ME 586: Biology-Inspired Robotics

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project topic ideas

This document lists a few ideas for project topics in the general area of biology-inspired robotics. More detail on the parameters, suggested format of project, etc., will be provided later in the term. In the mean time, you can think of the project as a sort of advanced problem set, equal in work to 3–4 regular problem sets, with the addition of a proposal-like report that proposes follow-on work. The basic criteria for success is that your simulation/robot have some new capability or new way of doing something, rather than for example wiggle randomly. Associated papers that can be found on the course web page here.

Crazyflie ideas:

1. It is unknown how insects regulate their altitude above the ground or distance to obstacles. It is likely they use optic flow, which is a measure of the speed of motion as seen by a camera. One hypothesis suggests that insects may regulate their altitude by coupling *vertical thrust* to optic flow, rather than *forward thrust*. This can lead to a steady-state altitude. Such a controller would also descend in a headwind and rise in a tailwind, something that has anecdotally observed in flying insects. How well does this work on a helicopter, and in the wind? Reference: Franceschini2007: "A Biology-inspired robot sheds light on insect piloting abilities, *Current Biology.*

2. Another possibility for altitude regulation holds that they may use a velocity feedback loop that has a time delay (caused by for example sensing + neural processing). When combined with a high feedback gain, this can cause instability, which is manifested by unstable oscillation. If the animal could detect these oscillations, it could use that to estimate distance. Can you implement the same behavior to estimate altitude on a Crazyflie?
   Implementation suggestion: Read the optic flow in a python script in ROS and close the loop on your computer (by commanding forward velocities). Transmission between the crazyflie and base station will add the necessary time delay. No added sensor equipment required!
   Reference: deCroon2016, "Monocular distance estimation using optic flow," *Bioinspiration & Biomimetics.*

3. Wind vanes have been shown to be useful for the task of plume source localization on a palm-sized drone: they steer the vehicle so that it is always facing into the wind. Could they also be used to sense the strength of the wind by adding strain gauges to detect deflection of the vanes?
   Implenentation suggestion: create an op-amp circuit and wheatstone bridge strain gauges on the tail fins, read voltage through Crazyflie analog-to-digital converter. (**Note**: this project requires prior experience with soldering and precision op-amp circuits)
   Reference: Anderson2019: The "Smellicopter," a bio-hybrid odor localizing nano air vehicle, *IEEE Int. Conf. Robots and Systems.*

4. Wall following with an antenna. Cockroaches follow the walls by touching them with their antennae.
   Implementation suggestion: add a thin flexible rod to the crazyflie and measure its deflection at the base. Implement a PD controller in Python in ROS.
   Reference: Cowan2006: "Task-level control of rapid wall following in the American cockroach", Journal of Experimental Biology, 2006.

5. Bacteria are thought to find their way toward food by performing a "run-and-tumble" algorithm: go straight if they detect the concentration is going up, and tumble to a random new orientation if they detect the concentration is going down. Can you program a Crazyflie to find a light source using a similar algorithm? Reference: Macnab1972: "The Gradient-Sensing Mechanism in Bacterial Chemotaxis," *Proc Nat Acad Sci*.

6. The Newton-euler equations, with an added component of wind drag, represent a pretty good model for the flight dynamics of the crazyflie. But they do not capture the full picture, especially when performing dynamic maneuvers. A recent trend in robotics is to explore how to use machine learning tools like neural networks to fill in the gaps, adding a learned "residual" correction. Can you do the same for the crazyflie?
References: Nagabandi2018, "Model-based learning with model-free fine tuning," Int. conf robotics and automation (2018)

Topics that do not involve crazyflie helicopters:

1. In problem set 1, we explored creating a simulation of "Braitenburg Vehicles": simple robots whose wheel speed depends on light or other environmental stimuli. In this project, you would add additional sensor types, actuator types, memory, or other capabilities. The idea is to build in one or two significant new features into the vehicle to make it exhibit more sophisticated behavior such as alternating between different food sources.

2. In Paper 0:McLeod1996, the algorithm by which fielders catch a ball was explored. In this project, you will write a simulation of the ball's trajectory, subject to wind drag and disturbances. Then, use your simulation to investigate the findings of the paper: what components are necessary to intercept the ball if they use the algorithm suggested in the paper? Does your simulation predict the behavior shown in Figure 3? If not, can you propose a plausible additional mechanism or dynamics model (that is, one that could realistically be implemented by a human, such as a proportional, or proportional-integral controller, for example) that can reproduce the observed behavior?