Extraction of simple monophasic motor primitives towards bio-inspired locomotion assistance

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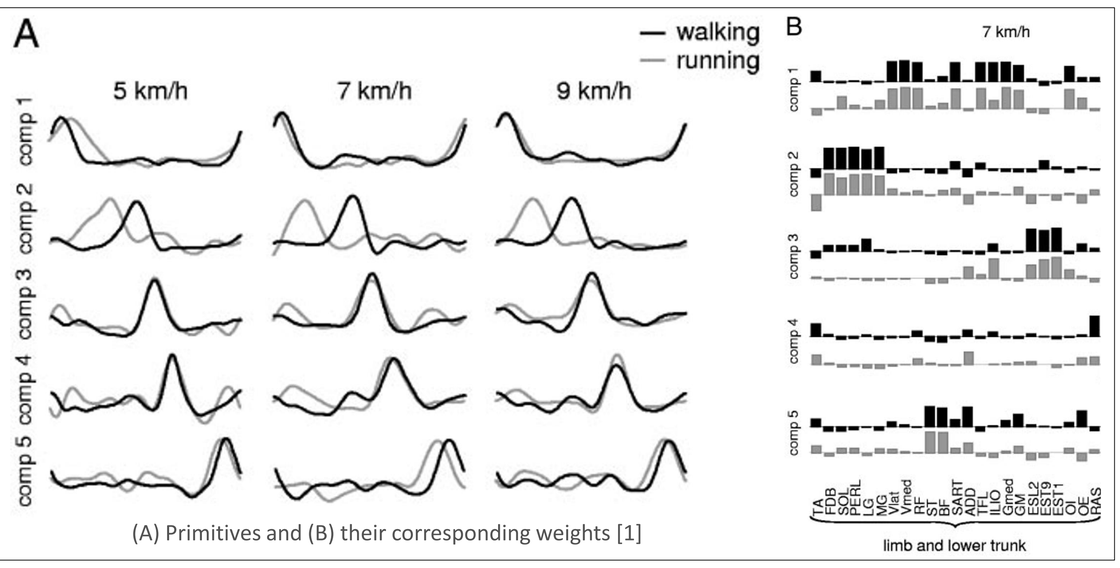
Introduction

- Motor primitives are basic control modules that, once combined by appropriate operations and transformations, generate a large repertoire of movements. For example, [1] identified 5 basic components reconstructing all the measured activation signals for human walking and running at different speeds.
- Inspiration can be gained from such primitives to implement control strategies for wearable robotics and/or prosthetic devices. These bio-inspired methods rely on a predefined set of basic periodic signals that are combined through a weighted summation in order to produce human-like joint moments.
- We developed a framework for extracting constrained-shape Gaussian-like motor primitives from literature data covering several locomotion tasks. Muscular stimulations were first extracted thanks to a musculoskeletal model, and then an optimization was performed to reconstruct at best these signals with constrained shapes primitives.

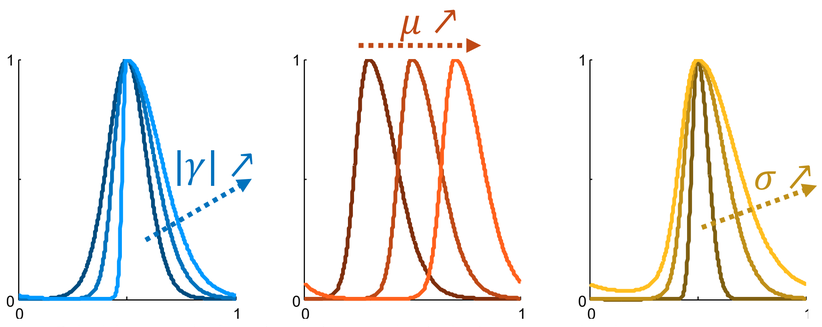


(A) Primitives and (B) their corresponding weights [1]

Primitive definition

Each motor primitive is defined by 3 parameters :

- Degree of asymmetry γ :
  → $f_\gamma(x',\gamma) = \frac{\gamma^2}{2}\,\mathrm{sigm}(x',\gamma) + \left(1-\frac{\gamma^2}{2}\right)x'$;
- Peak location μ :
  → $f_\mu(x,\gamma,\mu) = \cos\left(2\pi f_\gamma(x-\mu,\gamma)\right) - 1$;
- Primitive width σ :
  → $f_\sigma(x,\gamma,\mu,\sigma) = \exp\left(\frac{f_\mu(x,\gamma,\mu)}{\sigma}\right)$.



Primitives evolution along changes in their three constitutive parameters

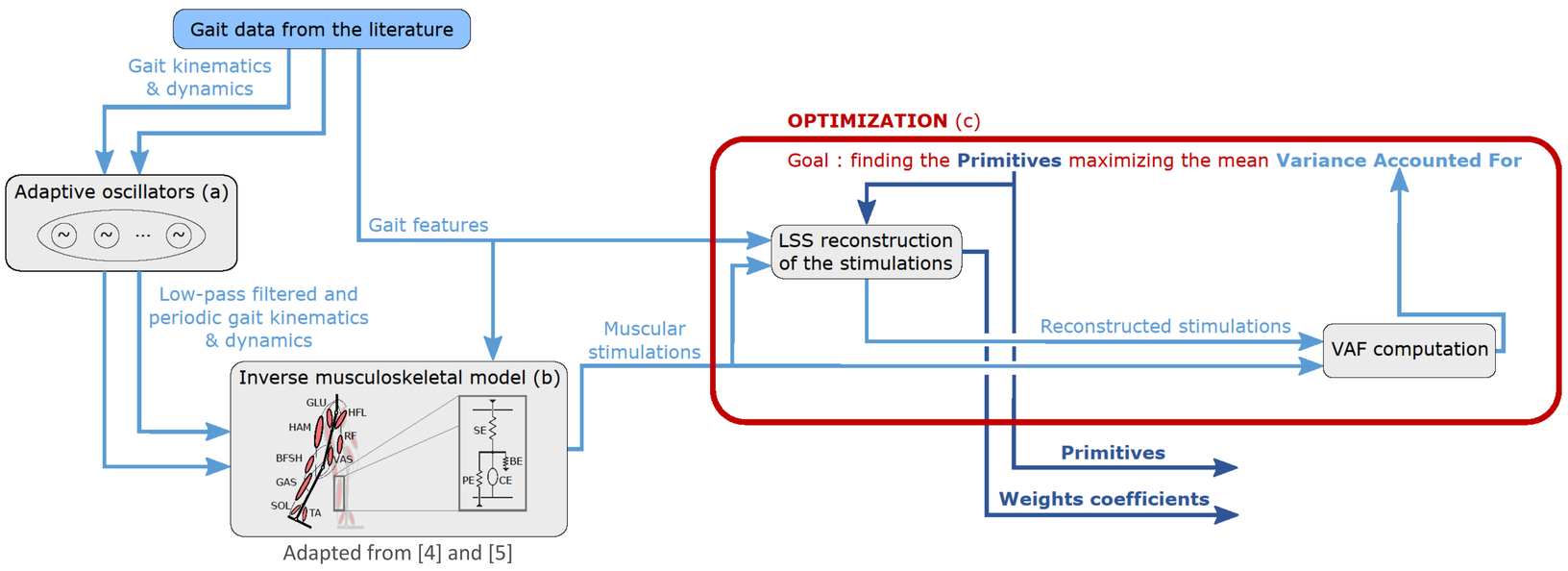
Gait data

Four different papers reporting gait kinematics and dynamics were selected.

Locomotion task			
Associated gait parameter(s)	- gait cadence - slope inclination	- stairs inclination	- running speed

(Adapted) icons made by Freepik from www.flaticon.com

Primitives extraction



Adapted from [4] and [5]

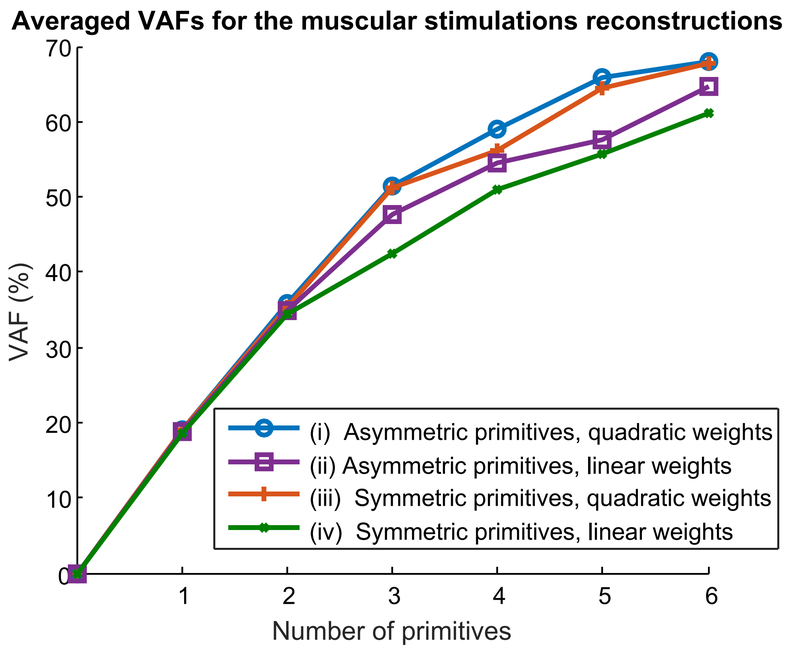
a) Low-pass filtering and "periodization" through a pool of adaptive oscillators and a kernel-based non-linear filter [2].

b) These filtered kinematic and dynamic data were injected into an inverse musculoskeletal model [3] that computed the muscular forces F by solving $\tau_j = \sum_m r_{m,j}\left(\theta_j\right)F_m + \tau_{j,\mathrm{lim}}(\theta_j)$ for every joint j and muscle m.
From there, muscular stimulations were retrieved using the Hill-type muscle model as defined in [4].

c) Motor primitives were computed via an optimization process :
   1. At each iteration, positive weights achieving the best reconstruction (Least-Squares Sense) were computed for a given set of primitives.
   2. These weights were imposed to follow a monotonic evolution law according to the relevant gait parameter.

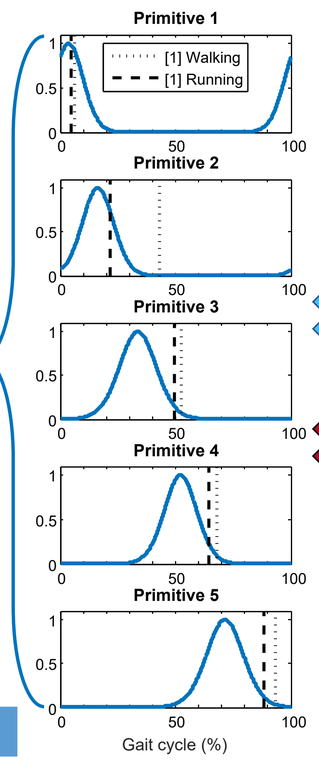
Results

Evolution of the Variance Accounted For

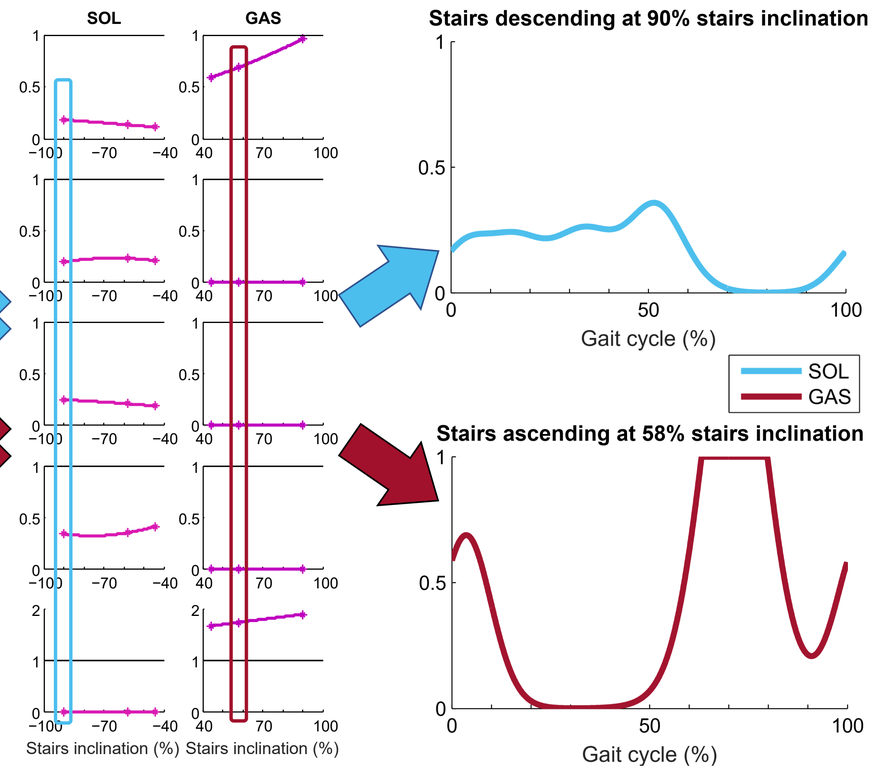


Extracted primitives

Results focus on the set of 5 extracted primitives with asymmetry and quadratic weight evolution. This corresponds to the same amount of primitives as in [1], whose locations are displayed in dotted and dashed lines, for walking and running respectively.

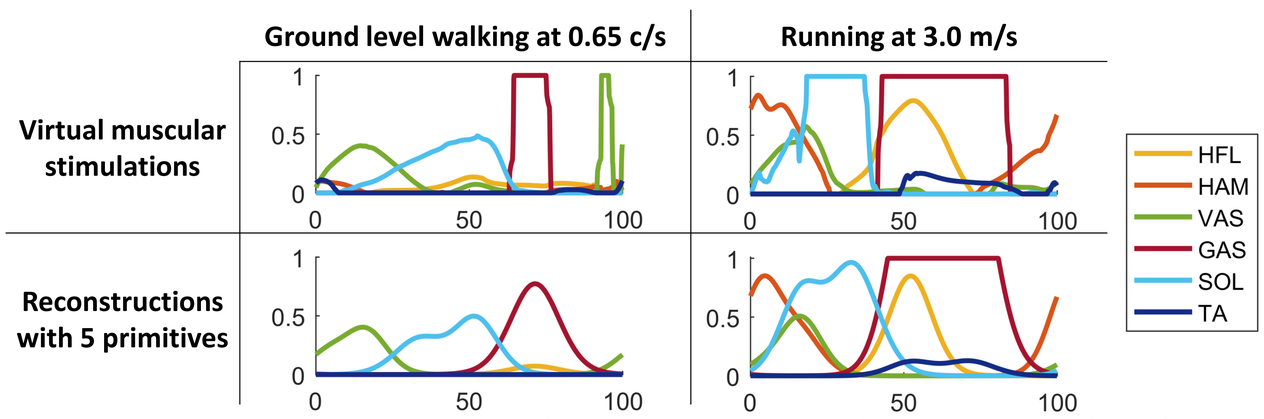


Reconstruction process



Example of two muscular stimulation reconstructions : each motor primitive is multiplied by a certain weight, determined from a quadratic evolution law of the corresponding gait parameter (here the stairs inclination at 90 % and 58 % for stairs descending and ascending). The primitives are then summed up and saturated.

Example of stimulation reconstructions



Worst and best reconstructed tasks : ground level walking has the lowest amount of variance accounted for, while running performed the best. Muscles whose stimulations stayed below 0.01 are not plotted.

Conclusion

- In this work, a new mathematical definition of simple Gaussian-shaped primitives has been used in order to reconstruct muscular stimulations previously extracted from several periodic locomotion tasks.
- Selecting 5 asymmetric primitives with quadratic weights allowed to account for more than 65 % of the variance. However, saturation effects appeared for some of the extracted muscle stimulations.
- Future work should interest more on the goodness of reconstruction of joint moments, which would eventually serve as reference torques for drivers of wearable robotics or prostheses.

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References

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