Improving Motor Coordination in Human-Robot Interactions Using Bio-Inspired Controllers

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Gestural communication is an important aspect of HRI (Human-Robot Interactions) in social, assistance and rehabilitation robotics. Indeed, social synchrony is a key component of interpersonal interactions which affects the interaction on the behavioural level, as well as on the social level. It is paramount for the robot to be able to adapt to its interaction partner. To achieve this, bio-inspired controllers endowed with plasticity mechanisms can be employed. The goal is to make these interactions as natural and enjoyable as possible by endowing robots with adaptive properties which leads to the emergence of motor coordination and hence social synchrony. A non-negligible part also consists in studying humans in HRI to understand human behaviour better and design better interactions.

Social synchrony is at the root of interpersonal interactions and humans thus expect robots to adapt to them and demonstrate appropriate responses. Robot controllers with adaptive capabilities are thus necessary for social acceptance. My work focuses on achieving motor coordination using a CPG (Central Pattern Generator) controller in HRI. CPGs are biological structures in the spine of vertebrates responsible for the generation of rhythmic patterns. They can generate a pattern without an input and also adapt to an external feedback.

Achieving Motor Coordination using CPGs

Mathematical Modelling

For the rhythm generator neurons, Rowat-Selverston cells are employed [1]:

$$\dot{V} = y - W\frac{y}{1+e^{-4y}} + \epsilon F \qquad (1)$$

$$\dot{y} = \left(\sigma_f - \frac{\tau_m}{\tau_s} - 1 - \sigma_f \tanh^2\left(\frac{\sigma_f}{A_f}V\right)\right)\cdot \frac{y}{\tau_m} - \frac{1+\sigma_s}{\tau_s\tau_m}V + \frac{A_f}{\tau_s\tau_m}\tanh\left(\frac{\sigma_f V}{A_f}\right) \qquad (2)$$

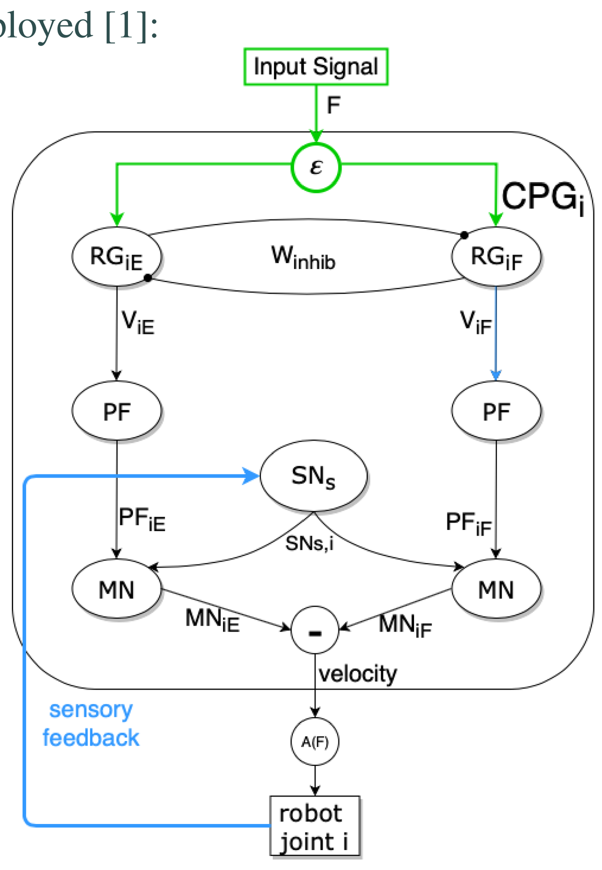
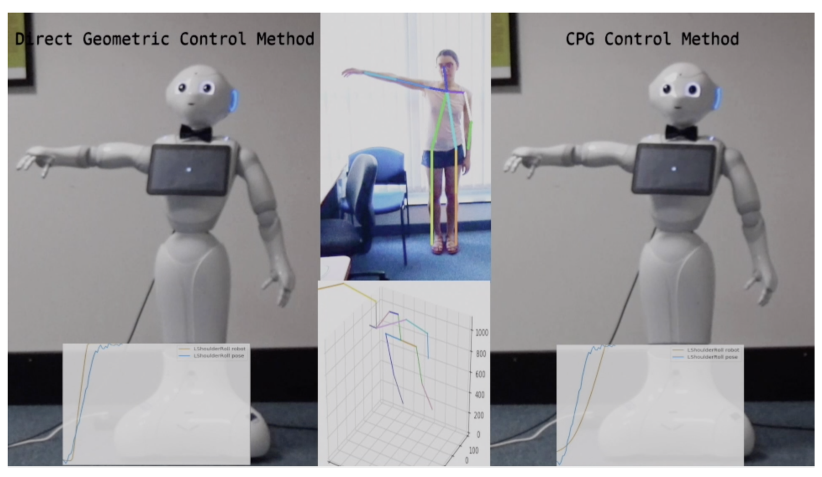


Figure 1: CPG architecture

F is the input of the CPG, ϵ a synaptic weight designed to scale the input and the term in W models the mutual inhibition between the extensor and flexor rhythmic cells. V is the membrane potential and τ_m and τ_s are time constants, A_f influences the output amplitude, while σ_f determines whether the neuron is able to oscillate or not. σ_s is a gain.

Properties and Advantages

- CPG controller based on the Rowat-Selverston neuron
- Can generate both rhythmic and discrete patterns
- Rhythmic mode: CPG adapts its intrinsic frequency, amplitude and synaptic weight thanks to plasticity mechanisms
- Discrete mode: CPG behaves like a PID controller and it can adapt to match the input amplitude
- No model of the robot necessary
- It can take in any kind of input (position, velocity, torque...) and achieve coordination through multimodal information (visual, contact...).



Compared to direct geometric control:

- Discrete mode: the CPG smooths out the signal and is thus less sensitive to noise
- Rhythmic mode, the CPG adapts its parameters and is thus able to "anticipate" the signal while the direct geometric approach tries to catch up with the signal and never matches the full amplitude

Evaluating Motor Coordination using CPGs

To understand human coordination better and evaluate the influence of adaptive controllers in a human-robot rhythmic interaction, we performed a user study where subjects interacted rhythmically with different partners able to adapt or not.

Methodology

- Twelve subjects (5 women, average age: 25.67 ± 2.4)
- Experiment was approved by Inria ethical committee
- The subject interacts with a human, a robot and a virtual partner who are master of the interaction, they cannot adapt
- Then, the subject interacts with a human and a robot controlled by CPGs who adapt to the subject.
- Subjects equipped with a 64-channels TMSI EEG cap, motion sensors and active noise-cancelling earphones
- NARS and post-questionnaires

Results

Humans expect interaction partners to adapt to them

- Subjects were uncomfortable with the non-adaptive human
- Subjects were significantly better coordinated with the non-adaptive robot and virtual partner than with the non-adaptive human
- Subjects were more engaged with the non-adaptive human than the non-adaptive robot or VP
- Subjects had the feeling that the robot and the VP were adapting to them.

Adaptive Interactions are more enjoyable

- Participants were significantly better coordinated and engaged with the adaptive human than with the non-adaptive one
- There was no significant difference between the non-adaptive robot and the adaptive one
- Due to technical difficulty in the movement detection, the interaction with the robot was frustrating for some participants. When successful, the subjects enjoyed testing the limits of the robot and the interaction was very playful.

Conclusion

- I incorporated plasticity mechanisms into CPG controllers to make them even more adaptive.
- Versatile control of a robot can be achieved to imitate both discrete and rhythmic movements.
- We also performed a user-study to evaluate the impact of adaptive controllers on human engagement and coordination.
  - Although it suffered from technical mishaps, most participants enjoyed the interaction much more when the partner was adaptive than when it was not
  - It also confirmed that humans expect their interaction partner to be able to adapt and feel the lack of adaptation as awkward
  - Most subjects also declared that they felt the non-adaptive partners adapted to them, demonstrating the egocentricity of humans and that the subjects unconsciously coordinated.

Future Works:

- Integrate a classification rule for the CPG to transition from one mode to the other.
- User study to evaluate human perception in imitation tasks with CPG controllers
- User study on a handshaking interaction to evaluate human perception and evaluate how stiffness can influence learning abilities of the CPG
- A pilot study aimed at motor rehabilitation for autistic children.

References

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