

Génération de mouvements acceptables pour la robotique d'interaction

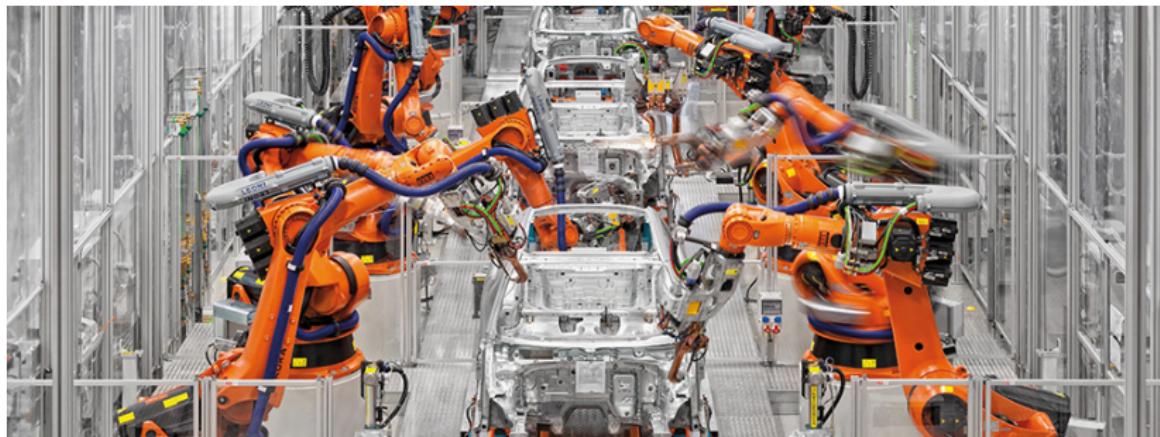
Journée des Jeunes Chercheurs en Robotique 2017

Kevin DESORMEAUX

Laboratoire d'Analyse et d'Architecture des Systèmes (LAAS-CNRS)
Robotique et InteractionS (RIS)

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Industrial context



- ☛ Repetitive tasks
- ☛ No interactions between Humans and Robots
- ☛ Fully automatized process

Collaborative robotic



All tasks cannot be automatized !

Synergy between the respective strengths



- ✓ Perception
- ✓ Reasoning
- ✓ Adaptation
- ✓ Expertise

Synergy between the respective strengths



- ✓ Perception
- ✓ Reasoning
- ✓ Adaptation
- ✓ Expertise



- ✓ Precision, accuracy
- ✓ Repeatability
- ✓ Force
- ✓ Speed

Advantages and interest for HRI robots

- ✓ Reduction of physical strain and injuries
- ✓ Flexibility and adaptability
- ✓ Optimization of the means of production

(KRÜGER et al., 2009)



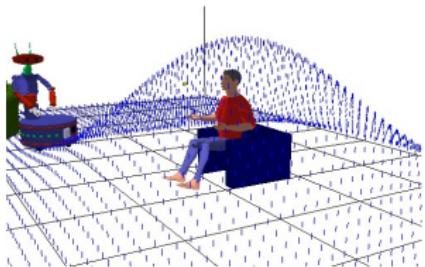
Issues

- Security
- Efficiency
- Ergonomics !

(ARAI et al., 2010 ; LASOTA et al., 2014)



Contributions at different layers :



Safety grid (Sisbot et al., 2006)

Planning

What social codes and implicit rules of interaction should be respected ?



(Broquere et al., 2010)

Lower layers

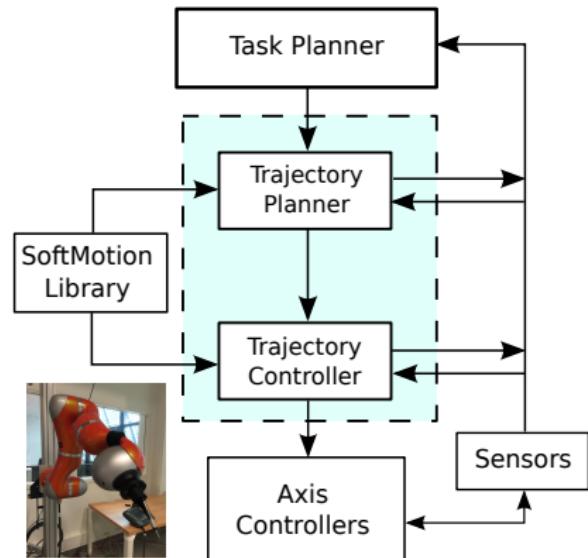
How the motion has to be built ? ⇒ Our work !

Trajectories

≡ Path + timing law

Some advantages

- ✓ $x(t), \dot{x}(t), \ddot{x}(t), \dddot{x}(t)$ and higher derivatives can be controlled.
- ✓ Time-optimisation under kinematic constraints.
- ✓ Better description of the motion, allowing a better control.



Possible architecture built around trajectories as the main support of informations

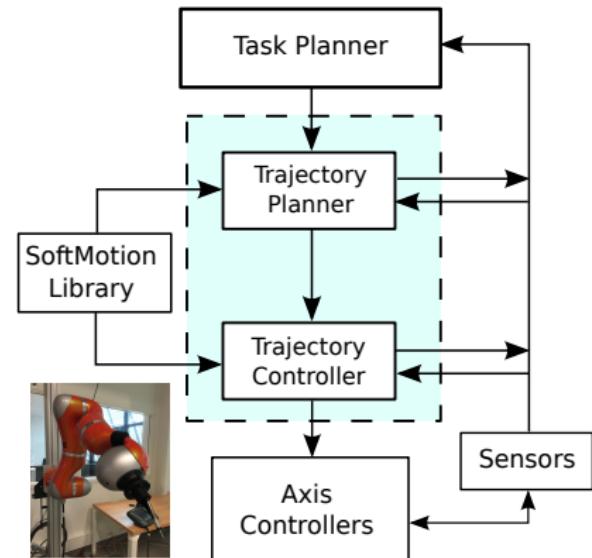
Trajectories

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Requirements

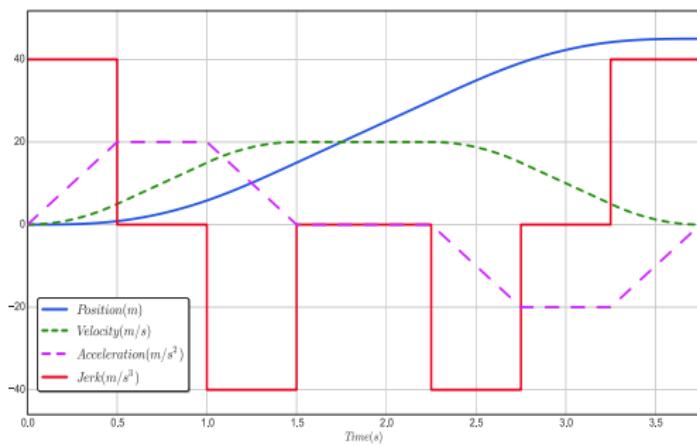
- Online.
- General conditions.
- Bounded $\dot{x}(t), \ddot{x}(t), \dddot{x}(t)$
- Time optimal.
- Asymmetric constraints.



Possible architecture built around trajectories as the main support of informations

Smooth trajectory (HOGAN, 1984)

Smoothness defined by the number of derivative of position and their extreme values



Generally a trajectory with bounded jerk

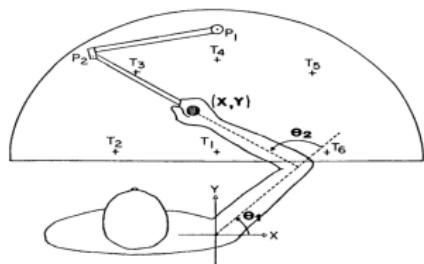
Qualities

- Improve accuracy
- Extend the life span of the manipulators
- Human-friendly

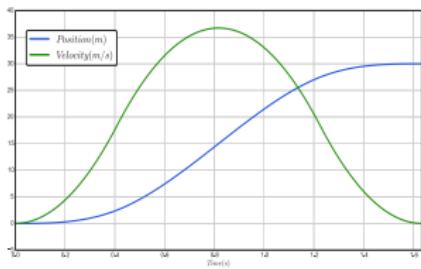
Two popular models

- ➡ Minimum-jerk model
- ➡ Constrained-jerk model

Minimum-jerk model



(FLASH et al., 1985)

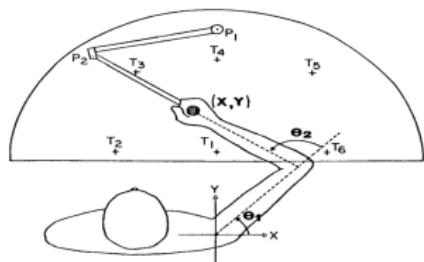


Symmetrical bell-shaped velocity curve.

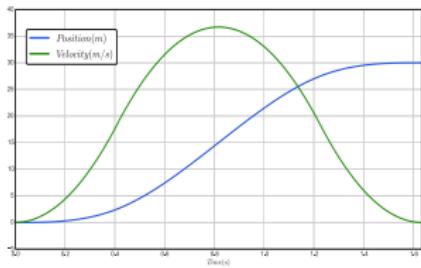
Observations

- ↗ Practice and learning → smoother movements
- ↗ Symmetrical bell-shaped velocity curves
- ↗ Smoothness is related to Jerk

Minimum-jerk model



(FLASH et al., 1985)



Symmetrical bell-shaped velocity curve.

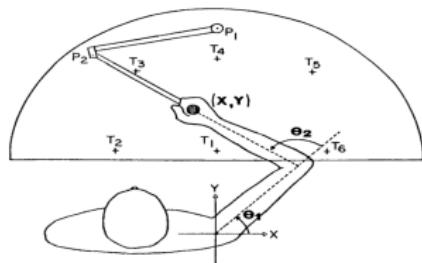
Observations

- ↳ Practice and learning → smoother movements
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Conclusions

- ⇒ Ideal movement should be the smoothest
- ⇒ Jerk minimization $\frac{1}{2} \int_0^{t_f} \ddot{x}(t)^2 dt$

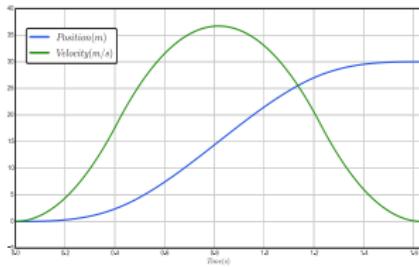
Minimum-jerk model



Advantages

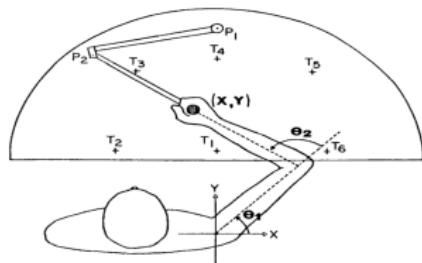
- ✓ Organizing principle

(Flash et al., 1985)

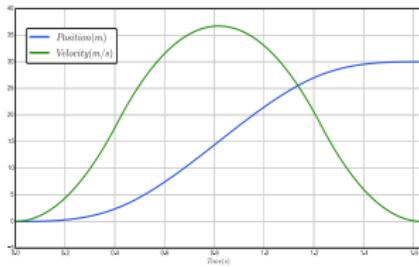


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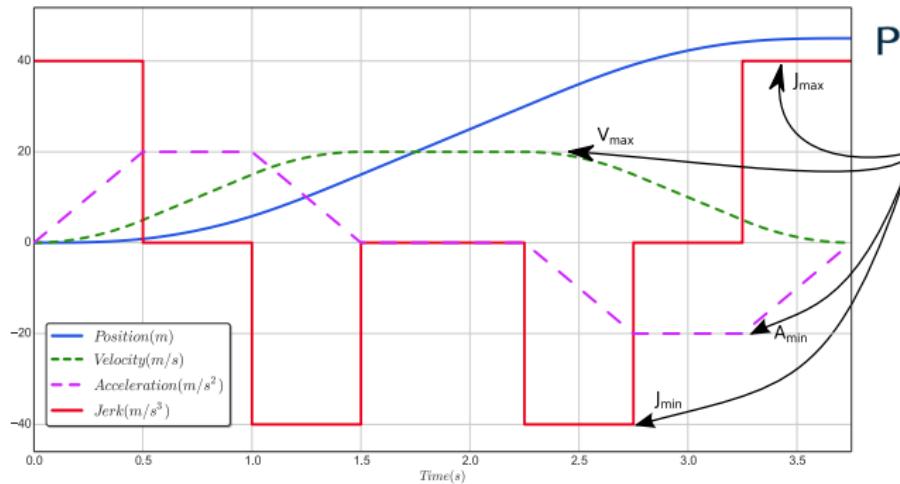
Advantages

- ✓ Organizing principle

Drawbacks

- ✗ Subjective hypothesis
- ✗ Lack of flexibility

Constrained-jerk model



Principle :

- ↳ Kinematic constraints specified
- ↳ Time optimization problem

Advantages

✓ Flexibility

Drawbacks

✗ Kinematic bounds have to be defined

Cubic vs quintic ?

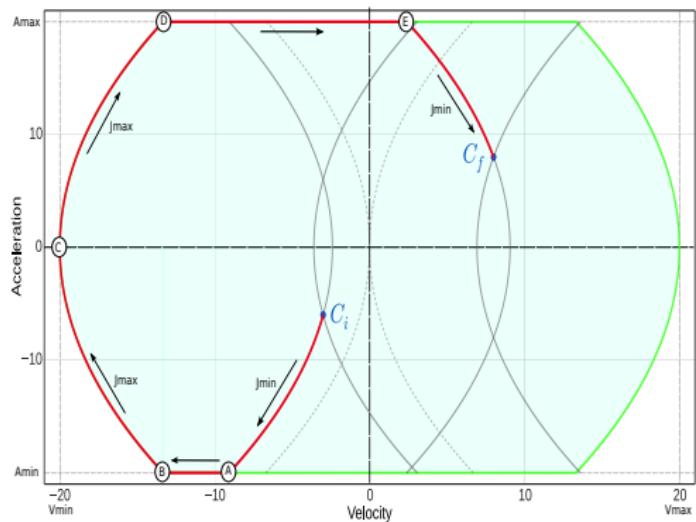
$$qt = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5$$

$$\begin{pmatrix} 1 & t_0 & t_0^2 & t_0^3 & t_0^4 & t_0^5 \\ 0 & 1 & 2t_0 & 3t_0^2 & 4t_0^3 & 5t_0^4 \\ 0 & 0 & 2 & 6t_0 & 12t_0^2 & 20t_0^3 \\ 1 & t_f & t_f^2 & t_f^3 & t_f^4 & t_f^5 \\ 0 & 1 & 2t_f & 3t_f^2 & 4t_f^3 & 5t_f^4 \\ 0 & 0 & 2 & 6t_f & 12t_f^2 & 20t_f^3 \end{pmatrix} \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{pmatrix} = \begin{pmatrix} q_0 \\ v_0 \\ a_0 \\ q_f \\ v_f \\ a_f \end{pmatrix}$$

One quintic is enough to join two arbitrary conditions ... but !

- ⇒ Runge's phenomenon
- ⇒ Complexity. And simpler solutions exists !

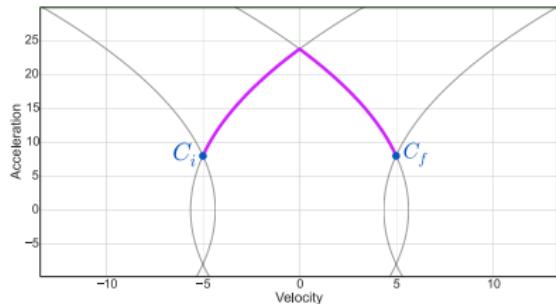
Acceleration/Velocity Frame



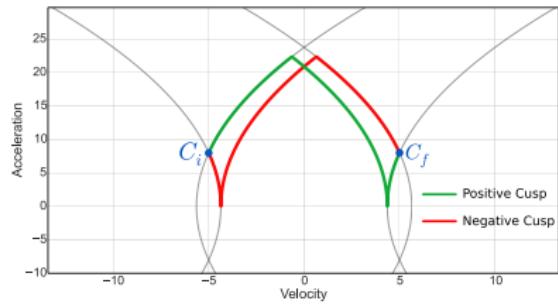
- green area = admissible conditions
- C_i, C_f = Initial/final conditions
- Parabolas defined by J_{min}/J_{max}
- C_i, C_f define four parabolas
- Green borders $\equiv V_{min}, V_{max}, A_{min}, A_{max}$
- V_{min} holds on point C

A seven cubic segment trajectory
 $(J_{min}, A_{min}, J_{max}, V_{min}, J_{max}, A_{max}, J_{min})$

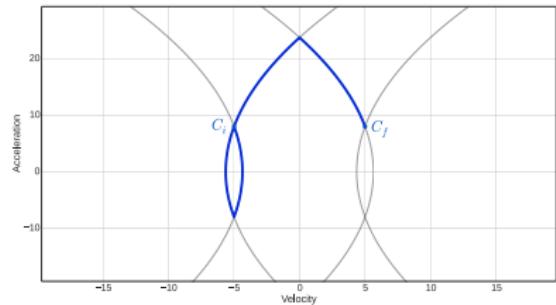
Different types of trajectory



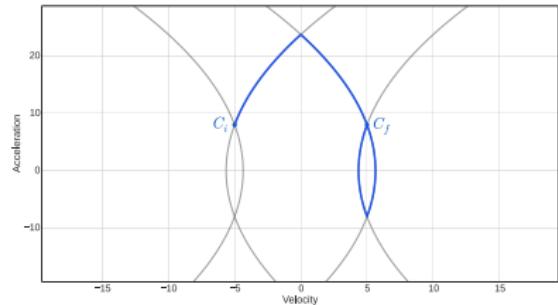
Direct trajectory



Cusps

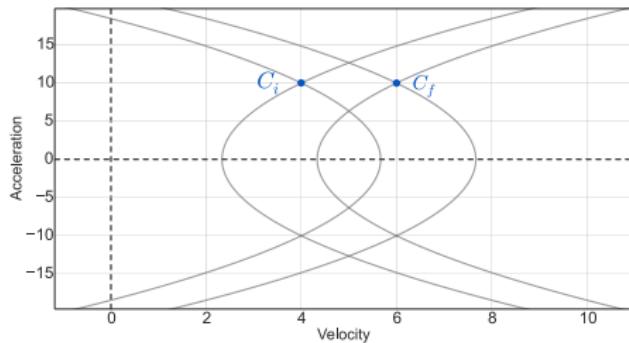
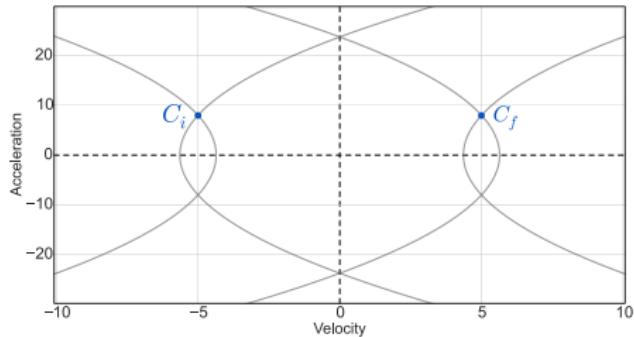


Negative loop



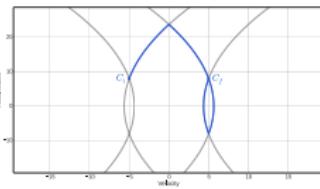
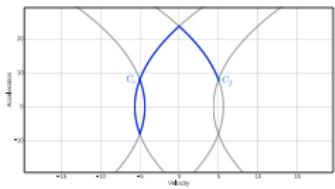
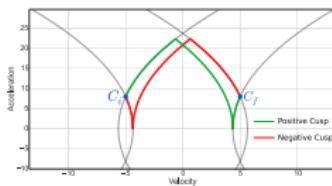
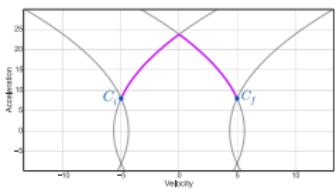
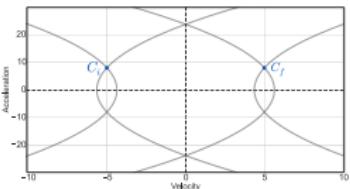
Positive loop

Algorithm



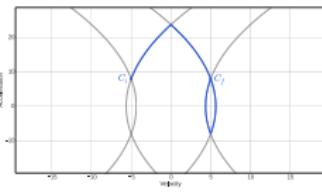
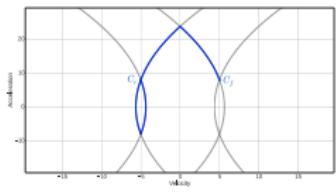
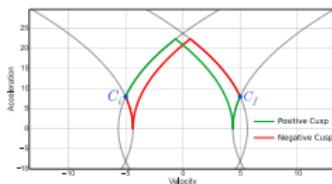
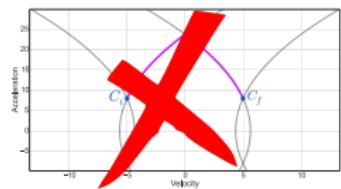
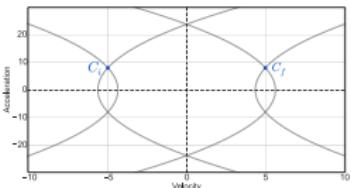
- ✎ Compute the local parabolas
- ✎ Compute the singular limit trajectories
- ✎ From x_f , determine what are the possible sequences of trajectories.
- ✎ For each possible sequence compute the time optimum trajectory.
- ✎ Choose the faster trajectory.

Third order trajectory generation : Algorithm



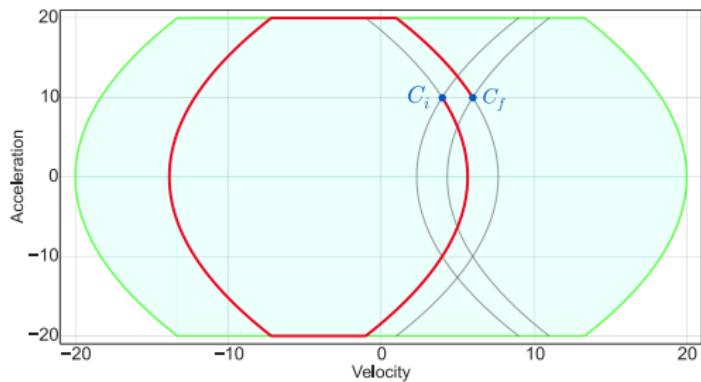
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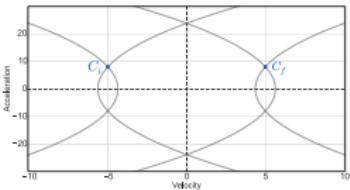
$$a_f = J_a * t_3 + a_2$$

$$v_f = J_a * t_3^2 / 2 + a_2 * t_3 + v_2$$

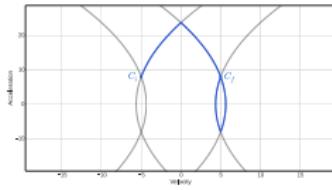
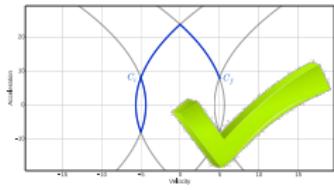
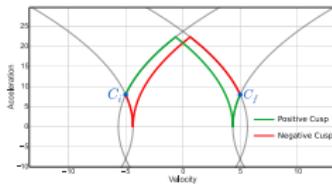
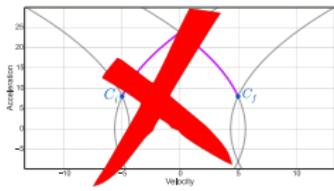
$$x_f = J_a * t_3^3 / 6 + a_2 * t_3^2 / 2 + v_2 * t_3 + x_2$$

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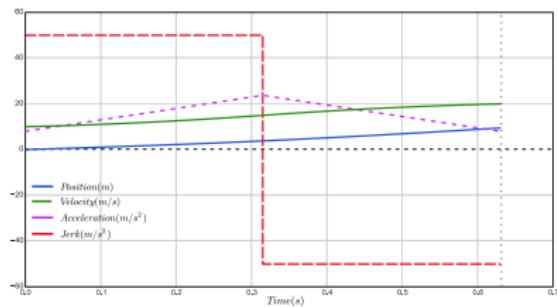
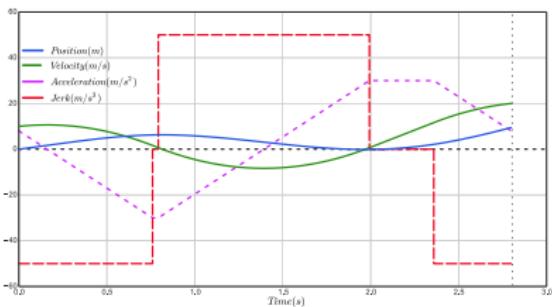
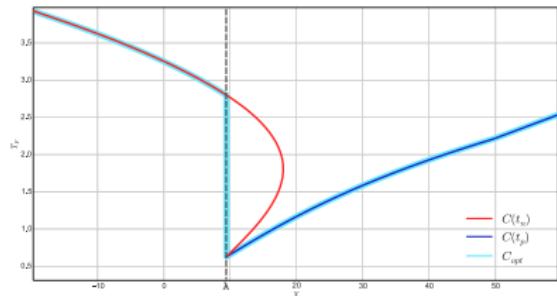
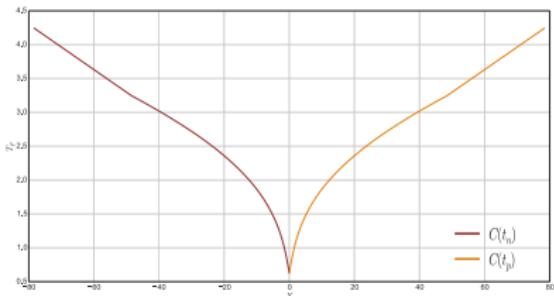
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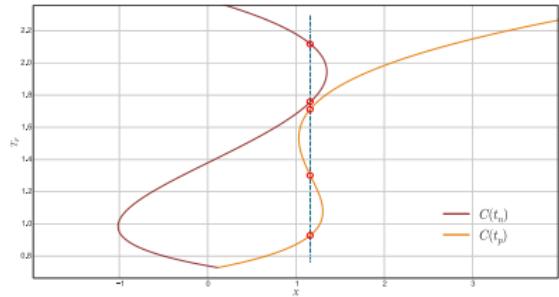
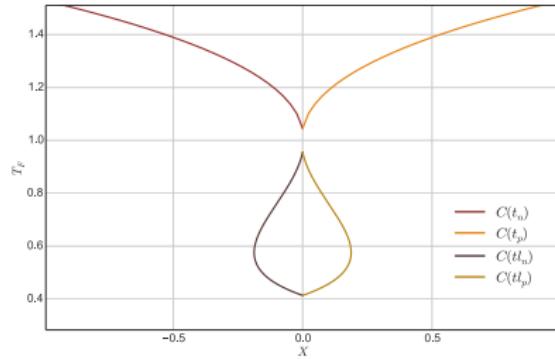
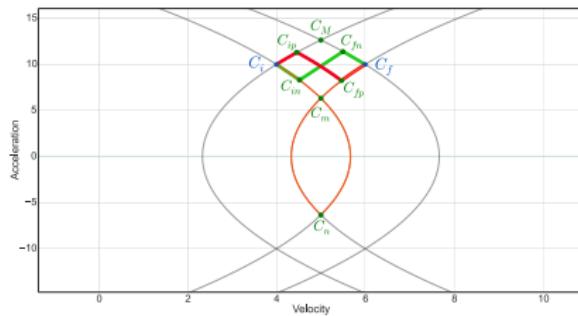
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Harsh points in trajectory generations : short motions



Harsh points in trajectory generations : short motions



Thanks a lot!!! Questions ?

-  HOGAN, N. (1984). "An organizing principle for a class of voluntary movements". In : *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience* 4.11, p. 2745–2754.
-  FLASH, T. et N. HOGAN (1985). "The coordination of arm movements : an experimentally confirmed mathematical model". In : *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience* 5.7, p. 1688–1703.
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-  ARAI, T., R. KATO et M. FUJITA (2010). "Assessment of operator stress induced by robot collaboration in assembly". In : *CIRP Annals - Manufacturing Technology* 59.1, p. 5–8.
-  BROQUERE, Xavier, Daniel SIDOBRE et Khoi NGUYEN (2010). "From motion planning to trajectory control with bounded jerk for service manipulator robots". In : *Robotics and Automation (ICRA), 2010 IEEE International Conference on*. IEEE, p. 4505–4510.
-  LASOTA, P. A., G. F. ROSSANO et J. A. SHAH (2014). "Toward safe close-proximity human-robot interaction with standard industrial robots". In : *2014 IEEE International Conference on Automation Science and Engineering (CASE)*. 2014 IEEE International Conference on Automation Science and Engineering (CASE), p. 339–344.