Technology for Health through non-linear control Theory

Thierry Marie GUERRA, Marcia Luciana Da Costa PEIXOTO

Thanks to:

(PhD students →) Drs Victor Estrada Manzo, Guoxi Feng, Mathias Blandeau, Michael Gray, Hajer Srihi, PhD Students: Mohamed Diouf, Nery Uriel Ortiz Gutierrez

Pr Philippe Pudlo, Pr Sébastien Delprat, Dr Antoine Dequidt, Dr AnhTu Nguyen, RI Sébastien Paganelli

Pr Lucian Bușoniu

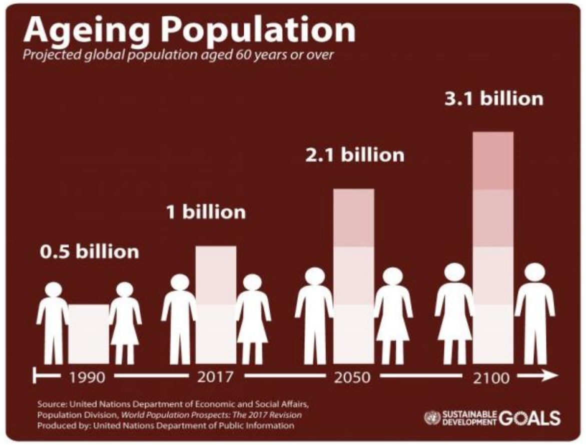
Pr Dany Gagnon

Dr Sami Mohammad

Global disability

- *About 15% of the world's population lives with some form of disability* [2011 world report of the World Health Organization]

- Disabled population is on the rise due to mainly aging



The first word is **Genericity**
Human is highly variable and changing, robustness, adaption of any device is mandatory

The second word is **Measure**
What can I measure? How can I measure (precision, repeatability)? To end with?

The third thing is **Think different**

Summary

Careful: working / Integrating a Human in the loop is challenging and (often) dangerous

4 different examples:

1. Robust Observer-Based Tracking Control Design for Power-Assisted Wheelchairs
   Personal assistance? User's intention?

2. Discrete Reference Tracking Control to Swing-Up an Electric Wheelchair
   Passing obstacles, safety? Robustness?

3. Stabilizing unstable biomechanical model to understand sitting stability for persons with spinal cord injury : modelling and observation problems (unmeasurable variables)

4. Cable-driven orthosis
   Control and observation problems (unmeasurable variables)

Context: PAWs

[Mohammad, Guerra 2015 Int. Patents]

- Power-assisted wheelchairs (PAWs)

PAW: NOMAD & DUO conversion kits that transform a manual wheelchair to an electric wheelchair

AutoNomad Mobility

Brushless Motors

Battery & electronics housing

Control box with or without joystick

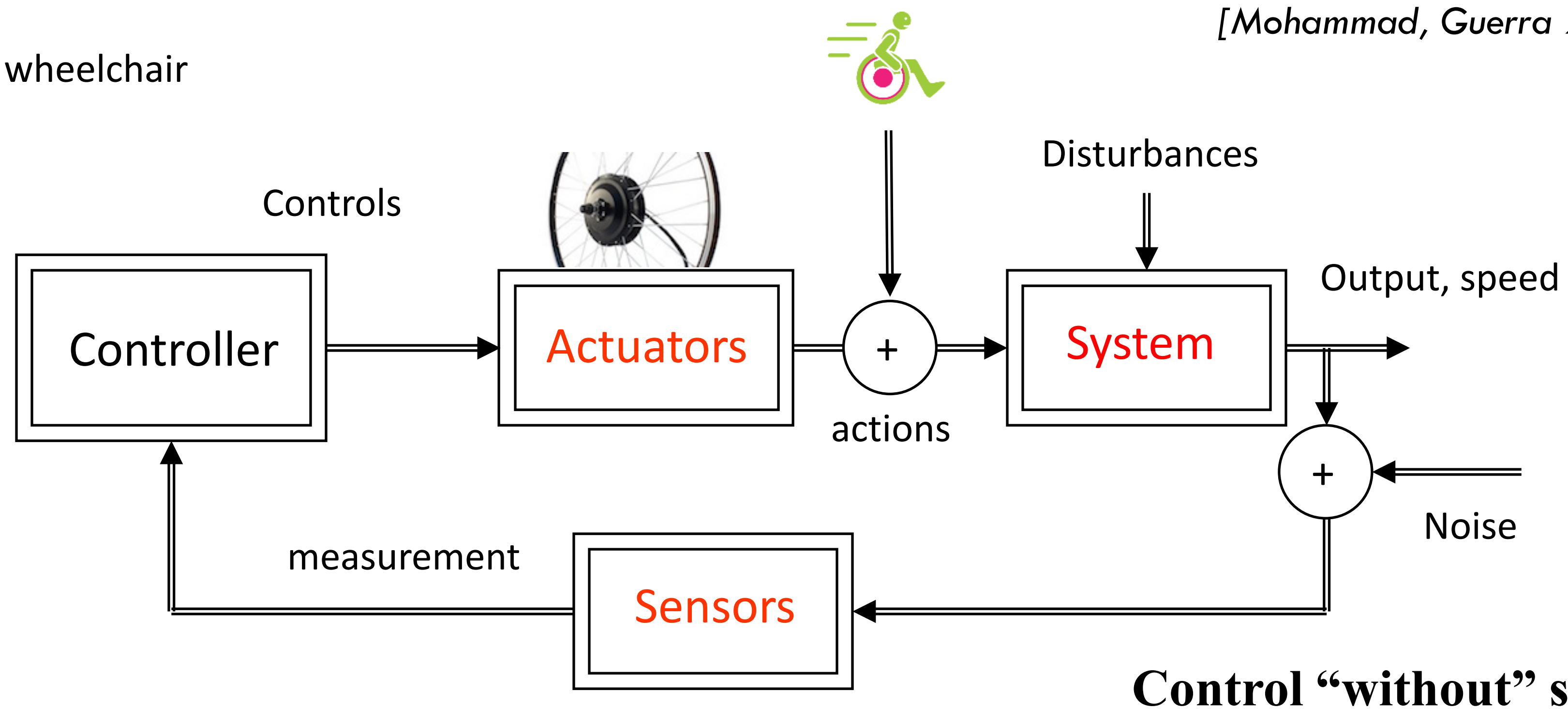
- Advantages:
  - Reduce overuse injuries compared to **manual wheelchairs**
  - Suitable physical exercise for users compared to **fully electrical wheelchairs**
  - Human propulsion and electrical motor propulsion

Power-Assisted Wheelchair

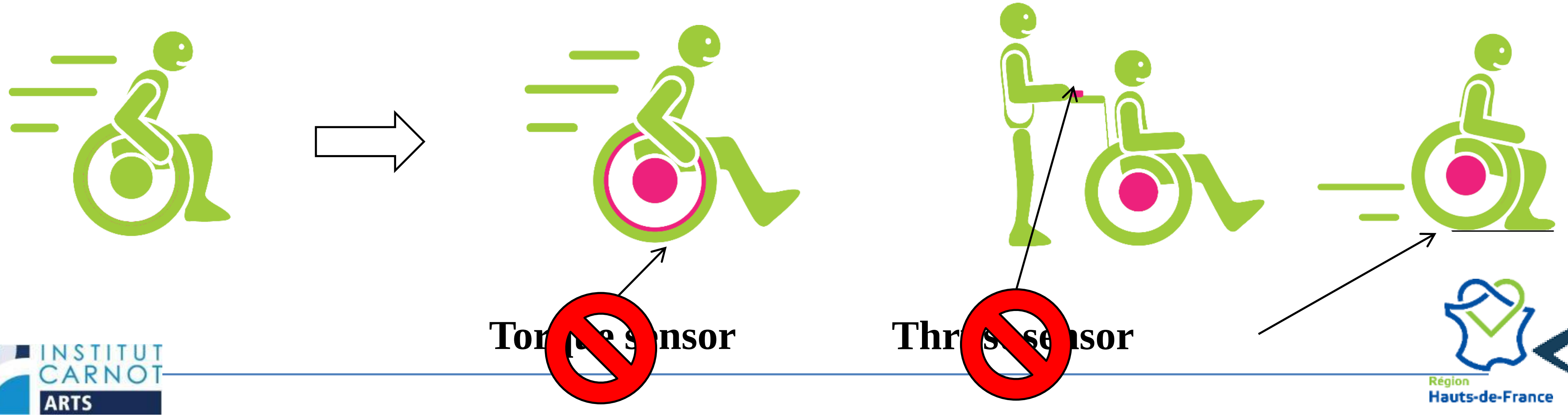
[Mohammad, Guerra 2015 Int. Patents]

Electric assistance kit for wheelchair

AutoNomad Mobility



Control "without" sensor



Robust Observer-Based Tracking Control Design for Power-Assisted Wheelchairs

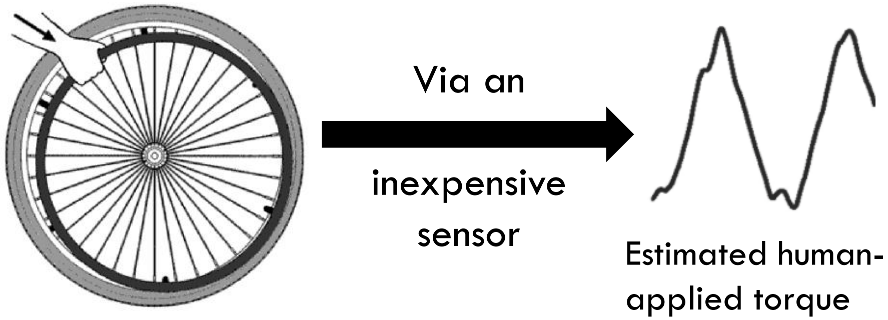
- Guoxi Feng, Thierry Marie Guerra, Anh-Tu Nguyen
- Lucian Bușoniu
- Sami Mohammad

[Feng, Buşoniu, Guerra, Mohammad (2019) IEEE T. Industrial Electronics]
[Feng, Guerra, Busoniu, Nguyen, Mohammad (2021) IFAC Int J CEP]

Challenges

- Torque sensor: Cost-increasing and hardware design complexity

Human-applied torque



- Different wheelchair and user's mass

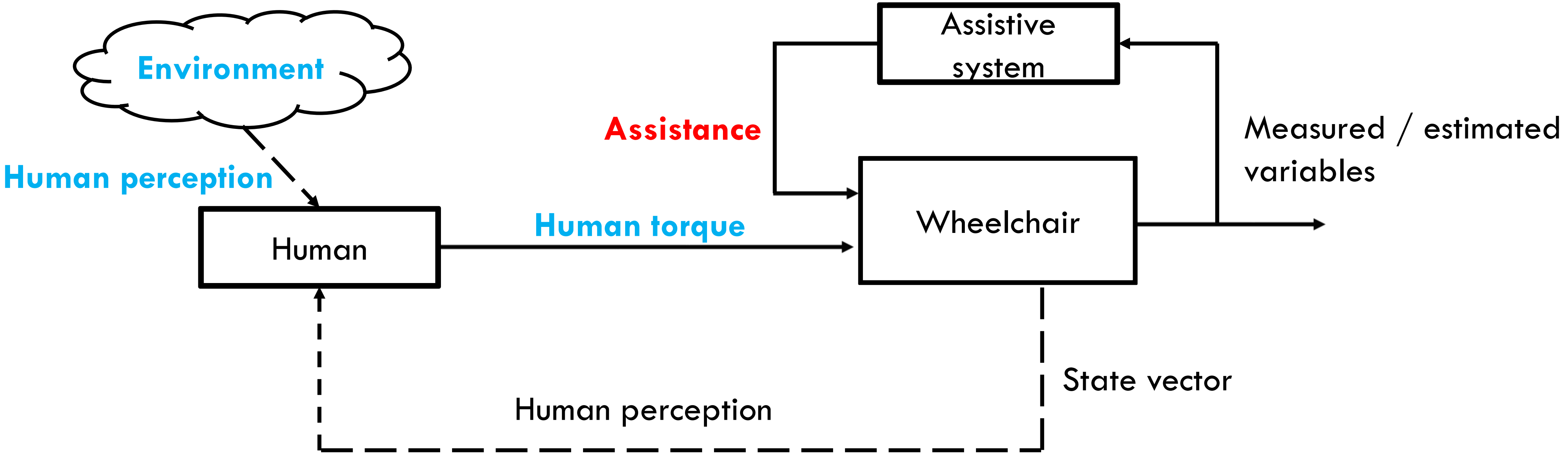
- Time-varying ground profile

Genericity:
Modeling? Measuring?
Unrealistic!

- Human intentions? Environment issues?

Challenges

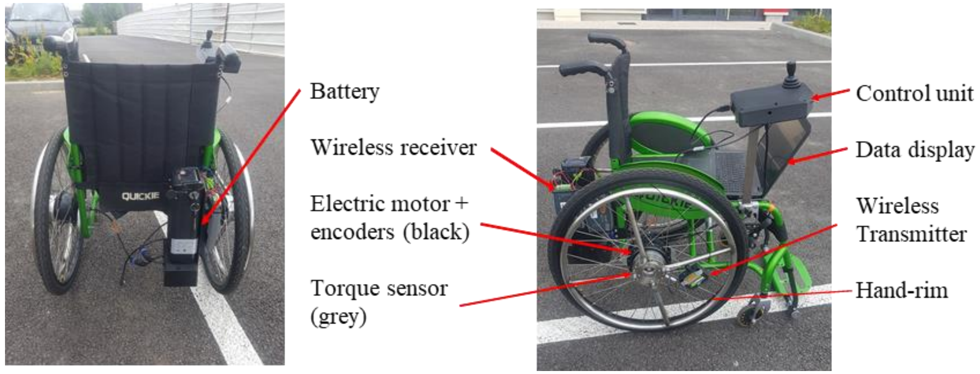
- Human-in-the-loop and good manoeuvrability for users + friendly



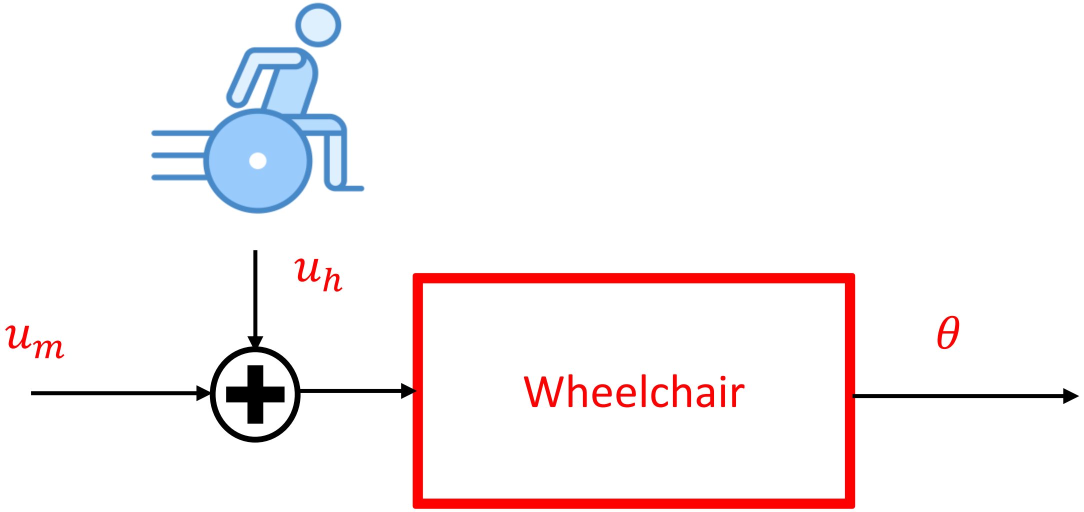
How to define the references?
Avoid being contra-intuitive…

Think different: transform the problem with an Automatic Control, point of view → estimation, robustness

Wheelchair: “stupid” model



AutoNomad Mobility

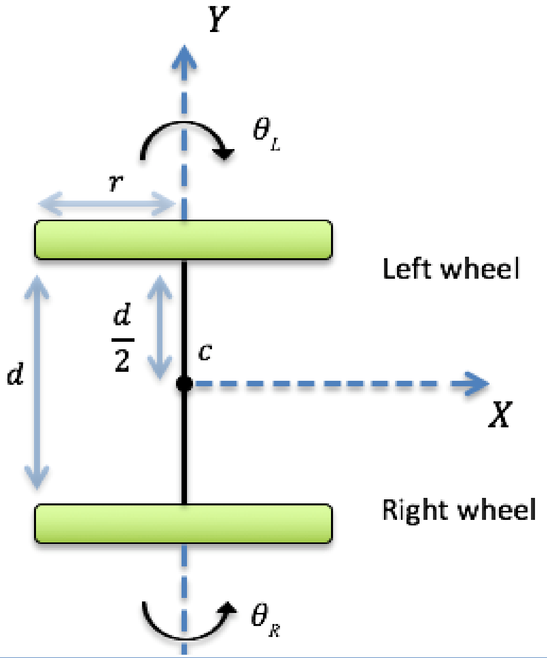


Wheelchair: "stupid" model

Two-wheeled PAW dynamics:

Shibata et Murakami 2008
Tsai et Hsueh 2012

$$\alpha\ddot{\theta}_R + \beta\ddot{\theta}_L = T_{Rh} + T_{Rm} - K\dot{\theta}_R$$
$$\alpha\ddot{\theta}_L + \beta\ddot{\theta}_R = T_{Lh} + T_{Lm} - K\dot{\theta}_L$$



Velocity $\dot{\omega}$ and rotation $\dot{\varphi}$ of the centre of gravity c:

$$\dot{\omega} = \frac{r}{2}\left(\dot{\theta}_R + \dot{\theta}_L\right)$$

$$\dot{\varphi} = \frac{r}{d}\left(\dot{\theta}_R - \dot{\theta}_L\right)$$

T_{Rh}, T_{Lh}: User torques
T_{Rm}, T_{Lm}: Assistive torques
$\dot{\theta}_R, \dot{\theta}_L$: Velocity of the right/left wheel
α, β : Inertial parameters

Symbol	Description
r	Wheel radius [m]
b	Distance between two wheels [m]
c	centre of gravity of the wheelchair with the human
m	mass of wheelchair including the human [kg]
K	Viscous friction coefficient [N.m.s]
I_C	Inertia of the wheelchair with respect to the vertical axis through c [N.m.s]
I_0	Inertia of each driving wheel around the wheel axis [kg.m^2]

Remarks:

Casters dynamics are not taken into account.

Non-modelled dynamics and uncertainties change the behaviour of the wheelchair.

Is two-wheeled model enough to capture the main behaviour for motion control designs?

Wheelchair: robustness

Descriptor form model:

$$E(m)\,x^{+} = A(m,\mathcal{K})\,x + B(u_h + u_m)$$

Unknown parameters — Unknown signal

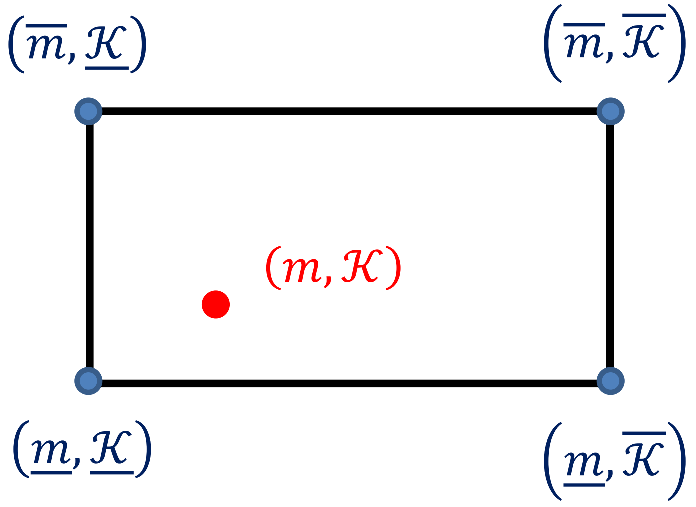
Non time varying $\underline{m} \le m \le \overline{m}$ time varying (road conditions) $\underline{\mathcal{K}} \le \mathcal{K} \le \overline{\mathcal{K}}$

Sector Non Linear approach:

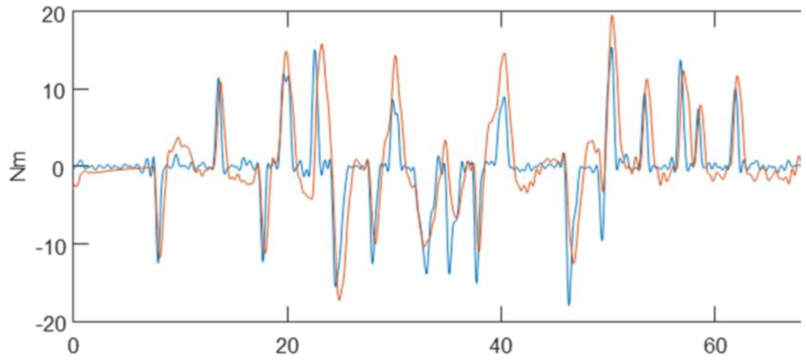
Tanaka et Wang 2001, Taniguchi et al. 1999

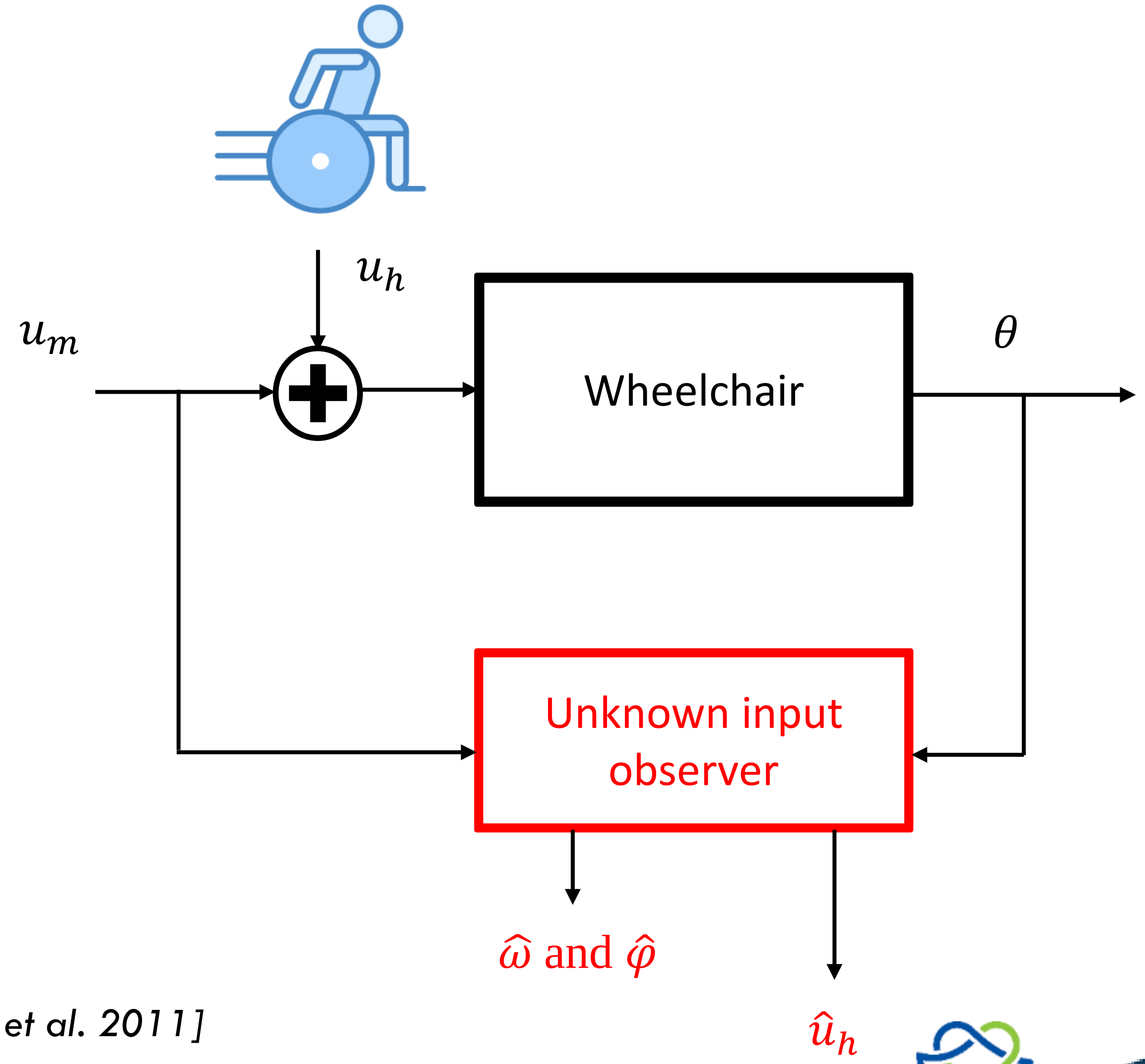
$$\sum_{j=1}^{2} \zeta_j(m) E_j x^{+} = \sum_{j=1}^{2}\sum_{i=1}^{2} \zeta_j(m)\,\vartheta_i(\mathcal{K}) A_{ij} x + B(u_h + u_m)$$

$$\zeta_j \in [0,1], \quad \vartheta_i \in [0,1], \quad \sum_{j=1}^{2} \zeta_j(m) = 1, \quad \sum_{j=1}^{2}\sum_{i=1}^{2} \zeta_j(m)\,\vartheta_i(\mathcal{K}) = 1$$



Unknown input observer

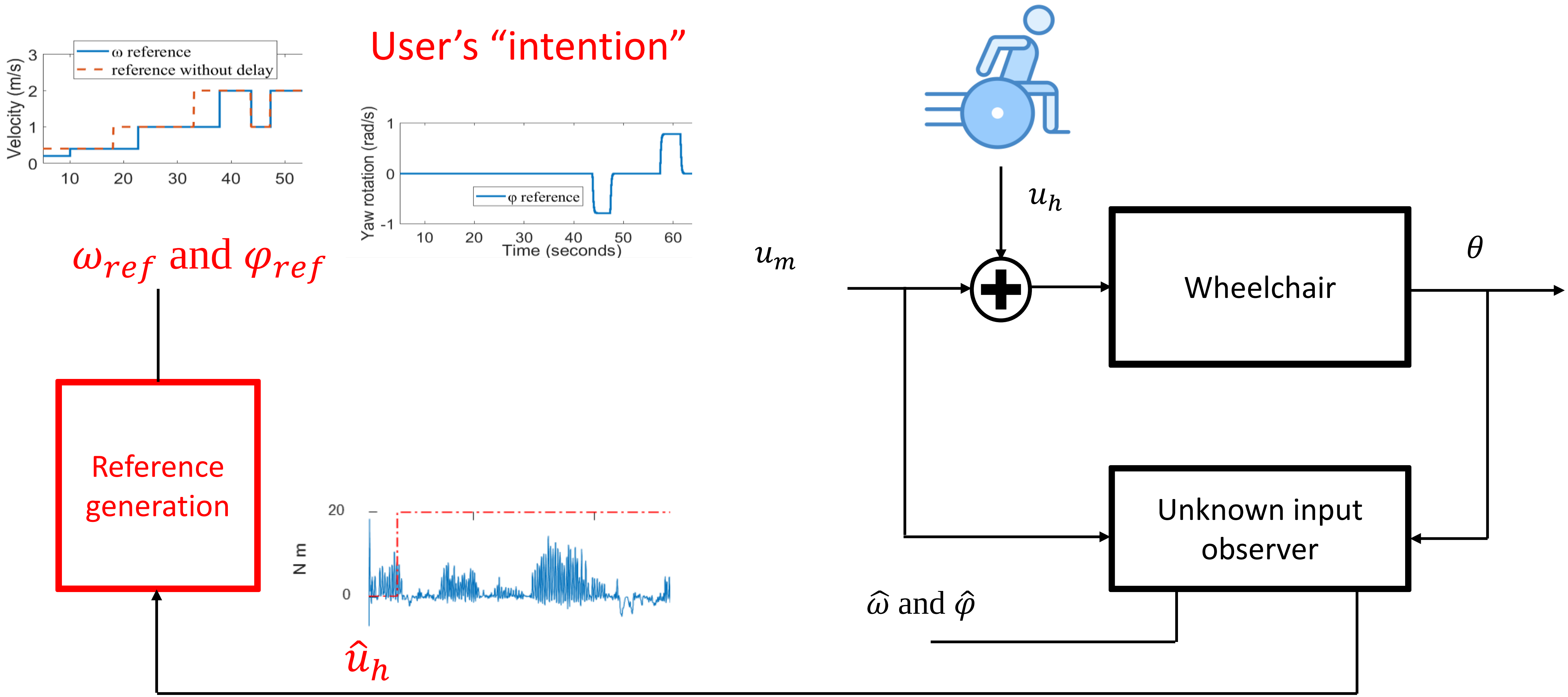




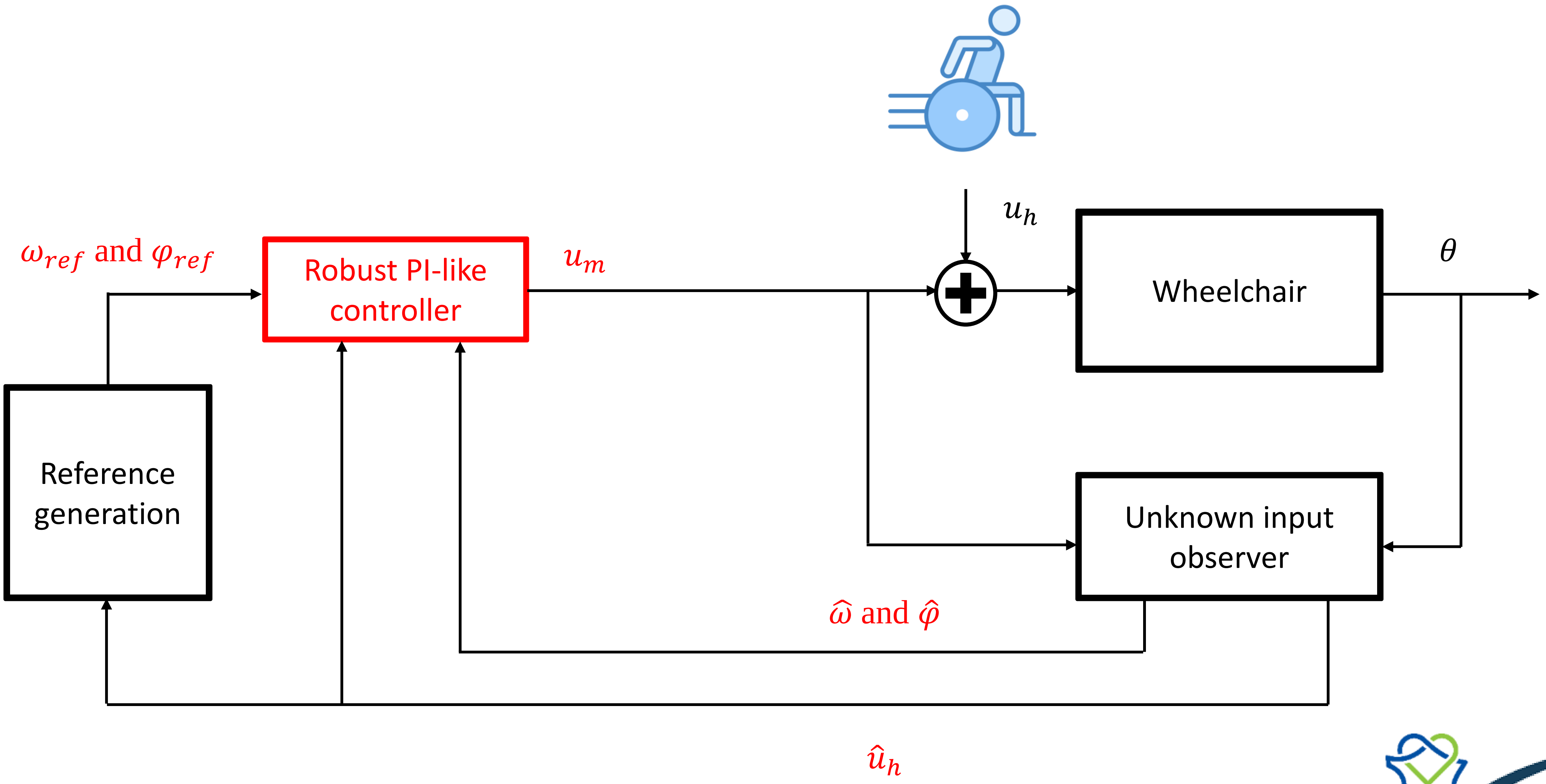
UIO PI-like observer: $\left(1-z^{-1}\right)^{n_p} u_{hr}\left(k\right)=0$

[Guan et al. 1991, Ichalal et al. 2011]

Reference generation



Robust control



Step 1: u_h is known

[Daafouz, J. et al., Márquez, R. 2014]

Lyapunov function: $$V(x_c) = x_c^T \sum_{j=1}^{2}\sum_{h=1}^{2} \zeta_j(m)\vartheta_i(\mathcal{K}) P_{c_{ij}} x_c = x_c^T P_c x_c$$

Parameter-dependent

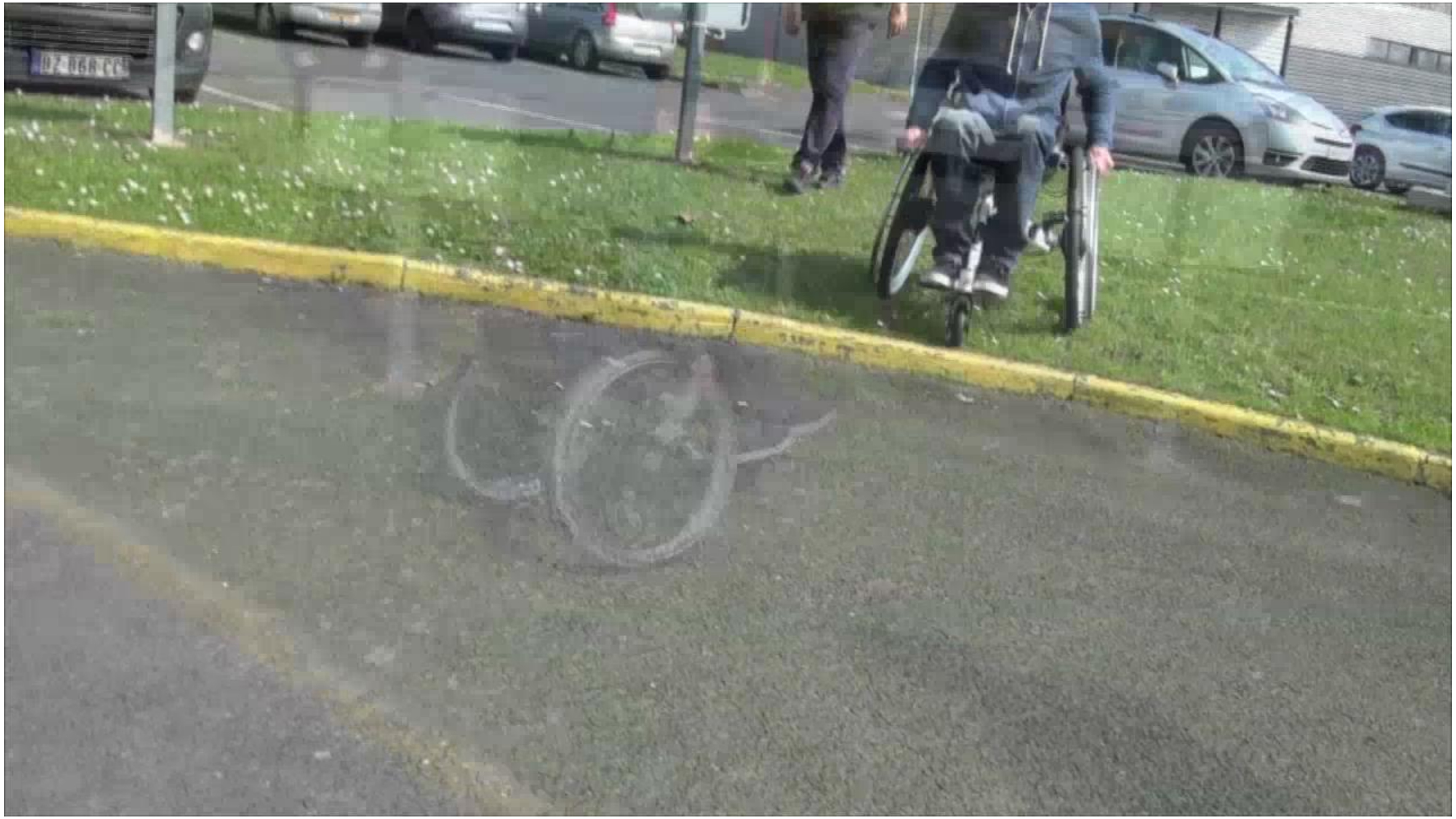
Variation (inequality constraint): $$\Delta V(x_c) = V(x_c^+) - V(x_c) = \begin{bmatrix} x_c \\ x_c^+ \end{bmatrix}^T \begin{bmatrix} -P_c & 0_{2n_x} \\ 0_{2n_x} & P_c^+ \end{bmatrix} \begin{bmatrix} x_c \\ x_c^+ \end{bmatrix} < 0$$

Finsler's lemma sufficient condition: [Márquez, R. 2014]

$$\begin{bmatrix} 0_{2n_x} \\ M_c^{-T} \end{bmatrix} \begin{bmatrix} A_c(m,\mathcal{K}) + B_c L_c M_c^{-1} & -E_c \end{bmatrix} + (*) + \begin{bmatrix} -P_c & 0_{2n_x} \\ 0_{2n_x} & P_c^+ \end{bmatrix} < 0$$

$$\begin{bmatrix} -X_{c_{ij}} & (*) \\ A_{c_{ij}} M_c + B_c L_c & X_{c_{hj}} - E_{c_j} M_c - (E_{c_j} M_c)^T \end{bmatrix} < 0 \Rightarrow L_c \text{ and } M_c$$

Illustration



AutoNomad Mobility

3 International Patents

cnrs

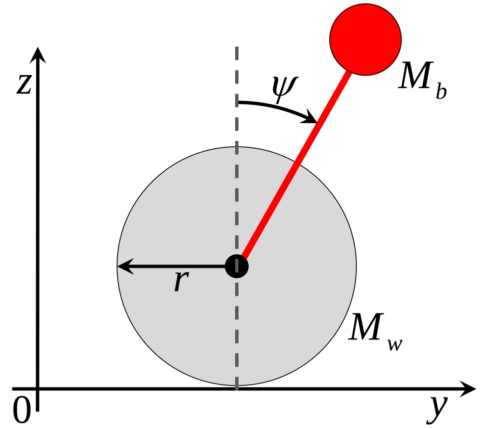
Université de Valenciennes et du Hainaut-Cambrésis

Discrete Reference Tracking Control to Swing-Up an Electric Wheelchair

- Michael Gray, Thierry Marie Guerra, Sébastien Delprat
- Sami Mohammad

[Gray, Guerra, Delprat, Mohammad(2020) IFAC Paper-on-Line]
[Gray, Guerra, Delprat, Mohammad (2023) Asian Journal of Control 25 (5), 3369-3383]

Modelling: simplest



$$E_c(\psi)\dot{x} = A_c(\psi,\dot{\psi})x + B_c u$$

Unknown, unmeasured

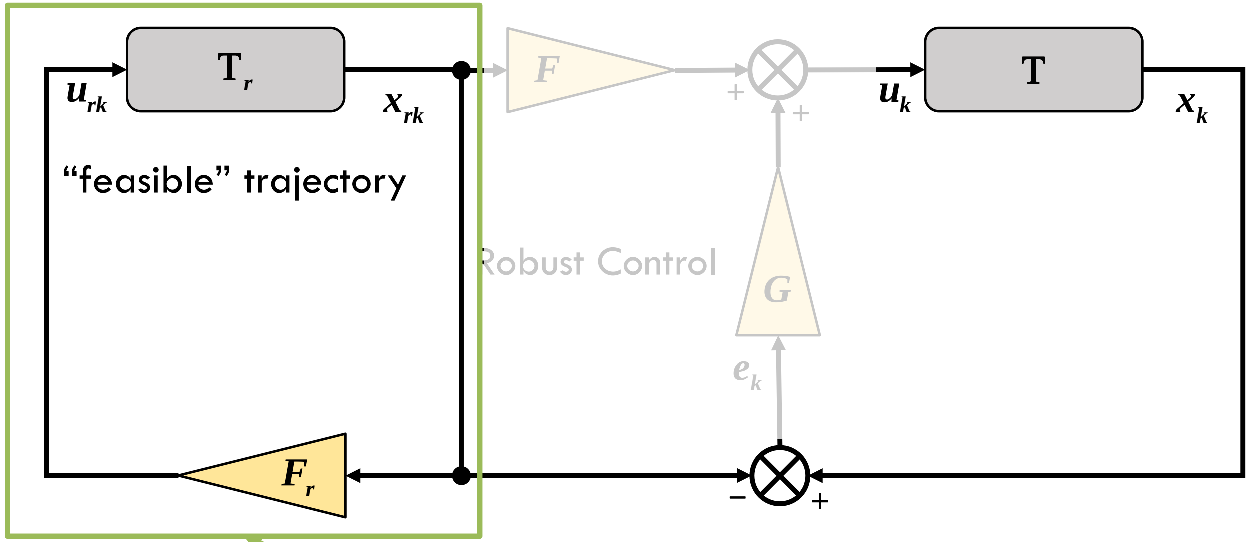
$$E_c(\psi) = \begin{bmatrix} M_b + 2M_w + \frac{2J_w}{r^2} & M_b l\cos(\psi) & 0 \\ M_b l\cos(\psi) & M_b l^2 + J_b & 0 \\ 0 & 0 & 1 \end{bmatrix}, A_c(\psi,\dot{\psi}) = \begin{bmatrix} -\mu_{wg} - \frac{2\mu_m}{r^2} & \frac{2\mu_m}{r} & M_b l\dot{\psi}^2 \operatorname{sinc}\left(\frac{\psi}{\pi}\right) \\ \frac{2\mu_m}{r} & -2\mu_m & M_b g l \operatorname{sinc}\left(\frac{\psi}{\pi}\right) \\ 0 & 1 & 0 \end{bmatrix}$$

Control: robustness

Control Box

Brushless Motor

Drivers & Battery

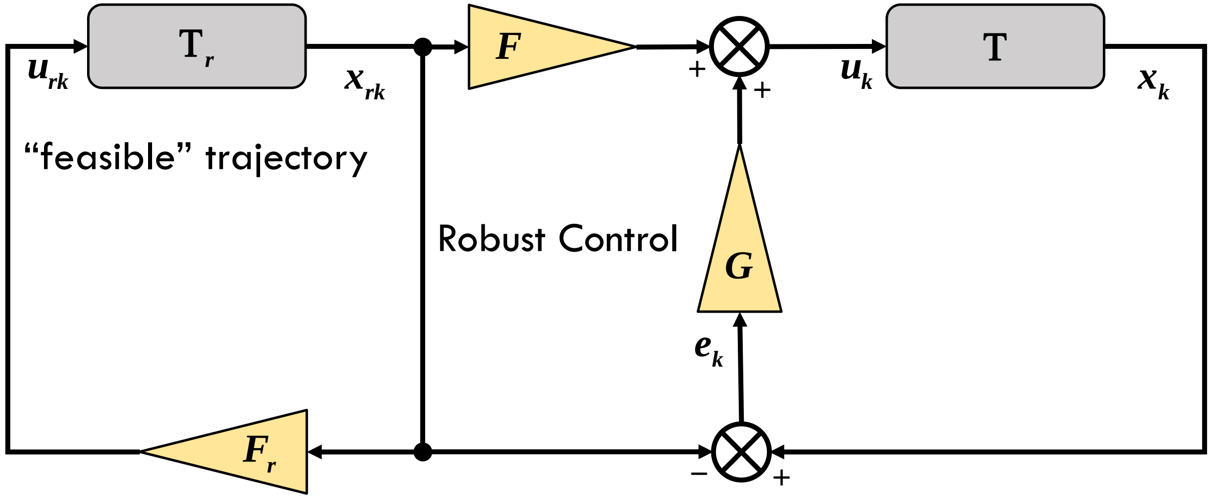


"Simple" ideas:

- follow a "feasible" trajectory (nominal system)

$$\begin{bmatrix} E_r & 0 \\ 0 & E_v \end{bmatrix}\begin{bmatrix} x_{rk+1} \\ e_{k+1} \end{bmatrix} = \begin{bmatrix} A_{rBF} & 0 \\ A_{vw} - E_v E_r^{-1} A_{rBF} & A_{vw} \end{bmatrix}\begin{bmatrix} x_{rk} \\ e_k \end{bmatrix} + \begin{bmatrix} 0 \\ B \end{bmatrix} u_k$$

Control: robustness



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- compensate the errors with a robust control
  Feedforward + Feedback

$$u_k = \begin{bmatrix} F(\cdot) & G(\cdot) \end{bmatrix} H_{(\cdot)}^{-1} \begin{bmatrix} x_{rk} \\ e_k \end{bmatrix}$$

Control: robustness

Unknowns (Blue)

$$\begin{bmatrix} -H_{(\cdot)} - H_{(\cdot)}^T + P_{(\cdot)-} & (*) & 0 & (*) \\ \begin{bmatrix} A_{rBF} & 0 \\ A_{vw} - E_v E_r^{-1} A_{rBF} & A_{vw} \end{bmatrix} H_{(\cdot)} + \begin{bmatrix} 0 \\ B \end{bmatrix} \begin{bmatrix} F(\cdot) & G(\cdot) \end{bmatrix} & -\begin{bmatrix} E_r & 0 \\ 0 & E_v \end{bmatrix} J_{(\cdot)} - (*) + \begin{bmatrix} 0 & 0 & 0 \\ 0 & m^2 S & 0 \\ 0 & 0 & 0 \end{bmatrix} & (*) & (*) \\ 0 & J_{(\cdot)} & -P_{(\cdot)} & 0 \\ \begin{bmatrix} \Omega_{vw} - \Upsilon_v E_r^{-1} A_{rBF} & \Omega_{vw} \end{bmatrix} H_{(\cdot)} & -\begin{bmatrix} 0 & \Upsilon_v \end{bmatrix} J_{(\cdot)} & 0 & -S \end{bmatrix} \prec 0$$

+ some performances: decay rate, smoothness, "low" gains / Comfort

$$\begin{bmatrix} -\lambda I & \begin{bmatrix} F(\cdot) & G(\cdot) \end{bmatrix} \\ \begin{bmatrix} F^T(\cdot) \\ G^T(\cdot) \end{bmatrix} & -P_{(\cdot)-} \end{bmatrix} \prec 0, \quad \lambda P \succ I$$

Real-time results

Lancer:

https://pod.uphf.fr/video/2956-continuous-swing-up-optimal-trajectories-demo/

Summary

Careful: working / Integrating a Human in the loop is challenging and (often) dangerous

4 different examples:

1. Robust Observer-Based Tracking Control Design for Power-Assisted Wheelchairs
   Personal assistance? User's intention?

AutoNomad Mobility

2. Discrete Reference Tracking Control to Swing-Up an Electric Wheelchair
   Passing obstacles, safety? Robustness?

3. Stabilizing unstable biomechanical model to understand sitting stability for persons with spinal cord injury : modelling and observation problems (unmeasurable variables)

ZODIAC AEROSPACE

4. Cable-driven orthosis
   Control and observation problems (unmeasurable variables)

Stabilizing unstable biomechanical model to understand sitting stability for persons with spinal cord injury

Thierry Marie Guerra, Mathias Blandeau, Anh-Tu Nguyen, Hajer Srihi, Antoine Dequidt

Université Polytechnique HAUTS-DE-FRANCE

Dany Gagnon

CRIR Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain

Université de Montréal

[Blandeau, Estrada-Manzo, Guerra, Pudlo, Gabrielli (2018) IFAC Eng Appl Artificial Intell 67, 381-389]
[Srihi, Guerra, Nguyen, Pudlo, Dequidt (2021) Frontiers in Control Eng 2, 710271]
[Blandeau, Guerra, Dequidt, Pudlo, Gagnon (2024) Asian Journal of Control 26 (3), 1134-1150]

Spinal Cord Injury (SCI): illustration

-> Reaching Target exercise

-> Human is highly variable and changing

-> Movements : Symmetric / Assymetric - 2D and 3D

-> High risk of fall *[Boswell-Ruys 2010]*

-> Postural regulation by the upper body *[Nelson et al. 2010]*

→ Reduced seated stability in seated position

Goal: estimate unknown torques (inputs) for SCI people with guarantee of state error convergence under assumption of “slow” (human compatible) varying input torques, possible results on recorded data

Problems

Goal: estimate unknown torques (inputs) for SCI people with guarantee of state error convergence under assumption of “slow” (human compatible) varying input torques, possible results on recorded data

Human

Active torques

$u(t)$

Passive moment (trunk)

Unknown inputs

Measurement (angles)

$y(t) = q(t)$

$x(t)$

Observer???

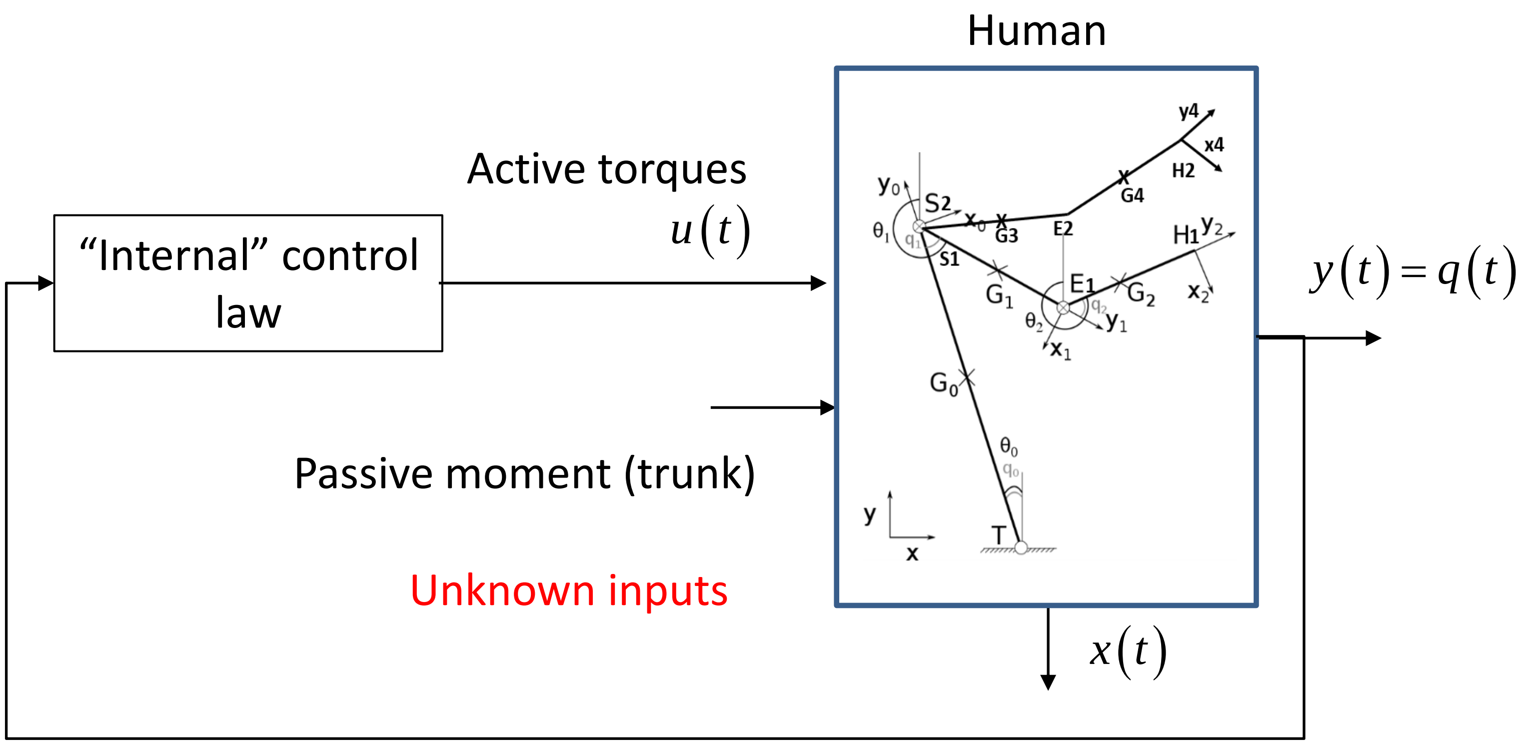
$\hat{x}(t), \hat{\Gamma}(t)$

Torques are unmeasurable (except using invasive methods → ethically prohibited)

More problems: for simulation

Classical Models are unsuitable for stability of SCI people, *[Reeves et al, 2009, Tanaka et al, 2010]*

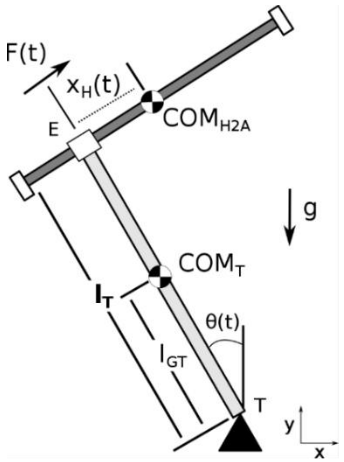
Goal: step 1 → biomechanical model BUT unstable open-loop + transmission delays + low stability region…



Out-of-scope for this talk

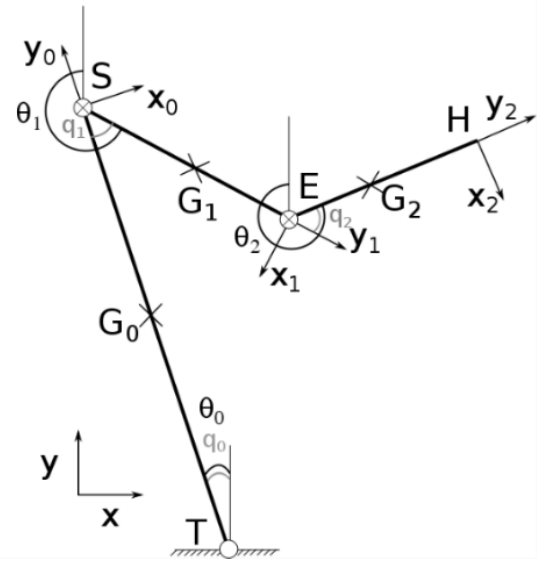
→ Focus on observer part

Previous works (PhD M. Blandeau 2018)



Head-2-Arms-Trunk” (H2AT) with 2 Degrees-of-Freedom

$$
\begin{cases}
F(t-\tau) = m_H \ddot{x}_H - m_H \ddot{\theta} l_T - \frac{1}{2}\dot{\theta}^2 m_H 2x_H + m_H g \sin(\theta) \\
0 = \ddot{\theta}\left(I_{G_T} + m_T l_{G_T}^2 + I_{G_H} + m_H l_T{}^2 + m_H x_H{}^2\right) - m_H l_T \ddot{x}_H + \dot{\theta} m_H 2 x_H \dot{x}_H - \left(m_H l_T + m_T l_{G_T}\right) g \sin(\theta) + m_H g x_H \cos(\theta)
\end{cases}
$$



Seated-3-segments” (S3S) model involving 3 DoF

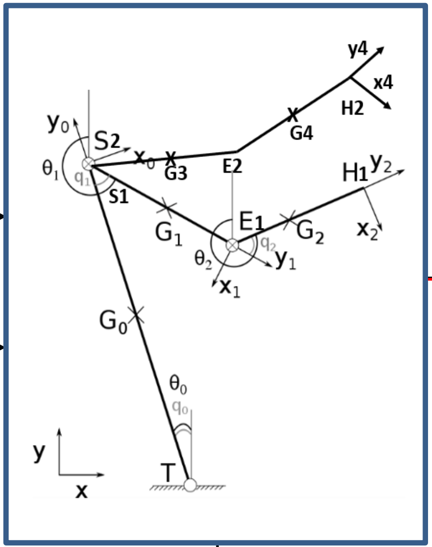
$$
\begin{cases}
\begin{aligned}
M_T = {} & \ddot{q}_0\left(I_{q0} - 2\left(m_1 l_0 l_{G_1} + m_2 l_0 l_1\right)\cos(q_1) - 2m_2 l_0 l_{G_2}\cos(q_2+q_1) + 2m_2 l_1 l_{G_2}\cos(q_2)\right) + \ddot{q}_1\left(I_{q1} - \left(m_1 l_0 l_{G_1} + m_2 l_0 l_1\right)\cos(q_1) - m_2 l_0 l_{G_2}\cos(q_2+q_1)\right) \\
& + \ddot{q}_2\left(I_{q2} - m_2 l_0 l_{G_2}\cos(q_2+q_1) + m_2 l_1 l_{G_2}\cos(q_2)\right) + \dot{q}_1{}^2\left(\left(m_1 l_0 l_{G_1} + m_2 l_0 l_1\right)\sin(q_1) + m_2 l_0 l_{G_2}\sin(q_2+q_1)\right) \\
& + \dot{q}_2{}^2\left(m_2 l_0 l_{G_2}\sin(q_2+q_1) - m_2 l_1 l_{G_2}\sin(q_2)\right) + 2\dot{q}_0\dot{q}_1\left(\left(m_1 l_0 l_{G_1} + m_2 l_0 l_1\right)\sin(q_1) + m_2 l_0 l_{G_2}\sin(q_2+q_1)\right) \\
& + 2\dot{q}_0\dot{q}_2\left(m_2 l_0 l_{G_2}\sin(q_2+q_1) - m_2 l_1 l_{G_2}\sin(q_2)\right) + 2\dot{q}_1\dot{q}_2\left(m_2 l_0 l_{G_2}\sin(q_2+q_1) - m_2 l_1 l_{G_2}\sin(q_2)\right) - \left(m_0 g l_{G_0} + m_1 g l_0 + m_2 g l_0\right)\sin(q_0) \\
& + \left(m_1 g l_{G_1} + m_2 g l_1\right)\sin(q_1+q_0) + m_2 g l_{G_2}\sin(q_2+q_1+q_0) \\
M_E = {} & \ddot{q}_0\left(I_{q1} + 2m_2 l_1 l_{G_2}\cos(q_2) - \left(m_1 l_0 l_{G_1} + m_2 l_0 l_1\right)\cos(q_1) - m_2 l_0 l_{G_2}\cos(q_2+q_1)\right) + \ddot{q}_1\left(I_{q1} + 2m_2 l_1 l_{G_2}\cos(q_2)\right) + \ddot{q}_2\left(I_{q2} + m_2 l_1 l_{G_2}\cos(q_2)\right) \\
& - \dot{q}_0{}^2\left(\left(m_1 l_0 l_{G_1} + m_2 l_0 l_1\right)\sin(q_1) + m_2 l_0 l_{G_2}\sin(q_2+q_1)\right) - \dot{q}_2{}^2 m_2 l_1 l_{G_2}\sin(q_2) \\
& - 2\dot{q}_0\dot{q}_2 m_2 l_1 l_{G_2}\sin(q_2) - 2\dot{q}_1\dot{q}_2 m_2 l_1 l_{G_2}\sin(q_2) + \left(m_1 g l_{G_1} + m_2 g l_1\right)\sin(q_1+q_0) + m_2 g l_{G_2}\sin(q_2+q_1+q_0) \\
M_C = {} & \ddot{q}_0\left(I_{q2} - m_2 l_0 l_{G_2}\cos(q_2+q_1) + m_2 l_1 l_{G_2}\cos(q_2)\right) + \ddot{q}_1\left(I_{q2} + m_2 l_1 l_{G_2}\cos(q_2)\right) + \ddot{q}_2 I_{q2} \\
& + \dot{q}_0{}^2\left(m_2 l_1 l_{G_2}\sin(q_2) - m_2 l_0 l_{G_2}\sin(q_2+q_1)\right) + \dot{q}_1{}^2 m_2 l_1 l_{G_2}\sin(q_2) + 2\dot{q}_0\dot{q}_1 m_2 l_1 l_{G_2}\sin(q_2) + m_2 g l_{G_2}\sin(q_2+q_1+q_0)
\end{aligned}
\end{cases}
$$

Tools

Human

Active torques

$u(t)$



$y(t)=q(t)$

Passive moment (trunk)

Unknown inputs

$x(t)$

Observer???

$\hat{x}(t), \hat{\Gamma}(t)$

Unknown input observer or PI-observer

Assumption: Human movements are slower enough to be captured by a cascade of *p* integrators

$$\frac{d^p u(t)}{dt^p} \approx 0 \quad U(t)=\begin{bmatrix} u(t) \\ \dot{u}(t) \\ \vdots \\ u^{(p-1)}(t) \end{bmatrix}$$

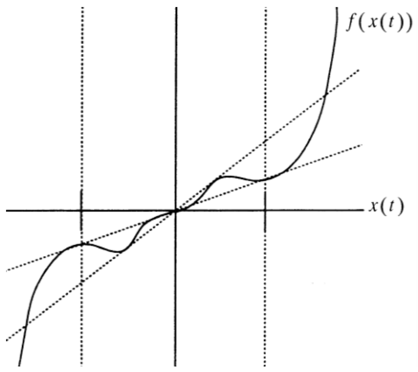
$$\begin{cases} \begin{bmatrix} E(y) & 0 \\ 0 & I \end{bmatrix}\begin{bmatrix} \dot{x}(t) \\ \dot{U}(t) \end{bmatrix} = \begin{bmatrix} A(x(t)) & [B \quad 0 \quad \dots \quad 0] \\ 0 & \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} \end{bmatrix}\begin{bmatrix} x(t) \\ U(t) \end{bmatrix} \\ y(t)=[C \quad 0 \quad \dots \quad 0]\begin{bmatrix} x(t) \\ U(t) \end{bmatrix} \end{cases}$$

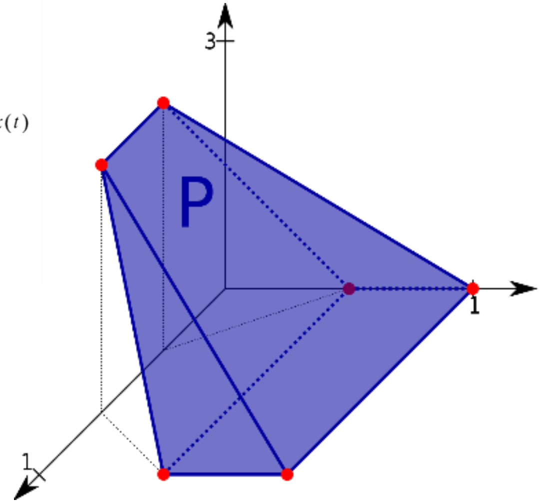
Extended model

$$\begin{cases} E^e(y)\dot{x}^e(t)=A^e(x^e(t))x^e(t) \\ y(t)=C^e x^e(t) \end{cases}$$

Polytopic representation & more problems

Non-linear descriptor Form: $\begin{cases} E^e(y)\dot{x}^e(t) = A^e(x^e(t))x^e(t) \\ y(t) = C^e x^e(t) \end{cases}$





$$\Omega_x = \begin{Bmatrix} -5 \le q_0 \le 5 & \|\dot{q}_0\| \le 29 \\ -20 \le q_{1S} \le 60\ , & \|\dot{q}_{1S}\| \le 57 \\ -10 \le q_{2S} \le 45 & \|\dot{q}_{2S}\| \le 57 \end{Bmatrix}$$

Sector nonlinearity approach

[Ohtake et al. 2001, Tanaka et Wang 2001]

Polytopic representation in a descriptor form:

$$\sum_{i=1}^{r} h_i(y)E_i\dot{x}^e(t) = \sum_{i=1}^{r} h_i(x)A_i x^e(t)$$ *[Taniguchi et al. 2001]:*

Build an observer:

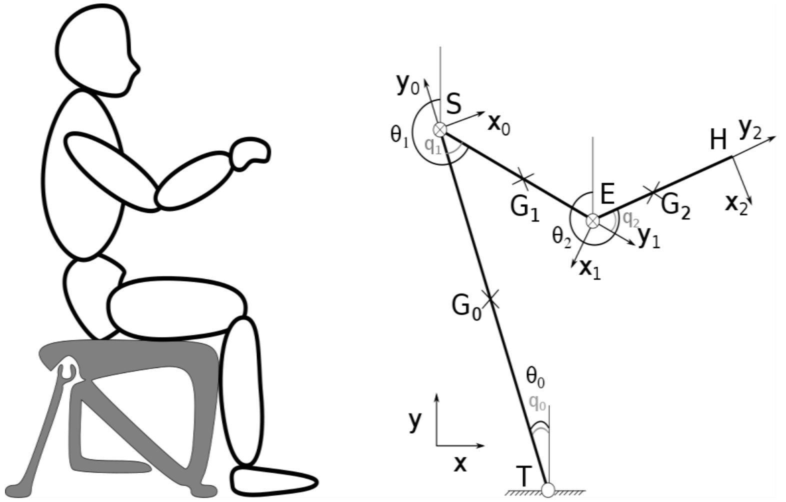
Not available

$$\sum_{i=1}^{r} h_i(y)E_i\dot{\hat{x}}^e(t) = \sum_{i=1}^{r} h_i(\hat{x})A_i\hat{x}^e(t) + K^e(y,\hat{x})(y-\hat{y})$$

Convergence of the error to 0? Mismatch due to:

$$E^e(y)\dot{e}(t) = \left(A^e(\hat{x}(t)) - K^e(\hat{x}(t))C^e\right)e(t) + \left(A^e(x(t)) - A^e(\hat{x}(t))\right)x(t)$$

Complexity: previous works



S3S Seated-3-Arms 3 DoF (*Blandeau, 2018*)

To give an idea of complexity, in discrete:

$$\begin{bmatrix} -\lambda P & \left(H(q_k)A_i^e - K_i C^e\right)^T \\ H(q_k)A_i^e - K_i C^e & P - H(q_k)E_i^e - \left(H(q_k)E_i^e\right)^T \end{bmatrix} < 0, \quad i \in \{1,2,\ldots,128\}.$$

$$A_i^e, E_i^e \in \mathbb{R}^{12\times 12}$$

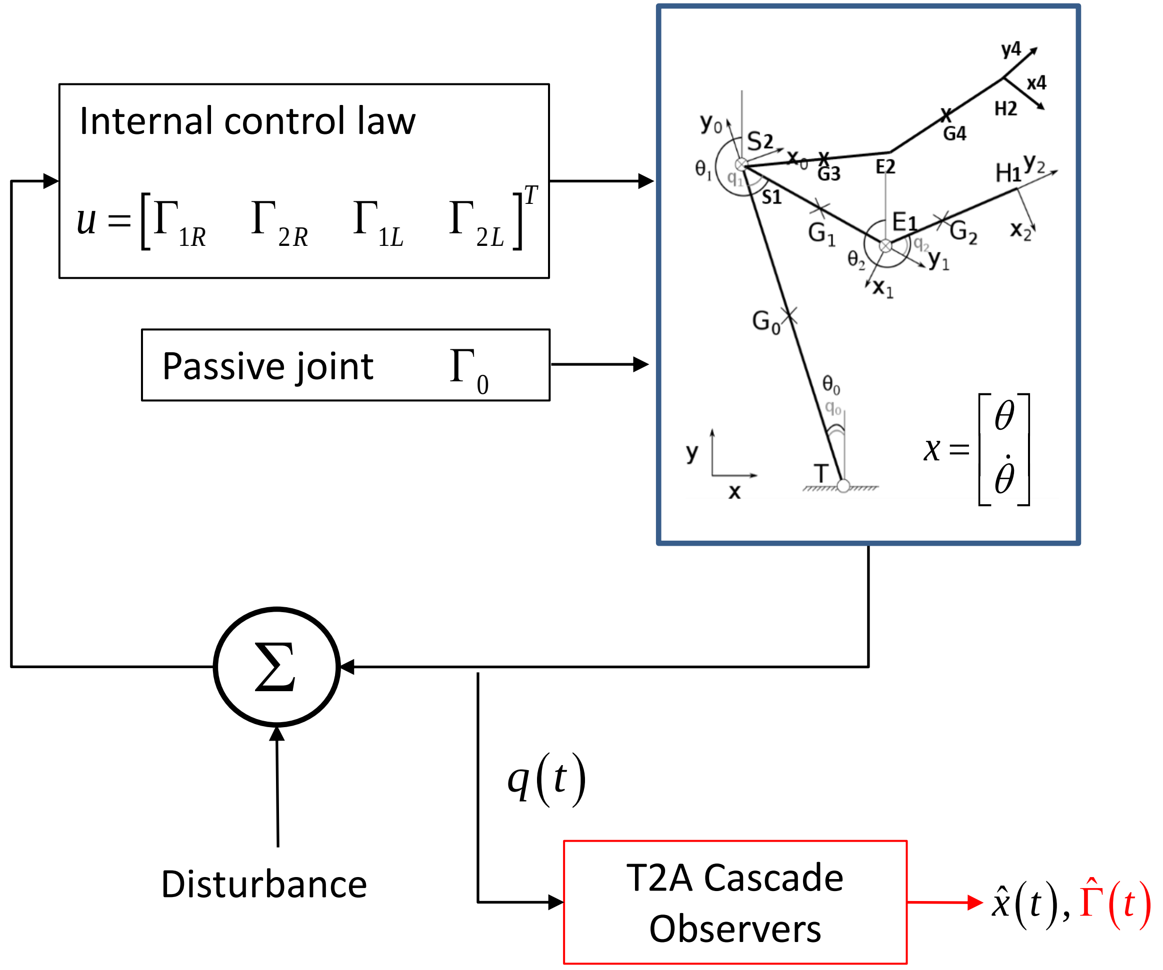
$H(q_k) = H$	Solver compatibility → No solution	128 LMI, 4830 variables, $\mathbb{R}^{24\times 24}$
$H(q_k) = \sum_{i=1}^{128} h_i(q_k) H_i$	Solver incompatibility	8256 LMI, 32092 variables, $\mathbb{R}^{24\times 24}$
$H(q_k) = \begin{bmatrix} H_{1,h} & H_2 & H_{3,h} \end{bmatrix}$	Solver compatibility → solution	128 LMI, 18510 variables, $\mathbb{R}^{24\times 24}$

$H_{1,h} \in \mathbb{R}^{12\times 3}, \; H_2 \in \mathbb{R}^{12\times 3}, \; H_{3,h} \in \mathbb{R}^{12\times 6}$

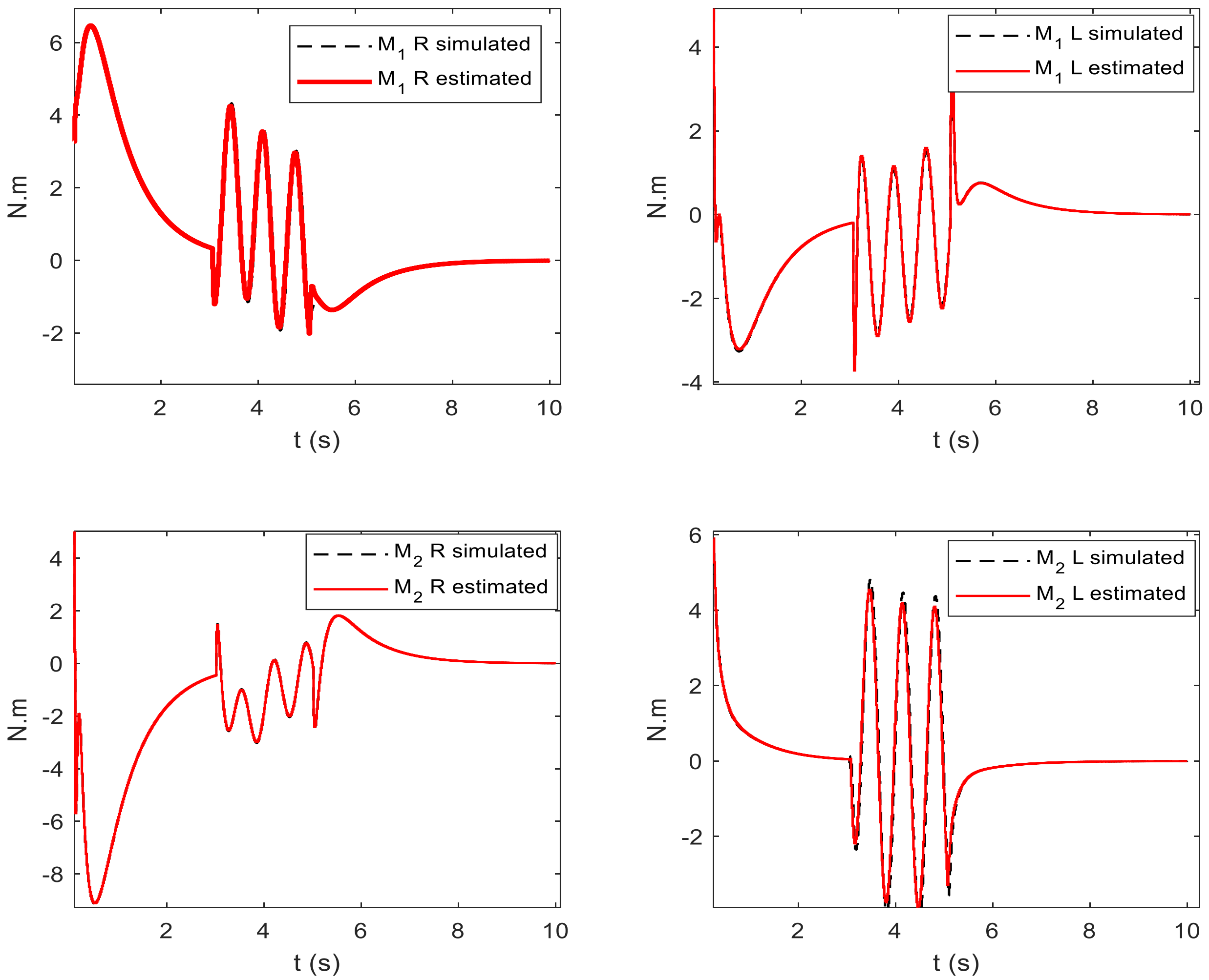
⇒ Close to solver limits

Simulations

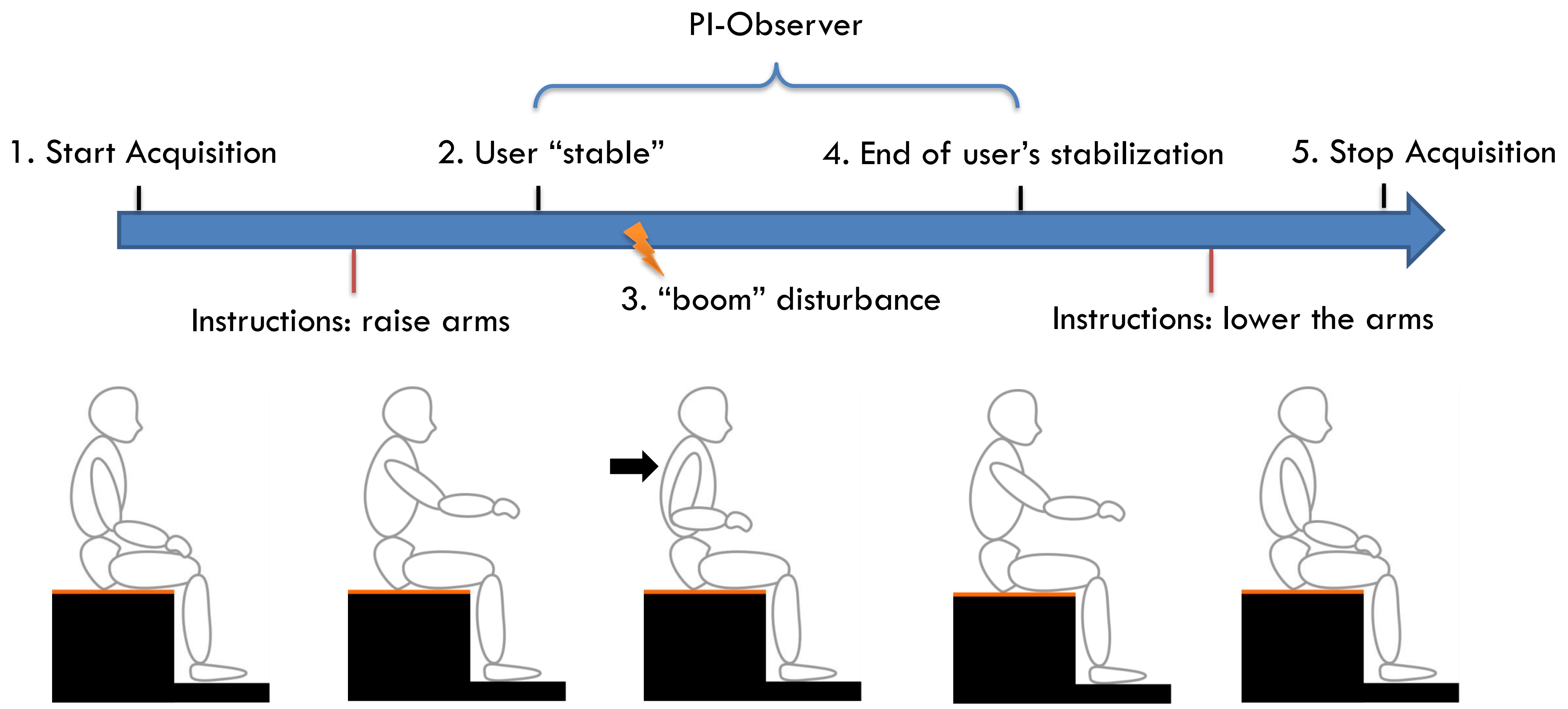
Simulation protocol



Torques at left and right shoulder and elbow level by T2A observers

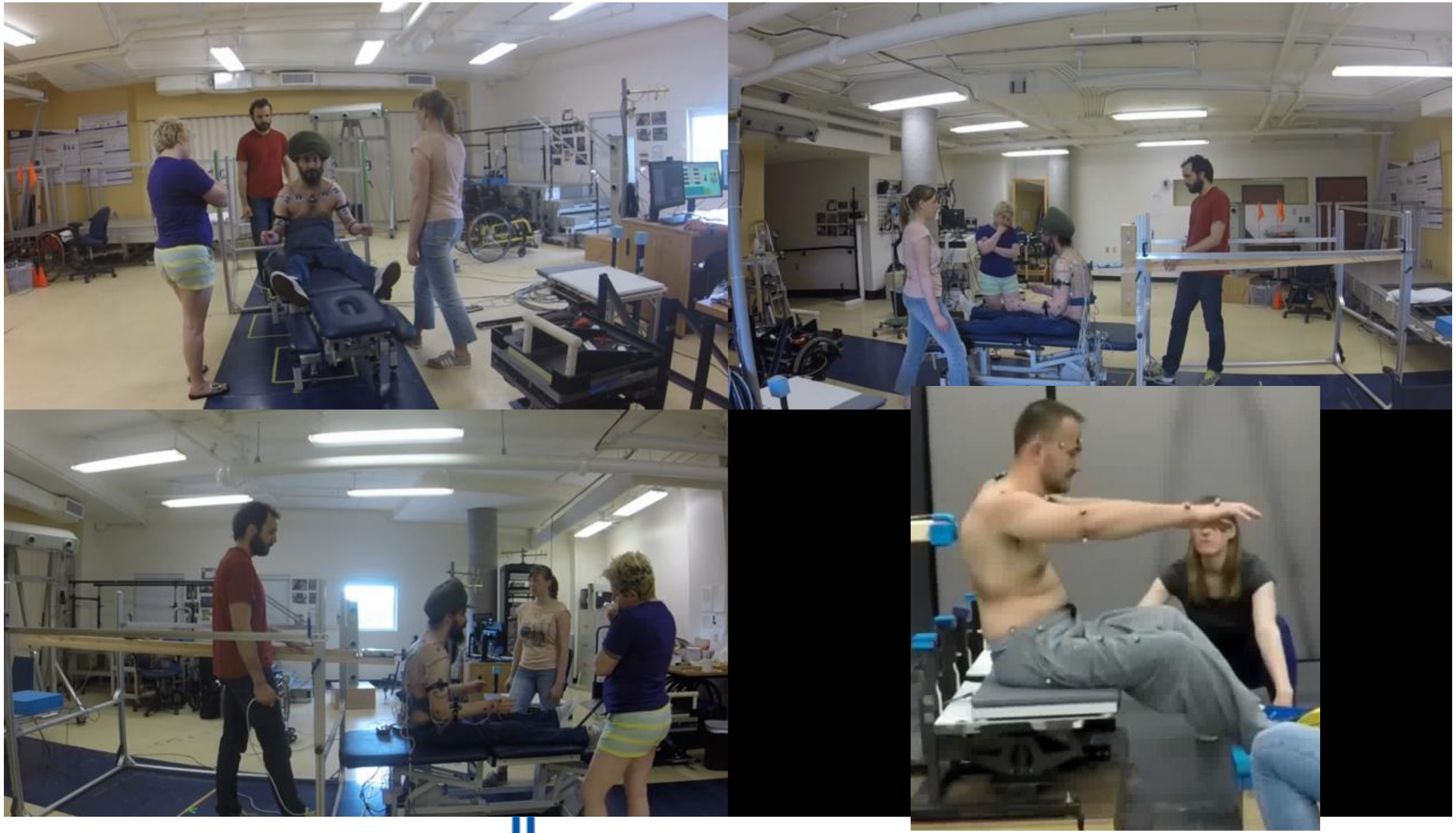


Protocol



$$\theta(t) \longrightarrow \boxed{\text{T2A Observers}} \longrightarrow \hat{\dot{\theta}}(t), \hat{\Gamma}$$

Experimental Validation



Université
de Montréal

Lumbar torque estimation (symmetric movements)

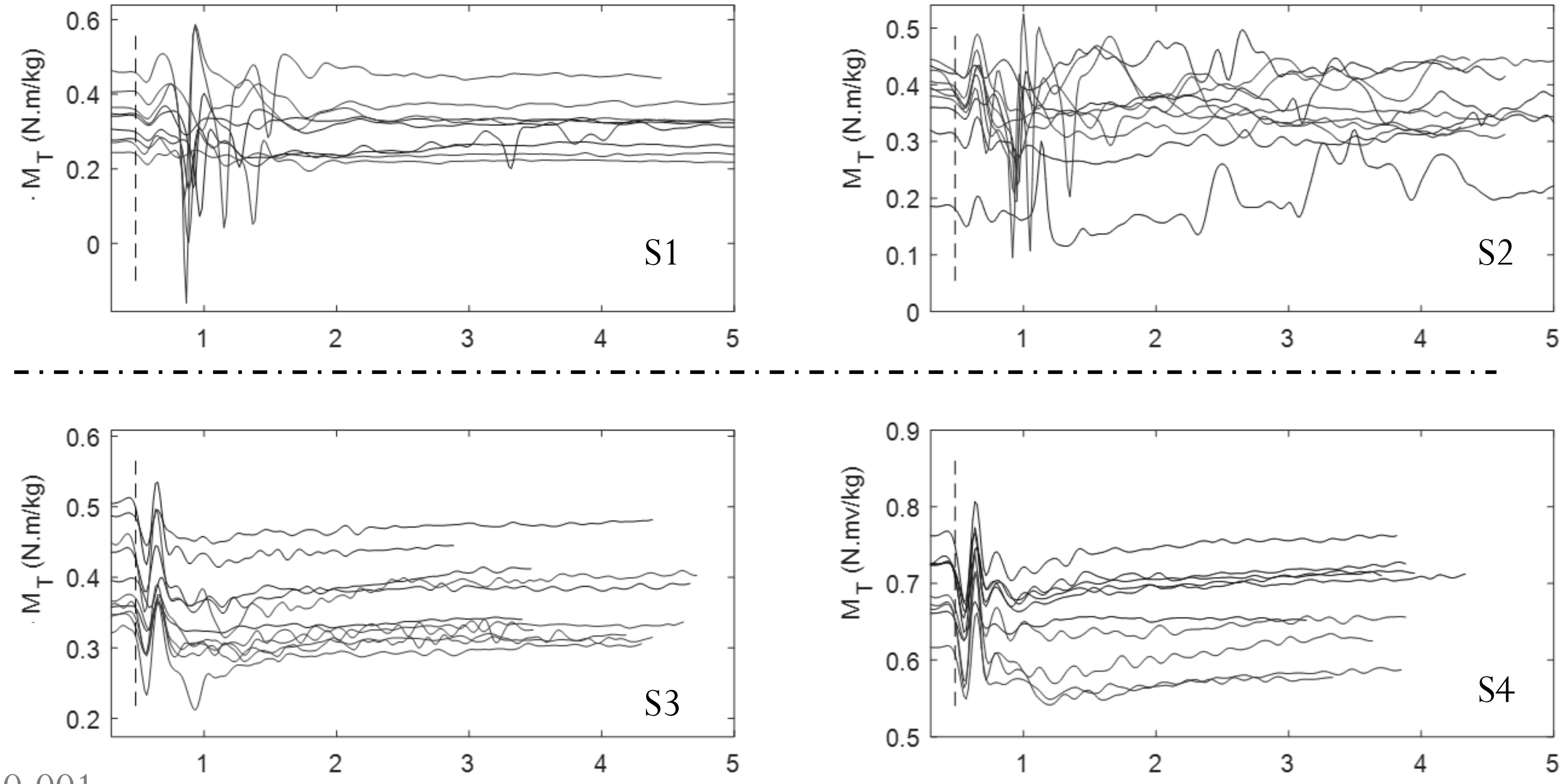
LAMIH UMR CNRS 8201 · cnrs · Université Polytechnique Hauts-de-France

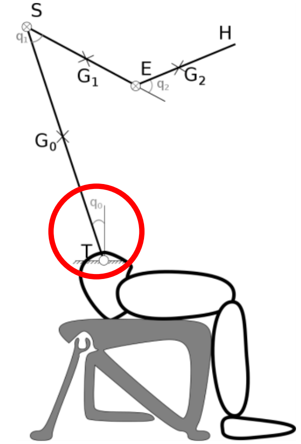
S1 & S2 : Low movement strategy
S3 & S4 : High fix strategy

2 conditions
6 trials / conditions

Basse Mobile

Haute Fixe





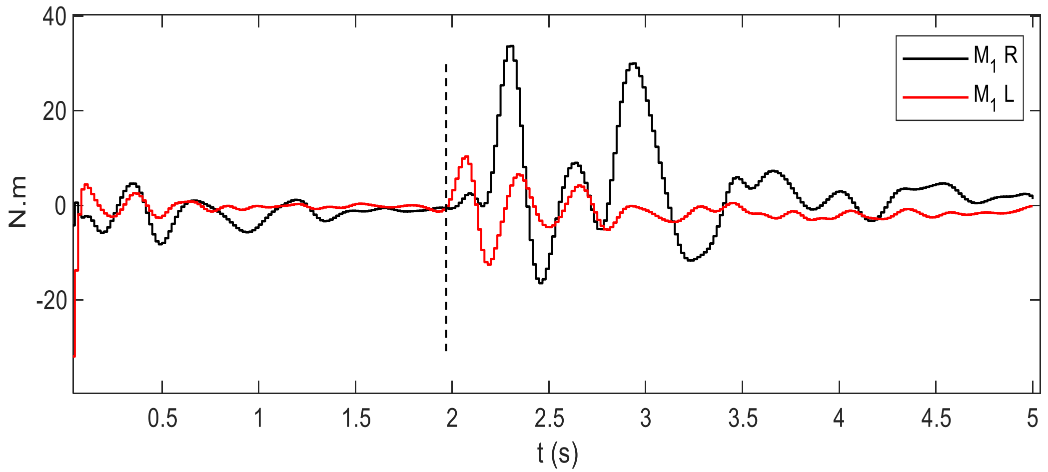
$p < 0{,}001$

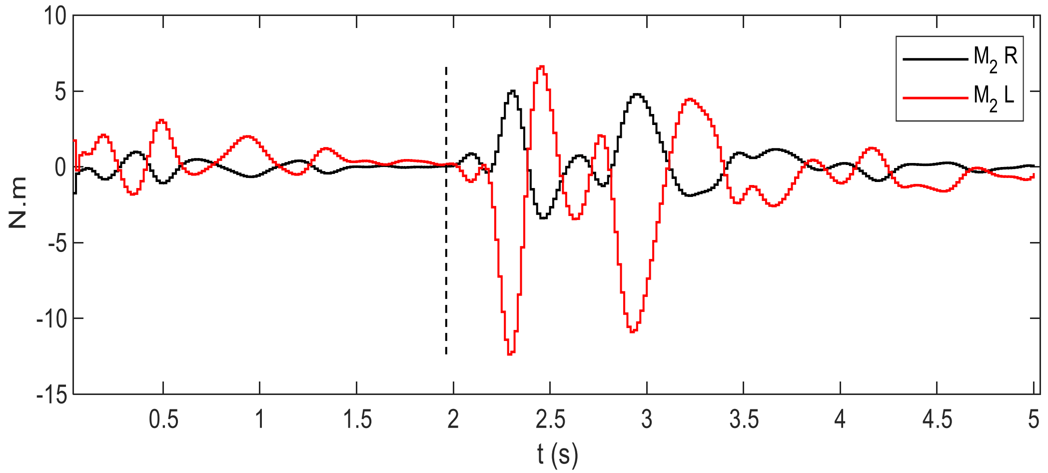
INSA Institut National des Sciences Appliquées Hauts-de-France · Institut Carnot ARTS

Experimental Validation (asymmetric)

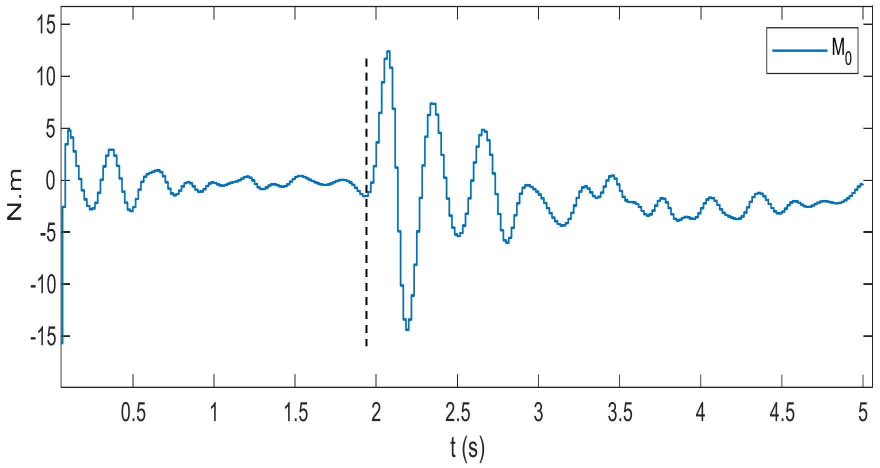
LAMIH UMR CNRS 8201

Estimated active torques (Shoulder and Elbow)





via $\hat{\Gamma}_0 = \hat{\Gamma}_U - \hat{\Gamma}_c$ → Lumbar torque



The Judge

The “controlled” Judge

Perturbation

Σ

“Internal” control law

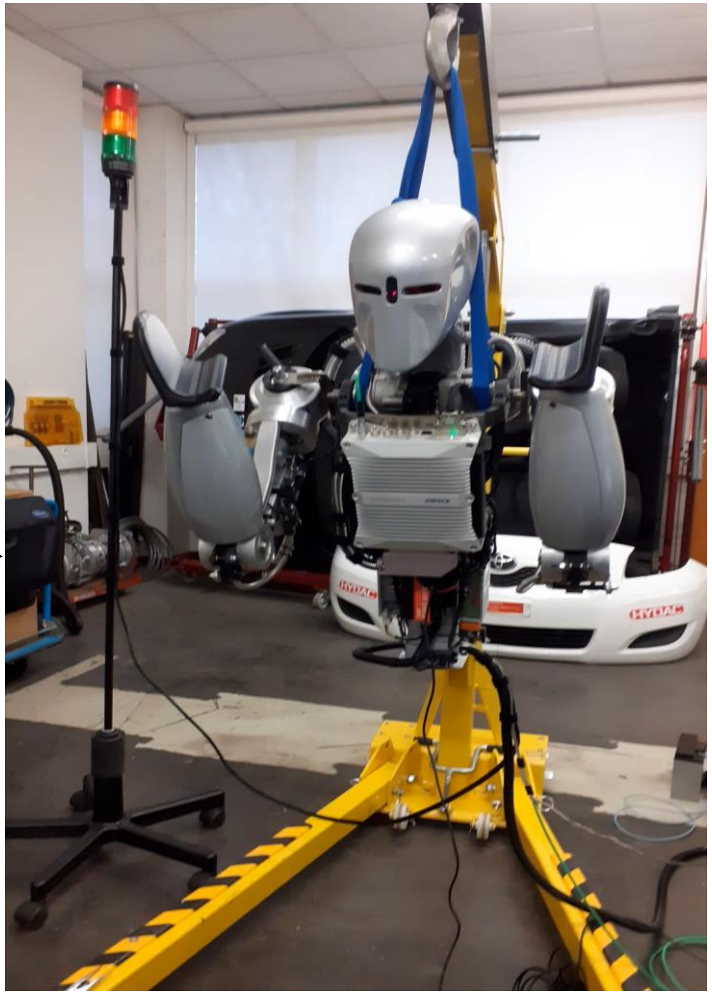
Active torques

$u(t)$

$\Gamma(t)$

Passive moment (trunk)

Experimentally known inputs



$y(t)=q(t)$

T2A Cascade Observers

$\hat{x}(t), \hat{\Gamma}(t)$

$$\varepsilon_i = \Gamma_i - \hat{\Gamma}_i$$

Summary

Careful: working / Integrating a Human in the loop is challenging and (often) dangerous

4 different examples:

1. Robust Observer-Based Tracking Control Design for Power-Assisted Wheelchairs
   Personal assistance? User's intention?

2. Discrete Reference Tracking Control to Swing-Up an Electric Wheelchair
   Passing obstacles, safety? Robustness?

3. Stabilizing unstable biomechanical model to understand sitting stability for persons with spinal cord injury : modelling and observation problems (unmeasurable variables)

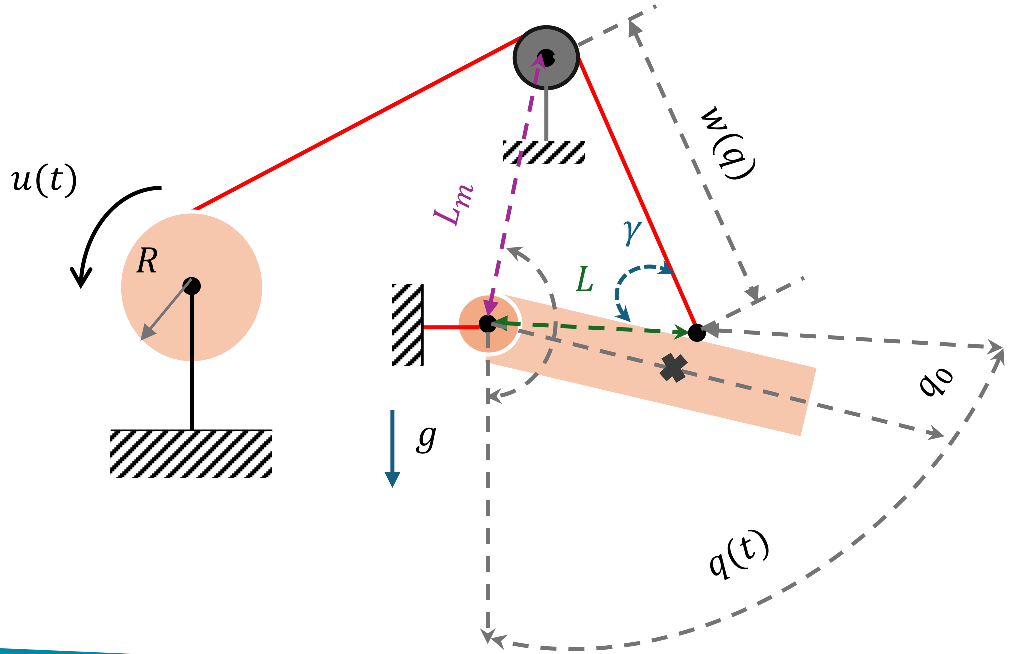
4. Cable-driven orthosis
   Control and observation problems (unmeasurable variables)

Assistance Orthosis… cable-driven

PhD Ney Ortiz Guterriez: Thierry Marie Guerra, Marcia Luciana Da Costa Peixoto

Vicenç Puig, PU Catalonia

One DoF (the knee) → but control and observation thought generic (from the start)



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Assistance Orthosis… cable-driven

Descriptor form:

$$\begin{bmatrix}1 & 0\\ 0 & e(q)\end{bmatrix}\dot{x}(t)=\begin{bmatrix}0 & 1\\ a_1(q) & a_2(q,\dot{q})\end{bmatrix}x(t)+\begin{bmatrix}0 & 0\\ 1 & b(q)\end{bmatrix}\begin{bmatrix}u(t)\\ u_h(t)\end{bmatrix},\quad x(t)=\begin{bmatrix}q(t)\\ \dot{q}(t)\end{bmatrix}$$

$$g(q)=\frac{L}{R}\cos(\gamma(q))\left(1-L\frac{\cos(\gamma(q))}{w(q)}\right),\quad h(q)=\frac{L}{R}\sin(\gamma(q)),\quad b(q)=1/h(q)$$

$$w(q)=\sqrt{L^2+L_m^2-2LL_m\cos(\phi_0-q(t))},\quad \cos(\gamma(q))=\frac{L^2-L_m^2+w^2(q)}{2Lw(q)}$$

$$a_1(q)=G_l\frac{\sin(q)}{q},\quad a_2(q,\dot{q})=J_m g(q)h(q)\dot{q}+B_m h^2(q)+B_l,\quad e(q)=J_m h^2(q)+J_l$$

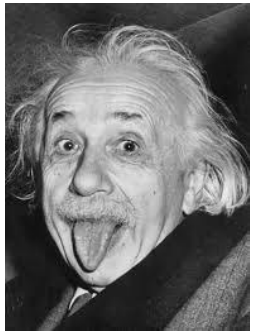
+ robust control + UIO observer…

Technology for Health through non-linear control Theory

Thierry Marie GUERRA, Marcia Luciana Da Costa PEIXOTO

Thanks

"The truth is rarely pure and never simple."
Oscar Wilde



"If we knew what it was we were doing, it would not be called research, would it?"

Definition of stupid: knowing the Truth, seeing the Truth, but still believing the lies (Unknown)