NRI: FND: COLLAB: Design of dynamic multibehavioral robots: new tools to consider design tradeoff and enable more capable robotic systems

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How to design robots that are good are multiple behaviors?

How to generate synergistic designs, and reason about their tradeoffs to avoid a ``swiss-army knife'' approach?

Approach

- Represent ``behaviors'' as reduced order systems.
- Multi-objective optimization over morphological parameters.
- Design for both control and parameters, e.g. co-optimization.

Key Challenges

- High-dimensional, nonlinear design space
- Conflicting design objects, as well was redundancies
- Encoding behaviors as good templates.

Broader Impact: Design for multibehaviorality will help produce e.g. home assistance robots that must move and interact in human environments.

REU: Undergraduate project to build legs that are good at both running and climbing by optimizing material properties and dimensions.

Single Behavior

- Each task as a (dynamic) template
- Design controller for lifted template to enforce multiple properties (stability, tracking, etc.) of anchor
- Mechanics suggests zero-acceleration surfaces are potentially useful.
- Prefer to realize template with morphological design, and use control minimally, i.e.,

$$\min_p \| \underbrace{\nabla(p)_{\dot{q}}\dot{q}}_{anchor} - \underbrace{\tilde{\nabla}_{\tilde{q}}\dot{\tilde{q}}}_{template} \|$$

subject to $\tilde{q} = \varphi(q)$

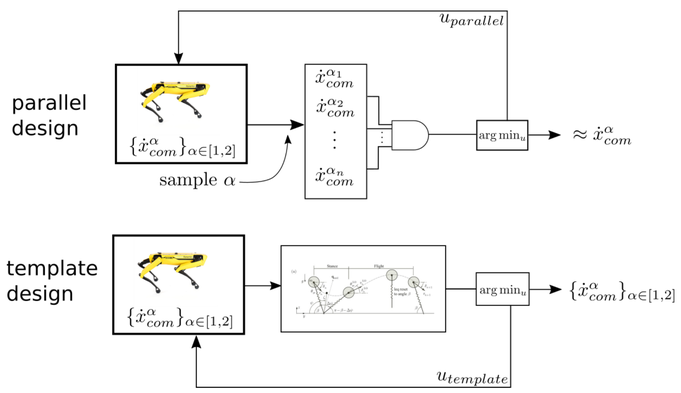

Fig. 1: Problem: get SPOT to run at every speed α between 1 and 2 m/s. Instead of treating this as an explicit parallel control problem (e.g., sample and use trajectory optimization), we propose that anchoring a template with a single controller (whose design optimizes masses, link lengths, etc. simulatenously) that can achieve the same continuum is desirable.

Multiple Behavior

- Multiple design syndrome – templates might not be exactly achievable (Pareto), or there might be redundancies even when all templates are exactly anchored.
- Motivates the need for *explicit coordinates* to navigate design space.
- Enables human analysis, or direct-descent multi-objective algorithms.

$$C(p) \approx DC(p_0)\delta p, \text{ write } \delta p = (p_{sh}, p_t, p_f) \quad p^* = \arg\min_{p\in P} \begin{cases} C^1(p,\dots) \\ C^2(p,\dots) \\ \vdots \end{cases}$$

$$\underbrace{Ar}_{shared} \oplus \underbrace{N_1 \oplus N_2}_{task\ specific} \oplus \underbrace{N_f}_{free} =: S$$

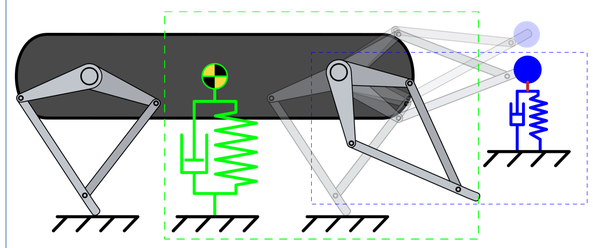

Fig. 2 : Task 1 (green) : Hop, i.e., move the CoM like a spring-damper. Task 2 (blue) : Hand-shake – move tip of one leg like a massy spring-damper. Both tasks need to use the same leg, but not at the same time. We want to optimize for both tasks, and identify any dependencies.

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