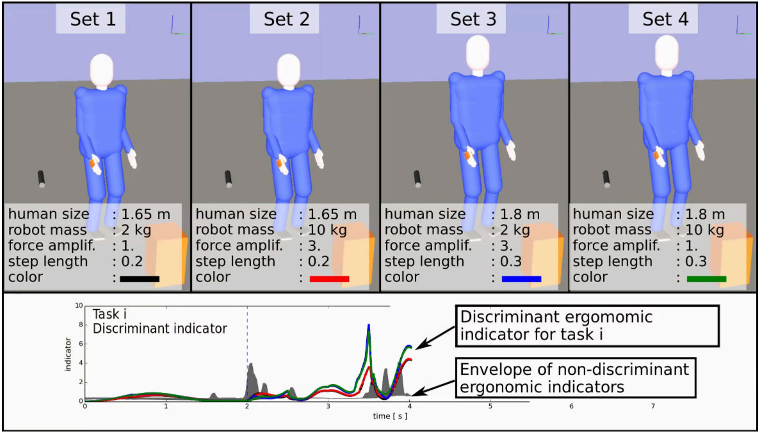
- Human control: Linear Quadratic Programming
- Autonomous simulation: no mocap needed
- Testing different human morphologies



Simulating human-robot co-manipulation: A robotics-based DHM controller

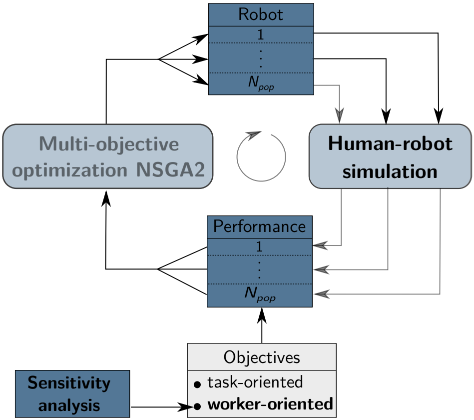


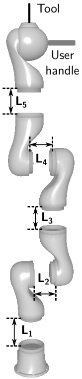
Indicators: position, velocity, acceleration, torque, power of right/left arm/back/legs, kinetic energy, balance, manipulability ...

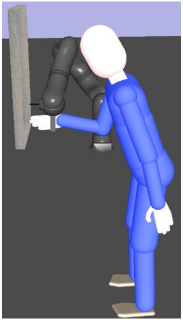


3 to 9 indicators selected among 30, represent >70 % of variance

Application: Optimal design of collaborative robots







Optimization variables

- Segments lengths L_i
- Base position
- Base orientation

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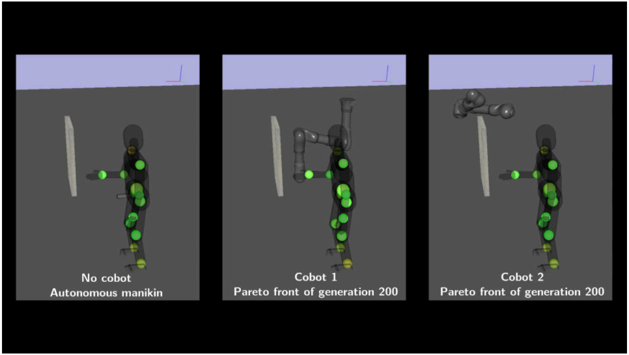
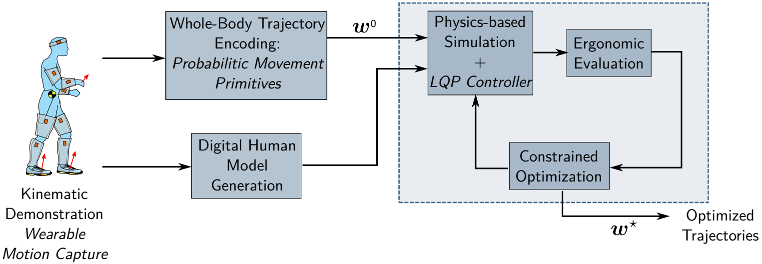
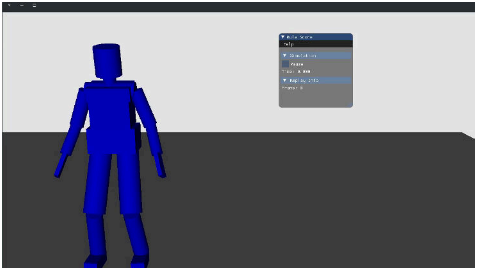


- Pre-selection of the best performing robots
- Human like aspect of simulated motion?

On-going work: Postural optimization for cobot control



Waldez Gomes
Serena Ivaldi
J.B. Mouret



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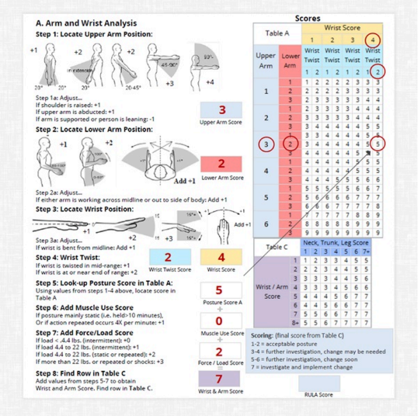
Automatic assessment of ergonomics in industrial settings



Adrien Malaisé
Serena Ivaldi
Francis Colas

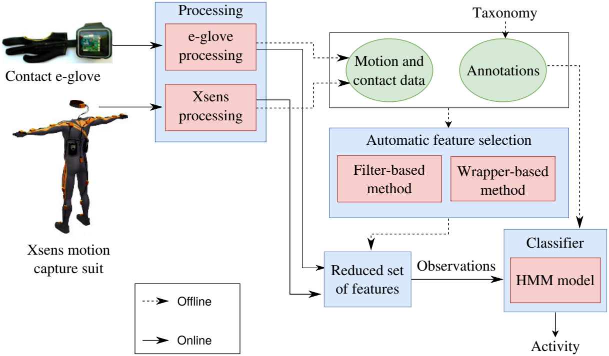
- **Context:** Reduction of work-related musculoskeletal disorders
- **Goal:** On-line warning, monitoring...
- **Issue:** Ergonomics is evaluated with pen-and-paper worksheets

Automatic identification of postures and actions with a reduced set of sensors

Activity recognition with Hidden Markov Models

- Geometrical measures not sufficient: Time-series and contextual elements needed
  $\rightarrow$ **Machine learning based models** (supervised)

- Industrial applications: Limit number of wearable sensors
  $\rightarrow$ **Feature selection methods**



- **Posture:** Based on the EAWS ergonomics assessment worksheet
  → Stand upright, stand bent forward, sit arms above head level...

Standing (and walking)				Kneeling or crouching		
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2			Standing, no body support (for other restrictions see Extra Points)	13		Bent forward
3		*a*	Bent forward (20-60°)	14		Elbow at / above shoulder level
		b	with suitable support			
4		*a*	Strongly bent forward (>60°)			
		b	with suitable support			

- **Action:** Goal-oriented actions
  → Reach, carry, screw, idle...

Human movement and ergonomics: An industry-oriented dataset

Database

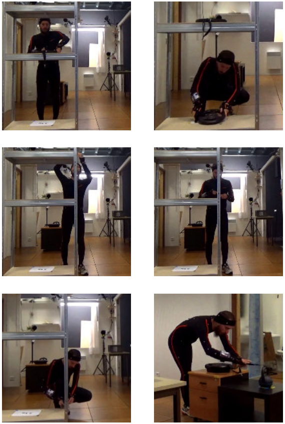
- 13 participants
- Series of 6 manual industry-inspired activities
- 5 hours of data

Sensors

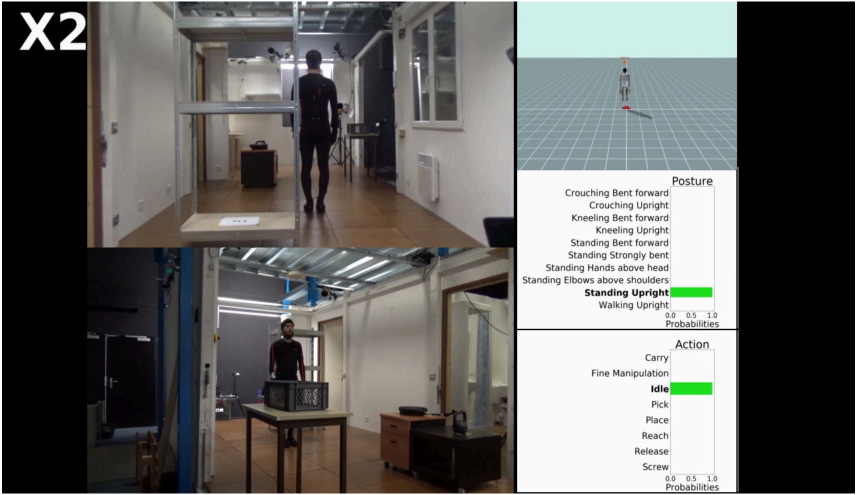
- **Xsens MVN inertial motion tracking suit**
- Qualisys optical motion capture
- **Sensorized e-glove**
- 2 video cameras

Annotations

- 3 independent human annotators

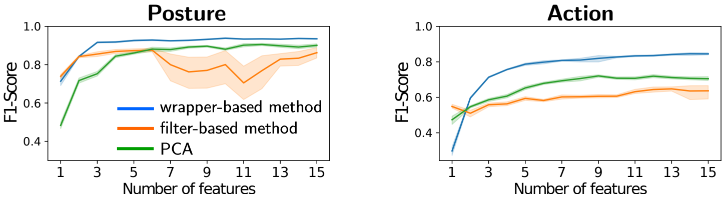


Publicly available database: `https://zenodo.org/record/3254403`



Code: `https://github.com/inria-larsen/AnDy-demo-activity-recognition`

Feature selection and recognition performance



Recognition only requires a small number of features

Features	Dimension	F1-Score Posture	F1-Score Action
Dedicated set	4	91.84	75.65
Dedicated set	8	92.72	81.00
Mandery *et al.*	4	30.63	23.75
Mandery *et al.*	8	67.22	55.12
All	779	89.30	81.39

A dedicated set of features gives better results

What's next: Warn the user

- **Motion prediction**
  $\rightarrow$ Detect a dangerous movement in advance

- **Feedback device**
  $\rightarrow$ Efficiently warn workers in real-time

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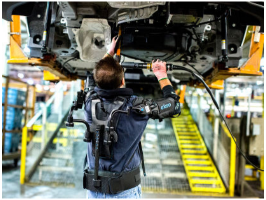
   [Maurice *et al.*, IEEE. Trans. Neural Systems and Rehabilitation Engineering, 2019]

   [Settembre *et al.*, Annals of Physical and Rehabilitation Medicine, 2020]

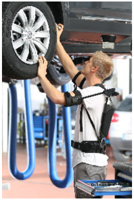
Passive exoskeletons to assist industrial work are on the market

AirFrame
Levitate Tech.



EksoVest
Ekso Bionics

ShoulderX
SuitX

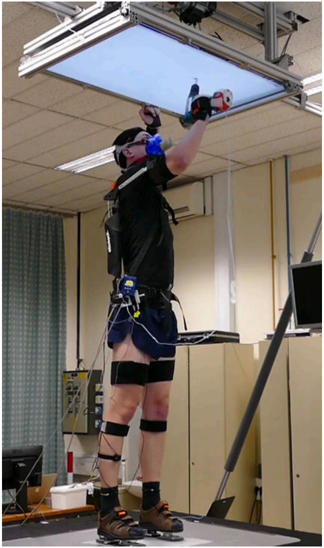


Paexo Shoulder
Ottobock

Paexo back
Ottobock

Laevo
Laevo

Overhead pointing task with Ottobock's passive exoskeleton PAEXO

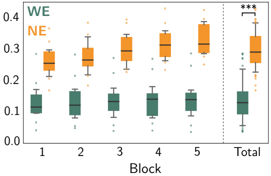


- 12 participants
- With/without exoskeleton **WE**/**NE**
- Exoskeleton supports 100 % of arm weight when shoulder and elbow flexed at 90°

Objective measures: Evaluation of the biomechanical benefit

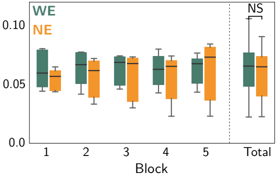
Impacted limb

RMS of normalized
Anterior Deltoid activation



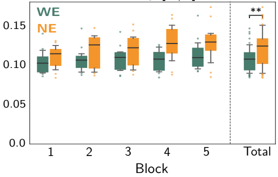
Side-effects

RMS of normalized
Erector Spinae activation



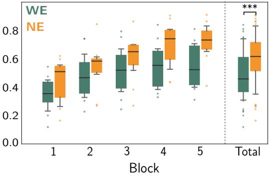
Side-effects

RMS of Center of Pressure
velocity [m/s]



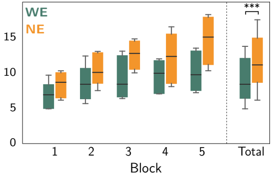
Workload

Normalized
heart rate



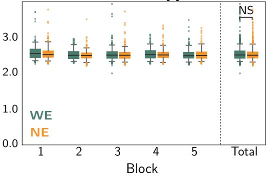
Workload

Oxygen consumption
[ml/kg/min]



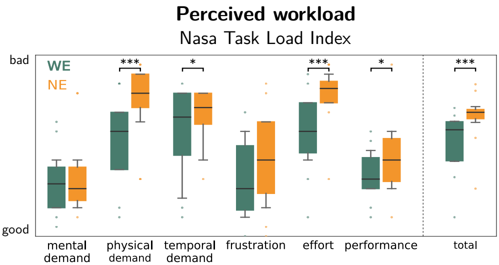
Task performance

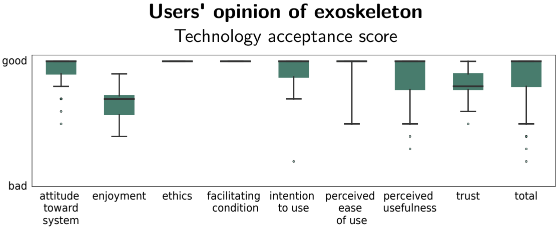
Movement
duration [s]



PAEXO reduces fatigue without degrading task performance

Subjective measures: Evaluation of users' opinion





Participants are positive about using the exoskeleton: all would use it again

Testing an exoskeleton to assist medical staff in ICU during Covid-19

Prone-positioning of mechanically ventilated patients

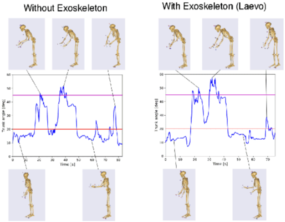
- First step: Pilot study at Hospital Simulation Center
- Second step: Feasibility tests in ICU at CHRU Nancy

Laevo low-back support passive exoskeleton

Pilot study: Biomechanical and physiological evaluation

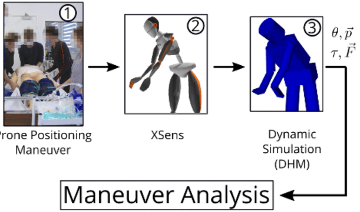
Kinematics analysis

Xsens MVN suit



(Anybody software for biomechanics)

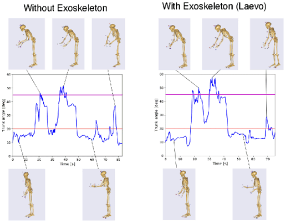
Torque analysis



- No modification of motion (practice)
- Small reduction of muscle effort

Kinematics analysis

Xsens MVN suit



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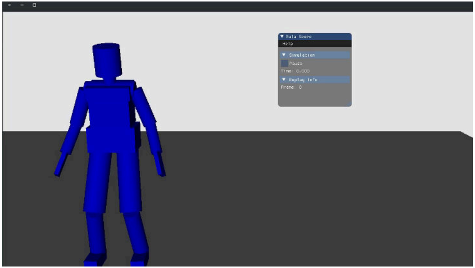

- No modification of motion (practice)
- Small reduction of muscle effort

ICU study: Feasibility and subjective evaluation

2 physicians used the Laevo in ICU in April

- Feasible to use Laevo even in strict Covid conditions
- Laevo perceived helpful at head position (static posture)

Used again during second wave

- Feedback from users: work in progress!

What's next: Active exoskeletons

- Passive exoskeletons provide limited support

- Active exoskeletons are more powerful...
  ... but: how to **predict human intention?**

Thank you!

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