Motion generation for humanoid robots aiming at industrial applications

June 21-22th 2017, Robotex, TechDays 2017, Clermont-Ferrand

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Team, LAAS-CNRS

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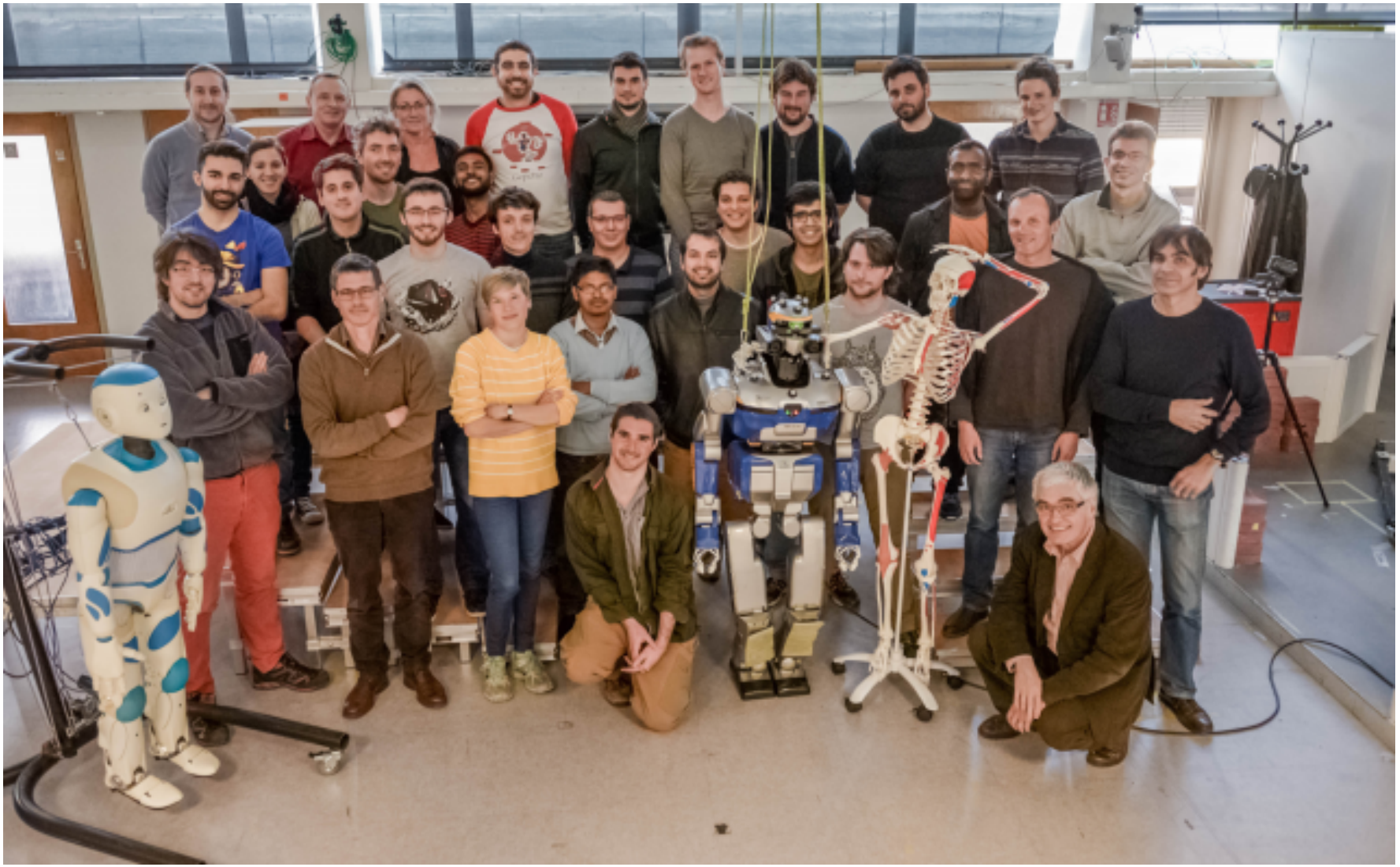
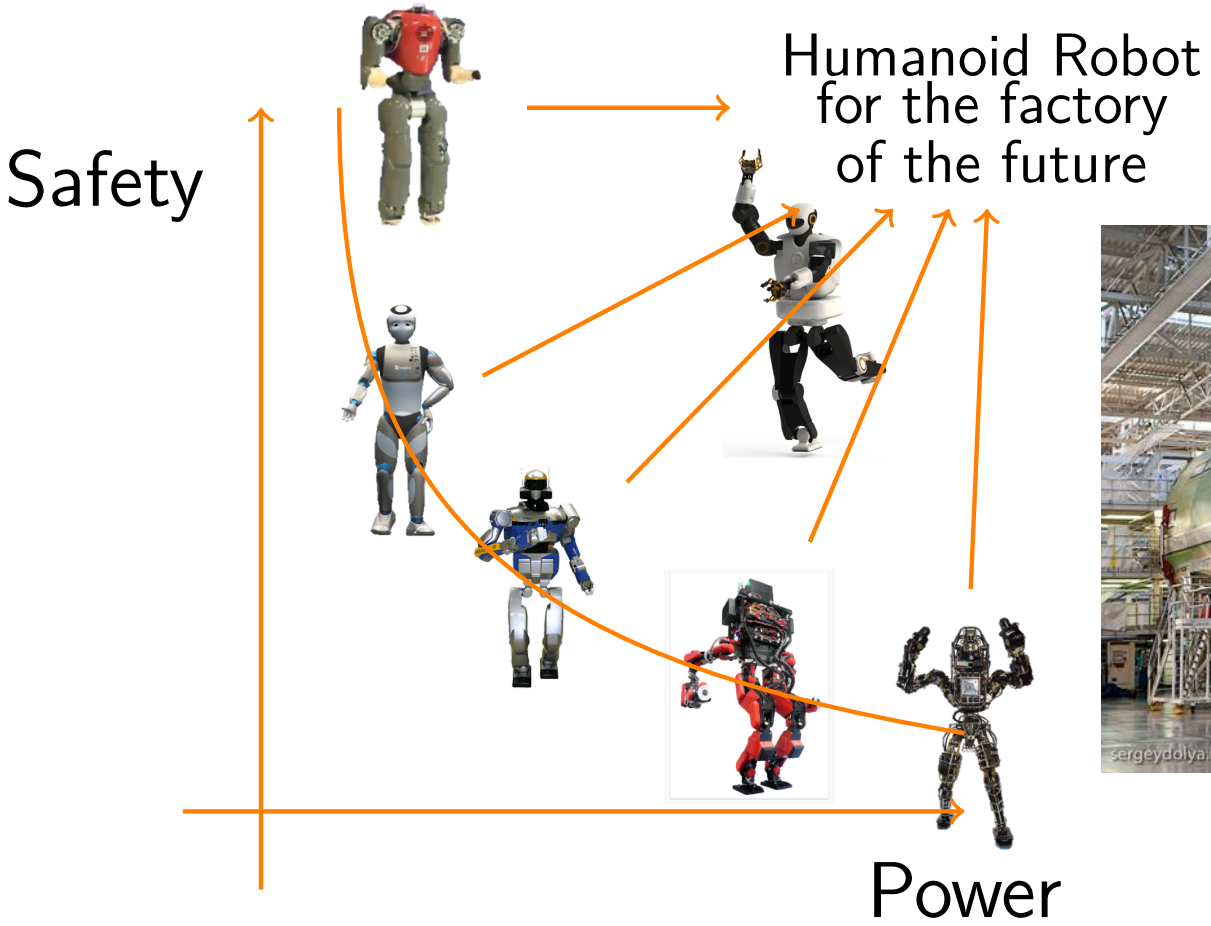
Acknowledgements



Testing our algorithms in real industrial use case



A replacement to HRP-2

- Pros
  - Highly reliable
  - Very robust (not able to jump ...)
  - Understanding of the software architecture
- Cons
  - Closed access to the low level part
  - DC - Brush motors (unable to achieve fast speed- high torque)
  - Low software support 10.04 LTS $\cdots$

Characteristics for a new humanoid

- Should hold a $10Kg$ tool at strech arm
- Reaction to push recovery (need high speed - high torque)
- Frequency of control at $1KHz$ for OSID
- Low level access needed
- Skin ?

The robots around

- ATLAS - Hydraulic actuation - 2 M$ - Not available
- WALKMAN - Electric actuation - Support is an issue
- Valkyrie - SEA - 2.7 M$ - Need a contract agreement with NASA (Edinburgh)
- TORO - Not available - Maybe one day through Kuka
- Proxi SRI - 97 % transmission efficiency
- REEM-C - Position control AC motor - HD - 300 k euros

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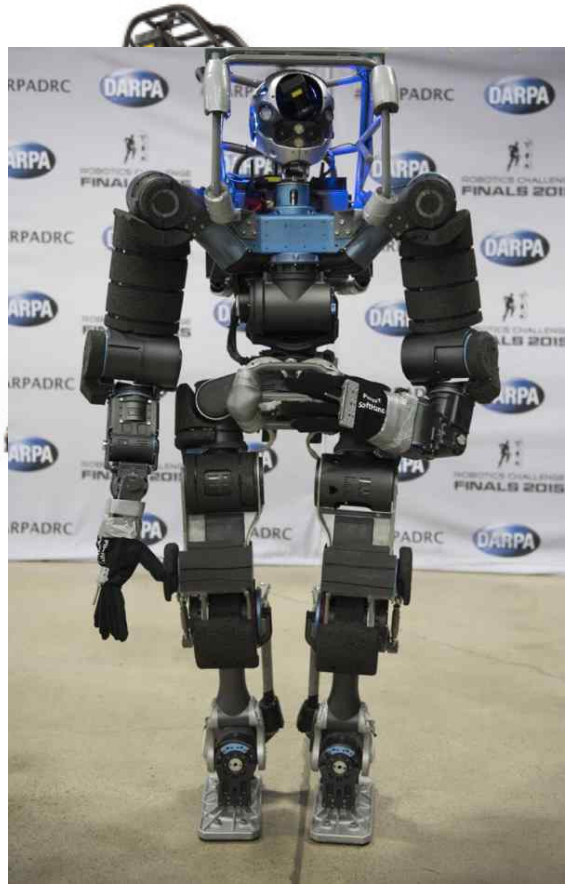

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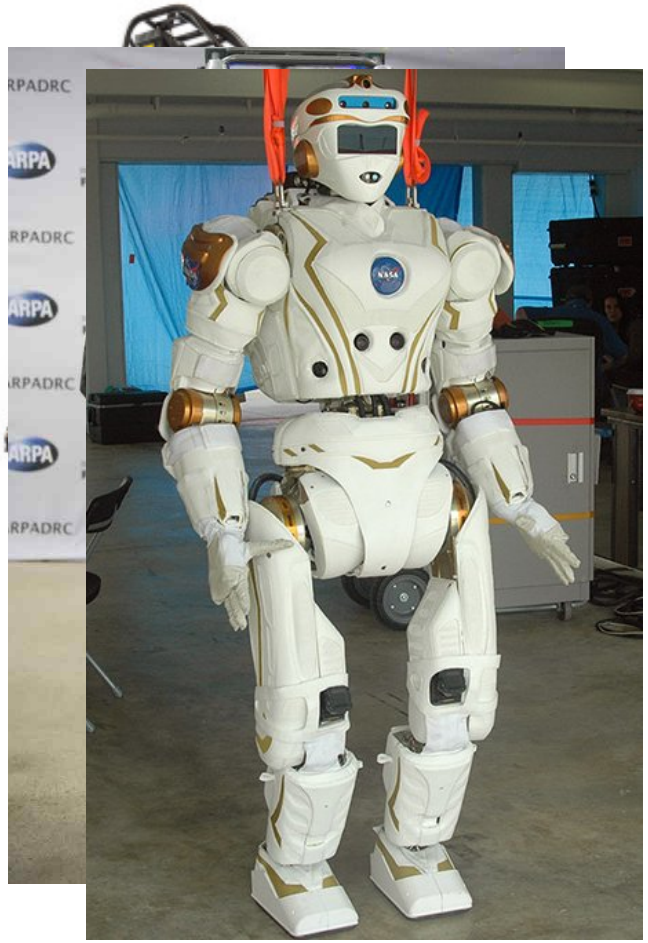

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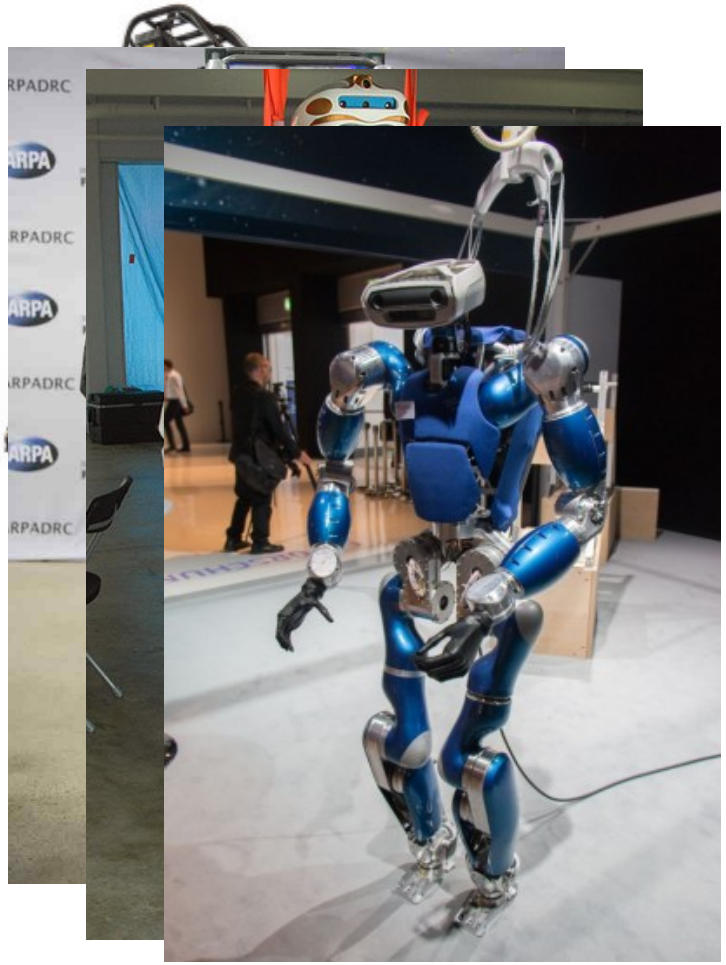

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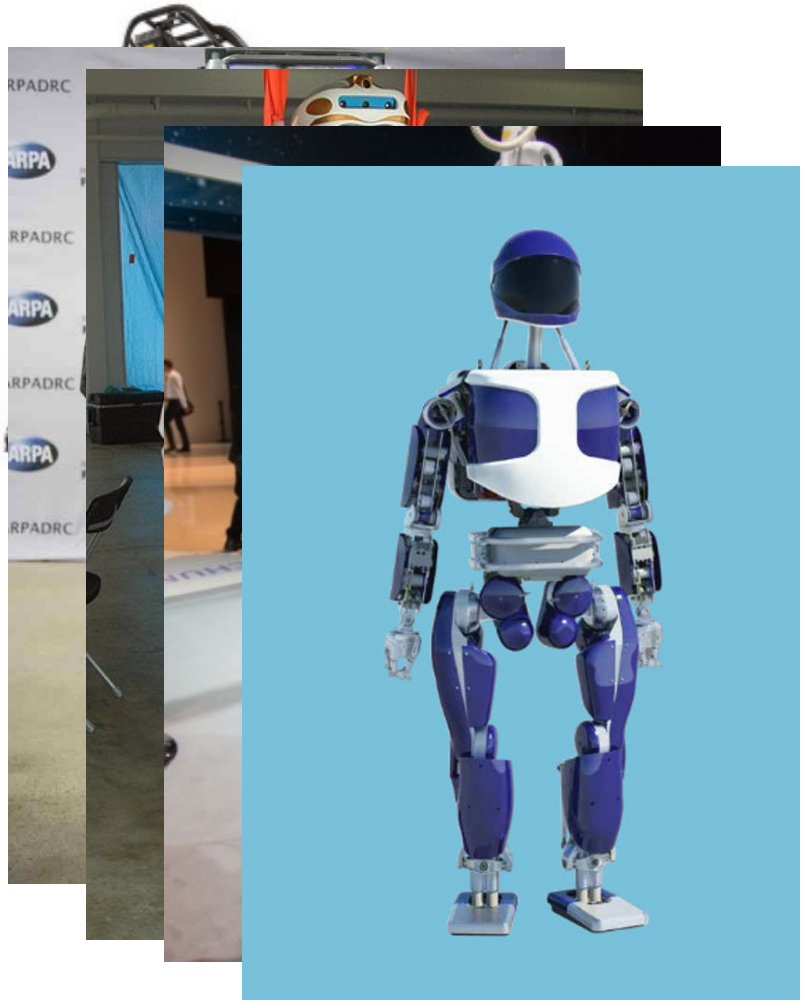

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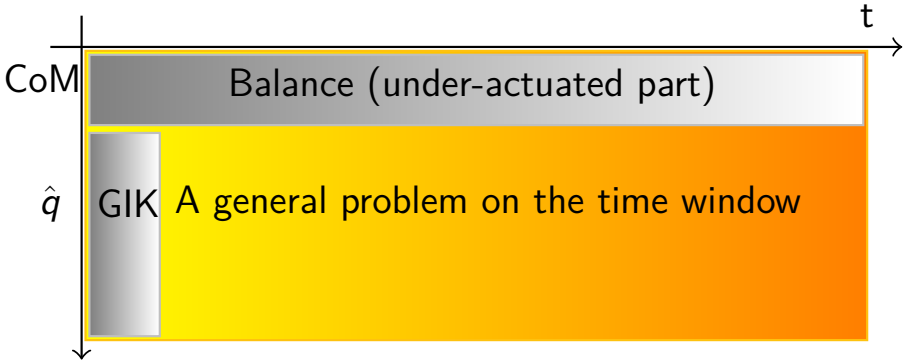
Pyrene: First prototype of the TALOS serie

[Submitted to IHRC 2017] https://www.youtube.com/watch?v=SxdNvP2jKcc

Motion generation: the problem

$$\begin{cases} \min f(\mathbf{u}(t), \mathbf{v}(t)) \\ \mathbf{g}(\mathbf{u}(t), \mathbf{v}(t)) < 0 \\ \mathbf{h}(\mathbf{u}(t), \mathbf{v}(t)) = 0 \end{cases}$$



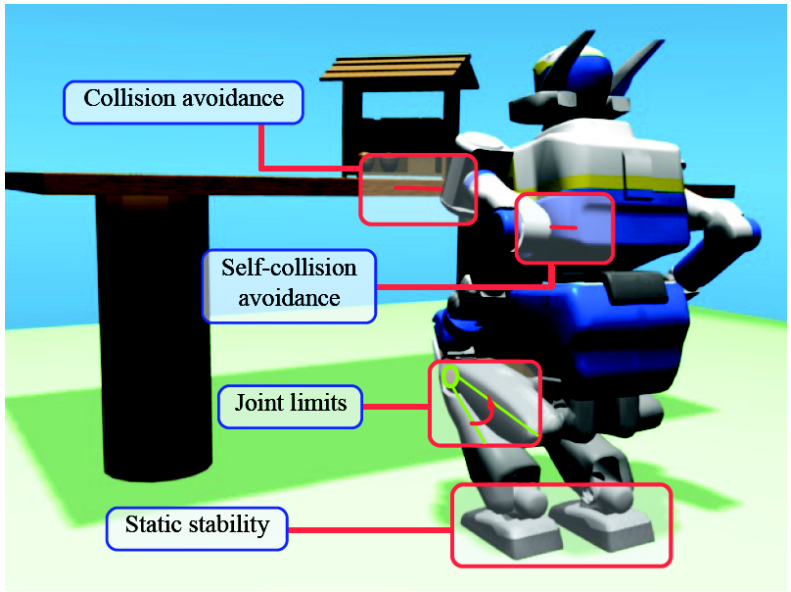
$\mathbf{f}(t)$: The cost function

$\mathbf{u}(t)$: The control vector

$\mathbf{g}(t)$: The inequality constraints

$\mathbf{h}(t)$: The equality constraints

$\mathbf{v}(t)$: The environment model

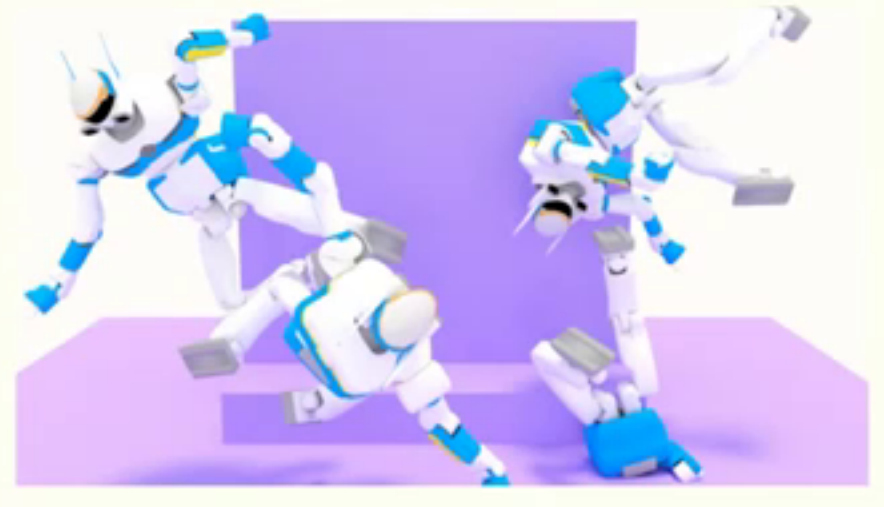


SDKs

- Gepetto is developping Software Development Kits
- Stack Of Tasks
- Humanoid Path Planner

- Try to identify software patterns from the problem formulation
- Write our own solvers when needed (often)
- Be as much generic as possible
- Fragment the code
- Integration through a build farm with binairies (robotpkg)

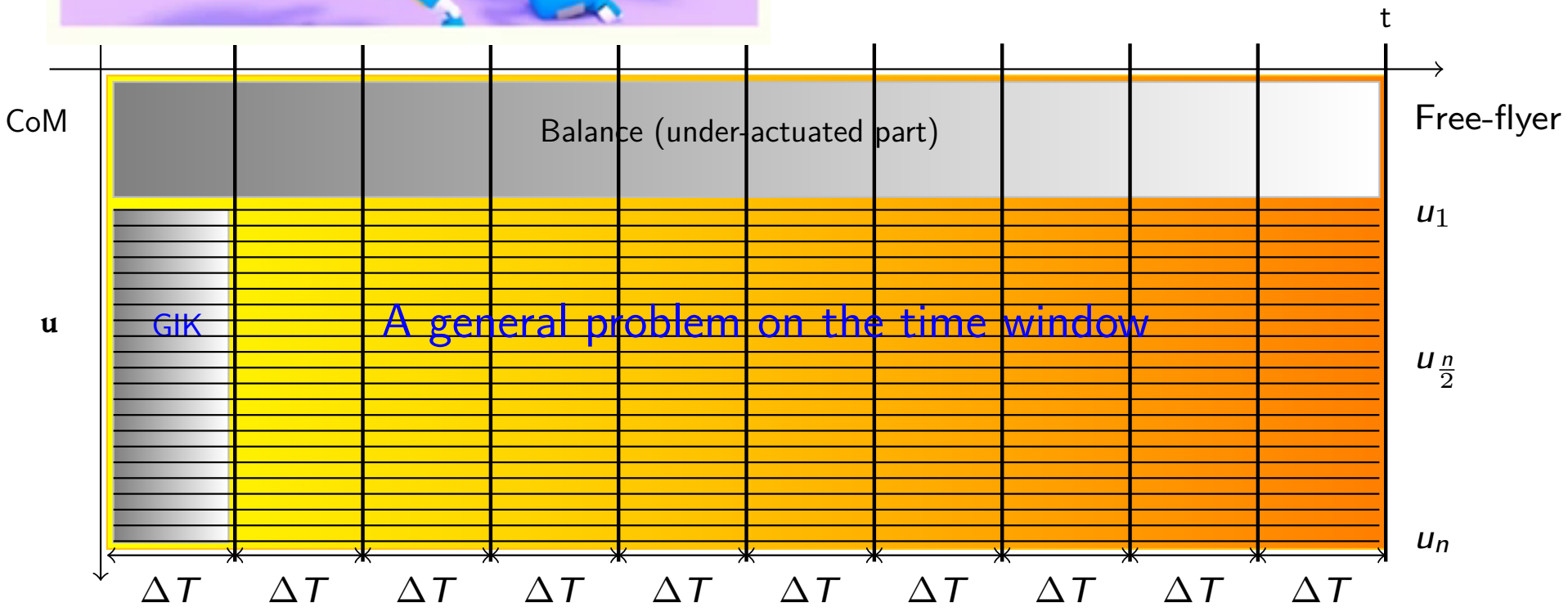
Motion generation



- Size of the problem

$$2 \times 200 \times 30 = 9600 \text{ variables}$$

- Non linear constraints
- Discrete nature due to contacts



MuJoCo [Koenemann, IROS 2015]

https://www.youtube.com/watch?v=WbsQBPzQakc

Motion generation

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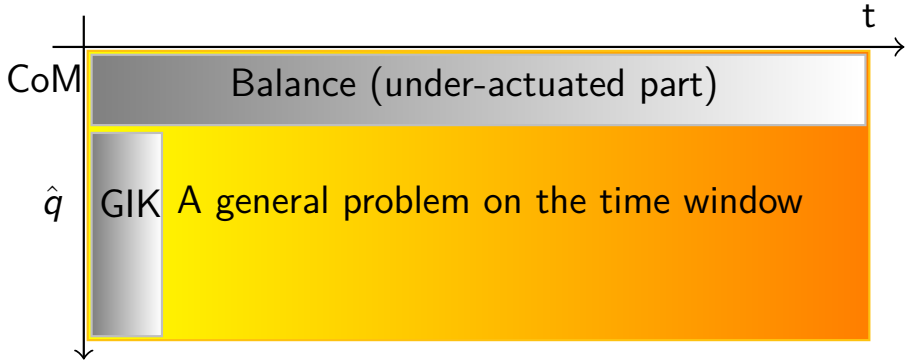


- Planning and control solve the same problem
  - Planning is looking for a global feasible solution
  - Control is looking for on online sensor grounded local solution
- Planning is too long when simulating the control
- Control can fails
  - Local minima leading to an incomplete behavior
  - Mismatch between the control and the hardware
- Accessibility set [Majumdar, ICRA Best Paper Award 2013]

HPP [IJRR Submitted]

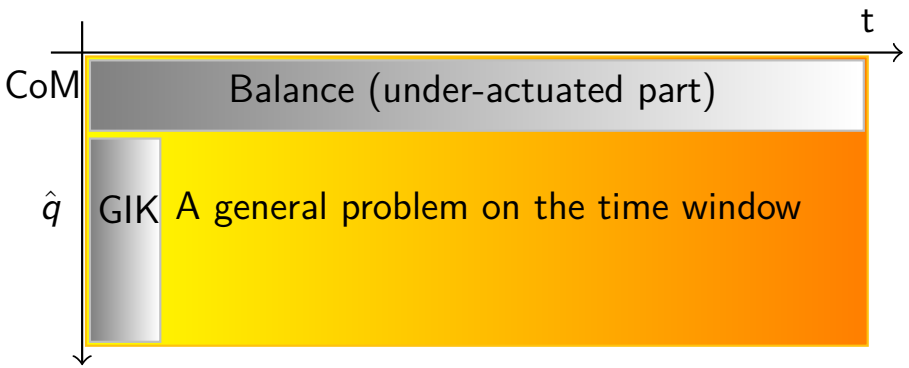
http://stevetonneau.fr/files/publications/ijrr16/video.mp4

Take away messages

- The *embodiment* (mechanical body, limits and controllers) defines the motion capabilities of the robot.
- We need to connect the accessibility set of our controllers to the planner.
- We need an efficient computation of the mechanical quantities
- We need to break down the problem complexity with small but representative problems
- We need to push higher the semantic level of our motion controllers

Motion generation: the constraints

$$\begin{cases} \min f(\mathbf{u}(t), \mathbf{v}(t)) \\ \mathbf{g}(\mathbf{u}(t), \mathbf{v}(t)) < 0 \\ \mathbf{h}(\mathbf{u}(t), \mathbf{v}(t)) = 0 \end{cases}$$

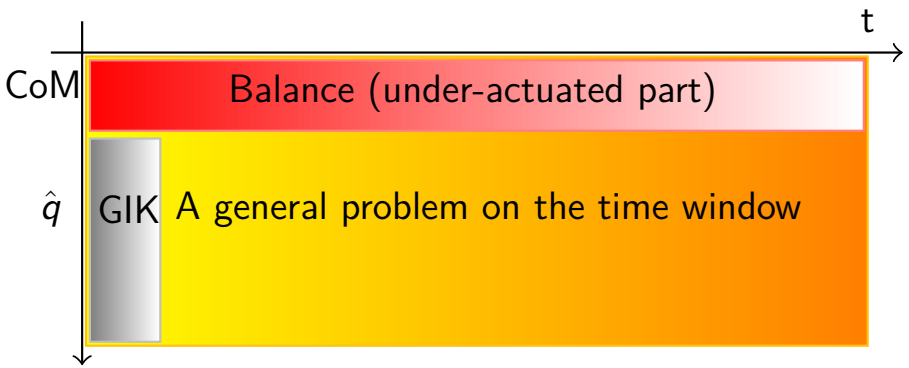


$$\begin{cases} \mathbf{M}_1(q)\ddot{q} + \mathbf{N}_1(q,\dot{q})\dot{q} + \mathbf{G}_1(q) = \mathbf{T}_1(\mathbf{q})\mathbf{u} + \mathbf{C}_1^\top(q)\lambda & \text{Actuated dynamics of the robot} \\ \mathbf{M}_2(q)\ddot{q} + \mathbf{N}_2(q,\dot{q})\dot{q} + \mathbf{G}_2(q) = \mathbf{C}_2^\top(q)\lambda & \text{Underactuated dynamics of the robot} \\ f(\lambda) \in \mathcal{F} & \text{General balance criteria} \\ \mathbf{u}_{min} < \mathbf{u} < \mathbf{u}_{max} & \text{Torques limits} \\ \hat{q}_{min} < \hat{q} < \hat{q}_{max} & \text{Joints limits} \\ d(\mathcal{B}_i(\mathbf{q}), \mathcal{B}_j(\mathbf{q})) > \epsilon, \forall p(i,j) \in \mathcal{P} & \text{(self-)collisions} \\ \ddot{\mathbf{e}}_i = \dot{\mathbf{J}}_i(q)\dot{q} + \mathbf{J}_i(q)\ddot{q} & \text{Tasks} \end{cases}$$

Motion generation: the constraints

Pattern generator

- Focus on the underactuated part
- Model predictive control



Simplifying the walking problem to control only the CoM reference

$$
\begin{cases}
\mathbf{M}_1(q)\ddot{q} + \mathbf{N}_1(q,\dot{q})\dot{q} + \mathbf{G}_1(q) = \mathbf{T}_1(\mathbf{q})\mathbf{u} + \mathbf{C}_1^\top(q)\lambda & \text{Actuated dynamics of the robot} \\
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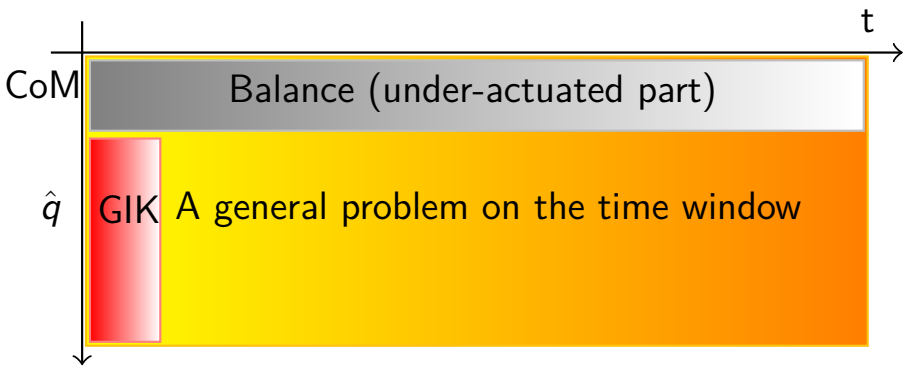
\ddot{\mathbf{e}}_i = \dot{\mathbf{J}}_i(q)\dot{q} + \mathbf{J}_i(q)\ddot{q} & \text{Tasks}
\end{cases}
$$

Motion generation: the constraints

Inverse dynamics

- Focus on the inertia matrix
- Forces
- Complete constraints



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\end{cases}
$$

Under actuation

Generalized locomotion Climbing stairs

[Carpentier, ICRA 2016]
[Kudruss, Humanoids 2015]

Previous work
[Luo, ICRA 2014]
[Vaillant, Humanoids 2014]
[Noda, ICRA 2014]
[Hirukawa, ICRA 2007]

$$\begin{cases} m(\ddot{\mathbf{c}}(\mathbf{u}) - \mathbf{g}) = \sum_{i=1}^{N_c} \mathbf{f}_i, \ \lambda_i = [\mathbf{f}_i^\top \mu_i^\top]^\top \\ m\mathbf{c}(\mathbf{u})_\times(\ddot{\mathbf{c}}(\mathbf{u}) - \mathbf{g}) + \mathbf{w}^\top(\mathbf{u})\mathbf{I}\mathbf{w}^\top(\mathbf{u}) = \sum_{i=1}^{N_c} \mathbf{p}_{i\times}\mathbf{f}_i + \mu_i \end{cases}$$

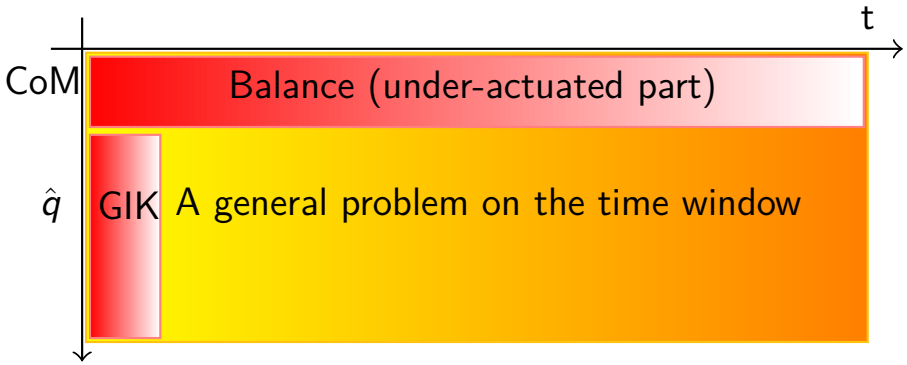
Whole body motion

Multi-contacts with Pyrene

Motion control: Instantaneous control

Inverse dynamics

- Focus on the inertia matrix
- Forces
- Complete constraints



Ignore the actuator dynamics

$$
\begin{cases}
\mathbf{M}_1(q)\ddot{q} + \mathbf{N}_1(q,\dot{q})\dot{q} + \mathbf{G}_1(q) = \mathbf{T}_1(\mathbf{q})\mathbf{u} + \mathbf{C}_1^\top(q)\lambda & \text{Actuated dynamics of the robot} \\
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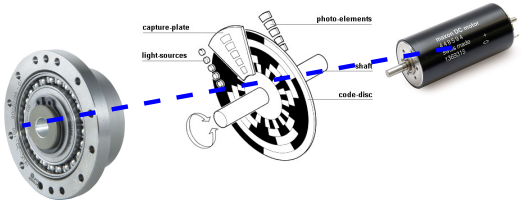
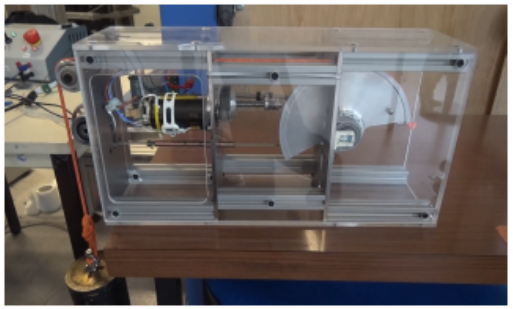
$$

Actuator dynamics

Classical actuator



SEA - Romeo - [IROS 2017]



Mc Kibben Muscle - [IROS 2016]

Actuator dynamics: necessity to control

$$\begin{cases} \phi(\mathbf{u}) = \tau_j & \text{Actuators dynamics} \\ \mathbf{M}_1(\mathbf{q})\ddot{q} + \mathbf{N}_1(\mathbf{q},\dot{q})\dot{q} + \mathbf{G}_1(\mathbf{q}) = \mathbf{T}_1(\mathbf{q})\tau_j + \mathbf{C}_1^\top(\mathbf{q})\mathbf{f} & \text{Actuated dynamics of the robot} \\ \mathbf{M}_2(\mathbf{q})\ddot{q} + \mathbf{N}_2(\mathbf{q},\dot{q})\dot{q} + \mathbf{G}_2(\mathbf{q}) = \mathbf{C}_2^\top(\mathbf{q})\mathbf{f} & \text{Underactuated dynamics of the robot} \\ f(\mathbf{f}) \in \mathcal{F} & \text{General balance criteria} \\ \mathbf{u}_{min} < \mathbf{u} < \mathbf{u}_{max} & \text{Torques limits} \\ \hat{q}_{min} < \hat{q} < \hat{q}_{max} & \text{Joints limits} \\ d(\mathcal{B}_i(\mathbf{q}), \mathcal{B}_j(\mathbf{q})) > \epsilon, \forall p(i,j) \in \mathcal{P} & \text{(self-)collisions} \\ \ddot{\mathbf{e}}_i = \dot{\mathbf{J}}_i(\mathbf{q})\dot{q} + \mathbf{J}_i(\mathbf{q})\ddot{q} & \text{Tasks} \end{cases}$$

Torque control with HRP-2

A. Del Prete, T. Flayols

Conclusions & Perspectives

- We are reaching the limits of our actuators
- They need to be taken into account in our control architecture
- New mechanical design are needed
- Reaching the functionnal level of human may involve

  robot looking less than human