Human motion analysis : application to an industrial screwing task

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23/06/2014

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Table of contents

Manual operations in car assembly lines

"Heavy" workstations

- Awkward postures to adopt
- Notable efforts to carry
- Short cycle time

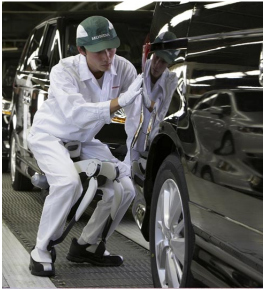
Consequences

- Ergonomics
- Musculo-skeletal Disorders

Ergonomics assistance of workers

- Collaborative robots [Akella, 1999]
  - Ergonomics improvements
  - Dexterity
  - Flexibility
- Standard Ergonomics analysis in industries
  - Based on observations
  - Rarely consider movement biomechanics
  - Unable to qualify collaborative robots supply

A6-15 Cobot
Rb3d



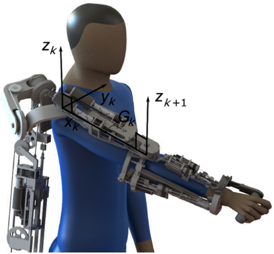
Bodyweight Support Assist
Honda

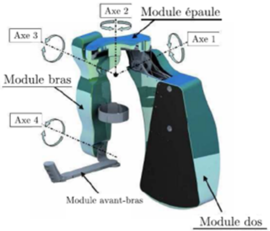
Analysed task : under-car screwing

Ergonomic contribution of ABLE exoskeleton for under-car screwing operation

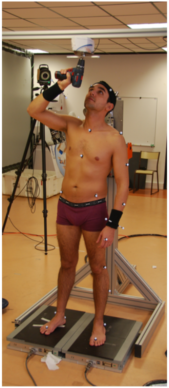
Presentation of ABLE exoskeleton [Garrec, 2008]

- Designed by CEA-List
- Mono-arm exoskeleton
- 7 axes: 3 for shoulder, 2 for elbow, 2 for wrist
- Tool emplacement
- Adjustable compensation levels



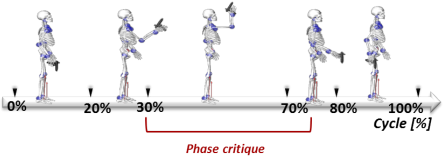


Experimentation



Free-arm movement

With exoskeleton



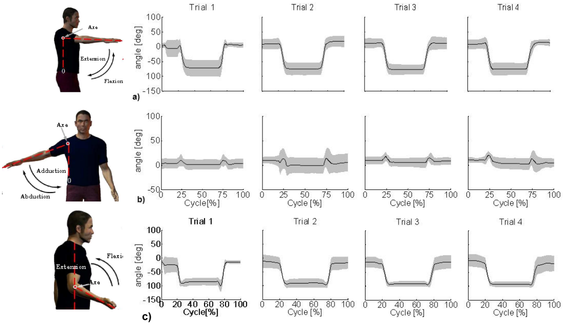
Measuring joint trajectories

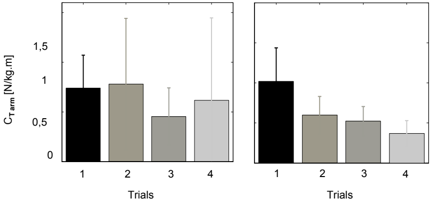
- Motion Capture
- 6 MX Cameras, Vicon, 100Hz
- 38 markers on anatomical landmarks

Trials

- Trial 1: without exoskeleton
- Trial 2: with exoskeleton, no compensation
- Trial 3: with exoskeleton, compensation level 1
- Trial 4: with exoskeleton, compensation level 1

Comparative analysis





Results [Sylla, 2014a]

- Low difference of joint angles between trials
- Clear reduction of joint torque, particularly in the critical phase

Industrial task analysis

Objectives

Inquiring criteria involved in worker's movement

- Analyse based on human motor control theory
- To improve standard ergonomic analysis in PSA
- To determine optimal collaborative robots

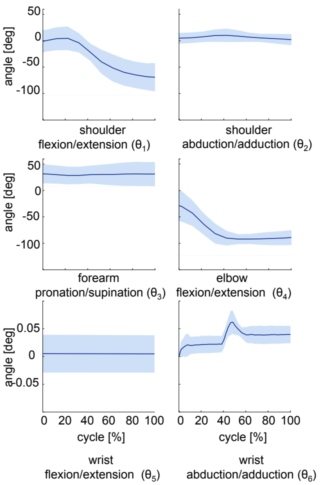
Human motor control theory

- Cost-functions minimization by the Central nervous system (SNC) [Bernstein, 1967]
- **Modelling by optimal control:** jerk [Flash, 1985], torque change [Uno, 1989], energy [Alexander, 1997] minimisation, etc...
- **Limitations:** No consensus between studies, the objective function need to be determined first

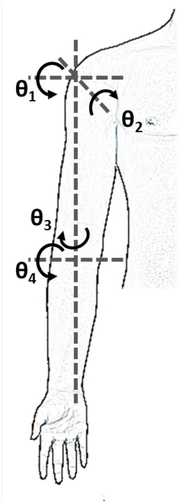
Contribution

- Identifications of involved criteria by hybrid cost function optimization [Berret, 2011]

Arm Geometric Model



Measured joint trajectories: low wrist movements amplitudes



Retained Arm model

Dynamic model of the arm

Determined by Lagrange formulation [Khalil, 1999]

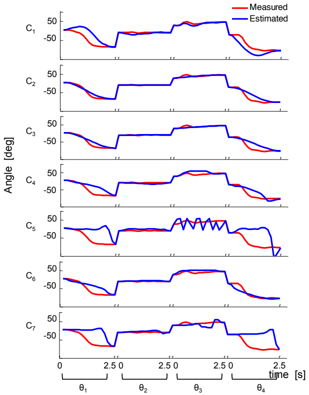
$$\mathbf{\Gamma} = \mathbf{A}(\theta)\ddot{\theta} + \mathbf{C}(\theta, \dot{\theta})\dot{\theta} + \mathbf{Q}(\theta), \tag{1}$$

- $\mathbf{\Gamma}$: Joint torques
- $\mathbf{A}(\theta)$: Inertia matrix
- $\mathbf{C}(\theta, \dot{\theta})$: Vector of Coriolis and centrifugal torques
- $\mathbf{Q}(\theta)$: Gravity Matrix

Optimisation of unique criteria

Criterion	Cost function[a]
Cartesian jerk	$c_1 = \frac{\sum_{j=1}^{n} \dddot{x}_j^2 + \dddot{y}_j^2 + \dddot{z}_j^2}{n}$
Angle jerk	$c_2 = \frac{\sum_{j=1}^{n} \sum_{i=1}^{4} \dddot{\theta}_{i_j}^2}{n}$
Angle acceleration	$c_3 = \frac{\sum_{j=1}^{n} \sum_{i=1}^{4} \ddot{\theta}_{i_j}^2}{n}$
Torque change	$c_4 = \frac{\sum_{j=1}^{n} \sum_{i=1}^{4} \dot{\Gamma}_{i_j}^2}{n}$
Torque	$c_5 = \frac{\sum_{j=1}^{n} \sum_{i=1}^{4} \Gamma_{i_j}^2}{n}$
Geodesic	$c_6 = \frac{\sum_{j=1}^{n} \sqrt{\dot{\boldsymbol{\theta}}_{\mathbf{j}}^{\mathbf{T}} \mathbf{A}(\boldsymbol{\theta}) \dot{\boldsymbol{\theta}}_{\mathbf{j}}}}{n}$
Energy	$c_7 = \frac{\sum_{j=1}^{n} \sum_{i=1}^{4} \lvert \dot{\theta}_{i_j} \Gamma_{i_j} \rvert}{n}$

a. n is the lengths of joint angles vectors



- Significant differences between measured and estimated trajectories
- **Solution:** Usage of hybrid cost function

Inverse Optimization

Retained hybrid cost functions [Berret, 2011]

$$J = \sum_{i=1}^{7} \alpha_i C_i \quad (2)$$

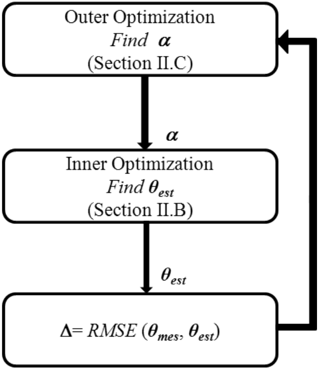
Objective

Find optimal values of α_i that lead to human joint trajectories

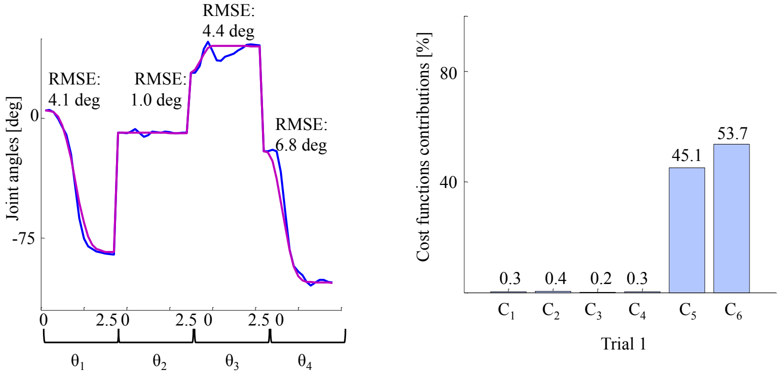
Processus

Bi-level optimisation

- Minimization of J cost-function
- Minimisation of RMSE between measured and estimated joint angles

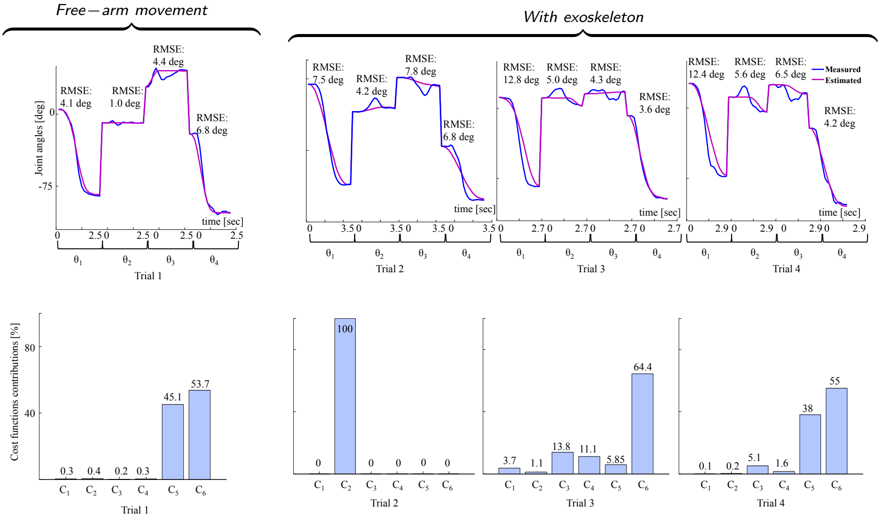


Results for a typical subject [Sylla, 2014b]



- $\alpha = [0.3\ 1.0\ 0.1\ 0.0\ 0.0\ 5.2\ 5.8]$
- Important contribution of energy [Alexander, 1997] and geodesic [Biess, 2006] criteria: workers minimize their energy expenditure, task duration, and choose the shortest path during the screwing task.

Relevance of Exoskeleton ergonomic compensation [Sylla, 2014c]



Conclusion

- Slight differences between joint angles show the relevance of using a hybrid cost function in human motion planning
- Criteria contributions during the movement, resulting from inverse optimization, helps in determining optimal assistive device in terms of degrees of freedom and command strategy to improve workers' comfort
- Results questions the control law of the exoskeleton
- Future works:
  - Performing inverse optimization to several subjects
  - Analysis of the screwing movement in realistic situation with experimented workers in factory
  - Development of a new control law for personalised compensation

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