Motion control bits for homemade robots

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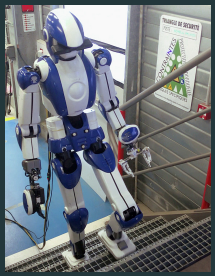


Morphology

Blast from six years ago

Hubo

Atlas

Video memories: `https://youtu.be/8P9geWwi9e0`

Two main designs at the time

Joint control	Sensors	State observation	Whole-body control	Example
Torque	Joint torques	Heavier	Impedance*	Atlas
Position	Force sensors	Lighter	Admittance	Hubo

* With leaky integrators, no passivity yet.

Here come the wheels

Handle

ANYmal on Wheels

Ascento

See also a great explorator of new morphologies: `https://www.youtube.com/user/jamesbruton`

New combinations come to light

Joint control	Sensors	State observation	Whole-body control	Example
Torque	Joint torques	Heaviest	Impedance	Atlas
Position	Force sensors	Lightest	Admittance	Hubo
Torque	Joint torques	Middle ground	Impedance	Ascento
⋮	⋮	⋮	⋮	⋮

Whole-body control of Ascento: `https://arxiv.org/pdf/2005.11431.pdf`

Building our own

Off-the-shelf actuators

Quasi-direct drive:

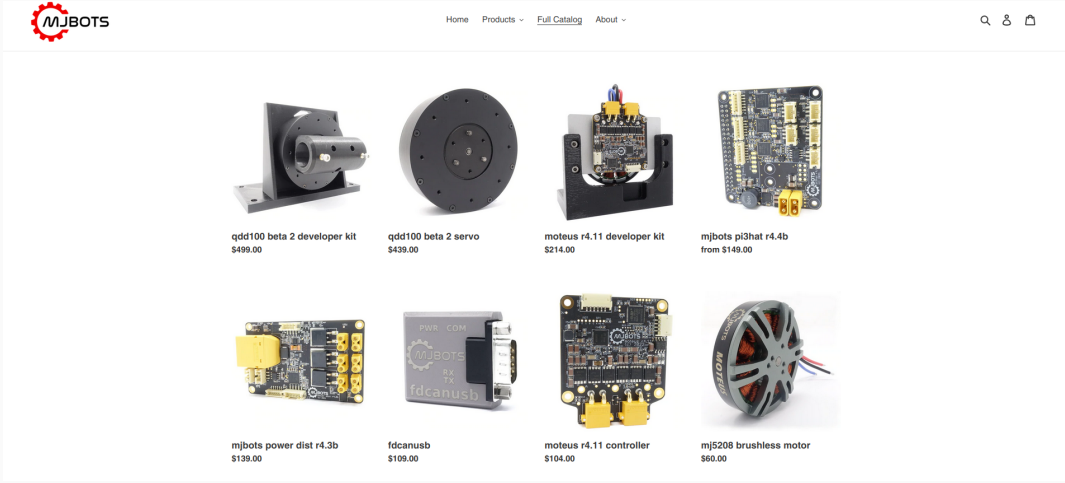
- Ben Katz's design for the Mini Cheetah
- Commercially available: mjbots, MAB, ...
- Torque range: cont. 6 Nm, peak 16 Nm
- Price range: 400–600$

Series-elastic:

- Gill Pratt's design from the 90's
- Commercially available: HEBI
- Torque range: cont. 10 Nm, peak 20 Nm
- Price range: 3000–4000$

Ben Katz's blog: `https://build-its.blogspot.com/`

mjbots stack

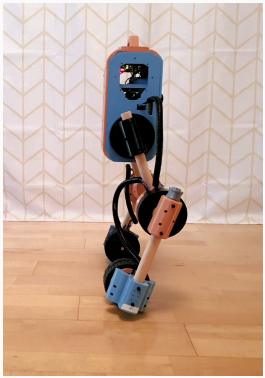


Store: `https://mjbots.com/`

Upkie

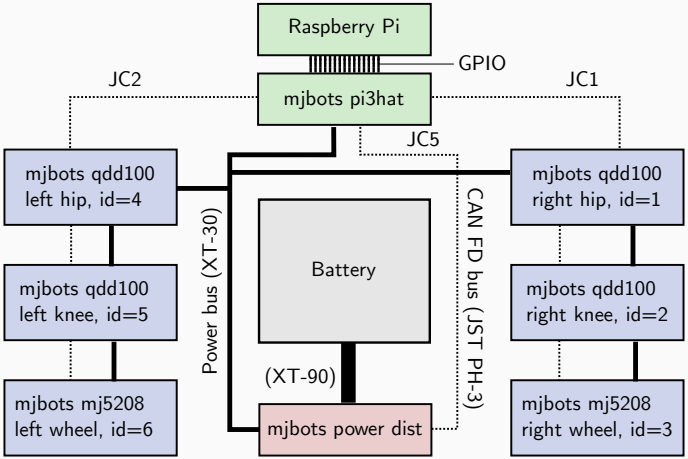
Wheeled biped:

- Joints: 6 (hips, knees, wheels)
- Total mass: 5.4 kg
- Print time: 33 h 14 min
- Knee torques: 2.0 Nm crouched
- Wheel torques: $0.2 + f(\alpha)$ Nm
- Autonomy: 3–4 h with 5.0 Ah battery
- Actuators + electronics: 2,400 €



Project page: `https://hackaday.io/project/185729-upkie-homemade-wheeled-biped-robot`

Electronics



Raspberry Pi hat: `https://github.com/mjbots/pi3hat`

How to share hardware?

Commercial actuators

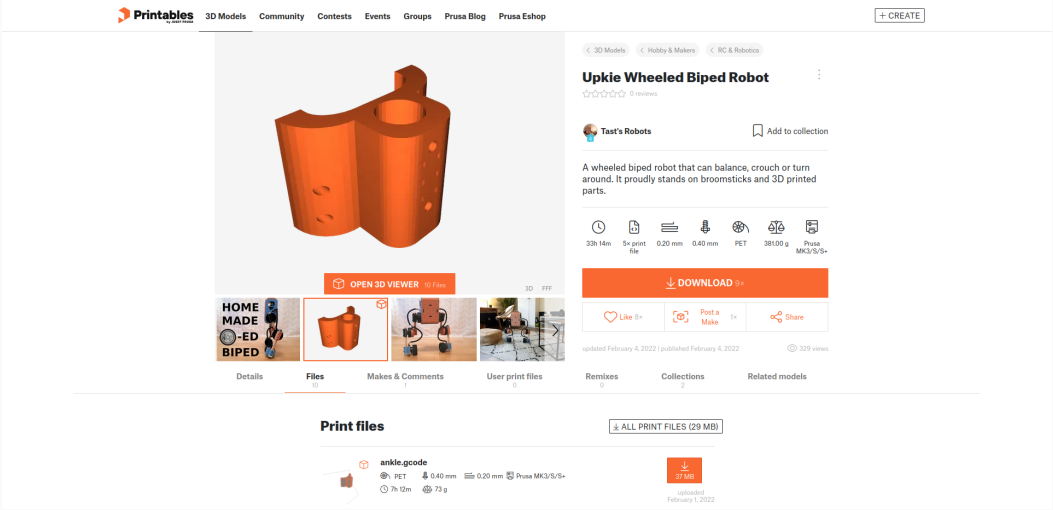
Pros:

- **Reproducibility:** available to others by online retail with public prices (no quote!)
- Maintain availability under chip shortages
- Open source options (*e.g.* mjbots)

Cons:

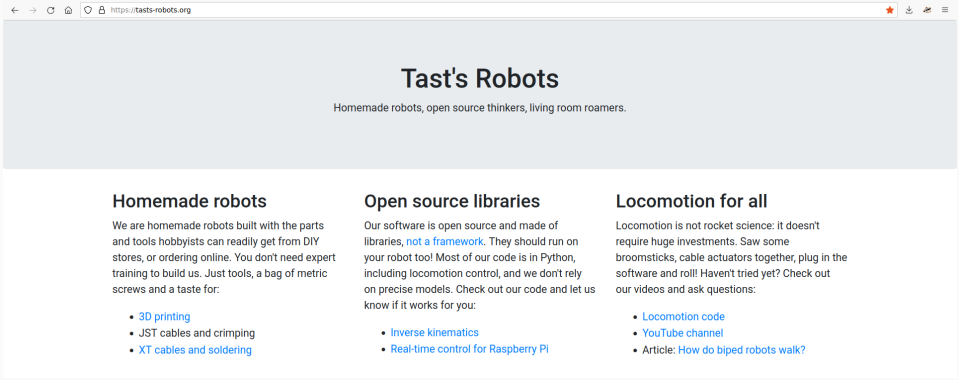
- Companies go out of business more often than not
- Net loss if closed source (*e.g.* ODrive)

Printables



https://www.printables.com/model/127831-upkie-wheeled-biped-robot

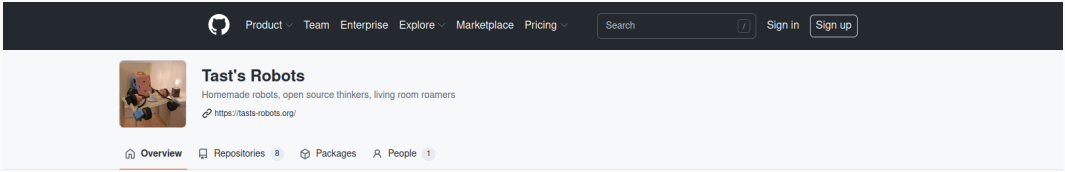
Makeable at home



Proposed definition: `https://tasts-robots.org/` ← feedback welcome!

How to share software?

Software



Aim for **incremental buy-in**.

Repositories: `https://github.com/tasts-robots`

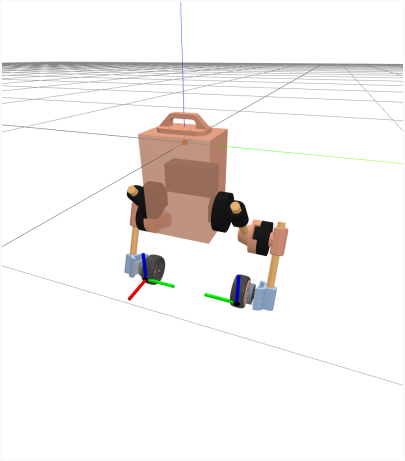
Pink

Task-based inverse kinematics:

- Long-lasting yet still active question
- Combine tasks by weights into a single QP
- Tikhonov and Levenberg-Marquardt damping

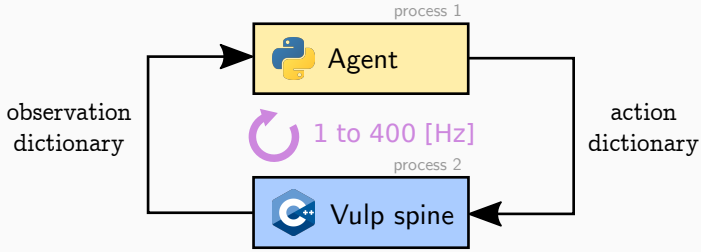
Open questions:

- Frequency-independent formulation?
- Eliminate damping parameters?
- Avoid instability near almost-feasible targets? ($\star$)



Distribution: `pip install pin-pink`

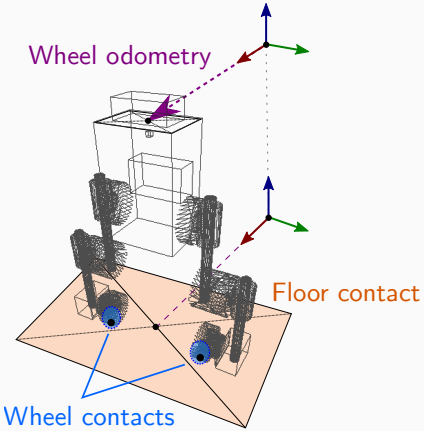
Vulp



- Balance control at low frequency (Python)
- Convert actions to servo commands at medium frequency (C++)
- Actuators run field-oriented control on-board at high frequency (C++)

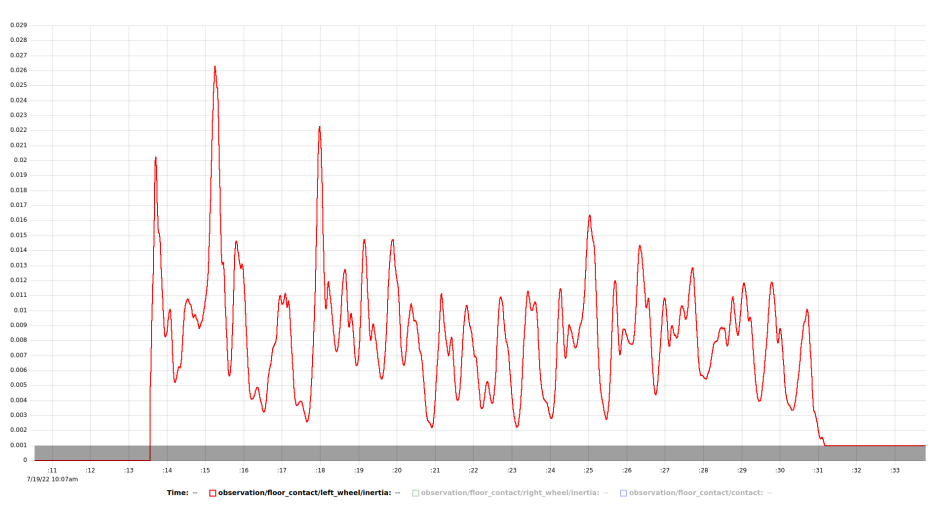
Balancing is a low-frequency task: `https://arxiv.org/pdf/1907.01805.pdf`

Wheeled biped observers



Code: `https://github.com/tasts-robots/upkie_locomotion`

Wheel contact observation



https://tasts-robots.org/doc/upkie_locomotion/classupkie__locomotion_1_1observers_1_1WheelContact.html

Takeaway

- It has become easier to try **new morphologies**.
- Sharing hardware: **reproducibility** requirements.
- Sharing software: **incremental buy-in**

Thank you for your attention!

These slides include feedback from Vincent Padois and Grégoire Passault, thanks!