Hummingbird-Inspired High-Speed Deceleration and Flea-Inspired Vertical Take-Off

Pavlo Vlastos [1]

Baskin School of Engineering, UC Santa Cruz

Abstract

A design for a bio-inspired robot and simulation are discussed. A flea-inspired jumping mechanism is detailed, in addition to a hummingbird-inspired wing system for accurate navigation and deceleration. The primary goal of the robot is to deliver a fragile payload, an egg, to a desired height and location. This paper reviews similar projects, research, and discusses a novel hybrid approach. The system is split into vertical take-off and controlled gliding.

Keywords: Flight, Bio-inspired, Hummingbirds, Fleas

1. Introduction

Some robots require specific infrastructure and where as some do not. A rumba for example requires flat surfaces to traverse, where as DARPA's Big Dog can navigate the uneven surface of a grassy hill. Robots that do not require specific environmental geometry can be deployed in countries that have limited infrastructure to deliver important supplies, conduct search and rescue, and study hazardous environments. In the case of disaster relief, supply delivery via all-terrain, long-distance autonomous vehicles can be critical to developing nations.

This paper outlines a proposal for a high-velocity aerial robot drawing inspiration from hummingbirds and fleas. The robot will use vertical take-off, requiring no runway. Additional bio-inspiration is drawn from the manner in which humming-birds rapidly decelerate. When hummingbirds are in mating season, the males attract females executing a looping *display dive* reaching speeds of up to approximately 27 meters per second, Bennet-Clark and Lucey (1967). The system incorporates an initial acceleration mechanism to propel the robot to a high altitude. Once the apex of the trajectory is reached, hummingbird-inspired wings and tail feathers will be deployed to mimic the deceleration.

The vertical take-off mechanism is inspired from the jumping mechanism of a flea. Fleas are capable of jumping with an acceleration of 102 g-forces, (Bennet-Clark and Lucey, 1967, p. 62).

[1] *pvlastos@ucsc.edu*

Preprint submitted to UCSC CMPE 216 Bio-Inspired Locomotion (Fall 2018) *October 30, 2018*

This is a tremendous acceleration that is not easily reverse engineered. This proposal will explore a design for a jumping mechanism based on scaling the acceleration capable of fleas, but with a larger mass. A comparison of energy density relative to size of a payload will be made. A simple free-body diagram is outlined in **section** 2. The forward and inverse kinematics are also discussed in **section** 2.

The basic design of the robot will be broken up in to two main sections: **1)** the initial acceleration mechanism and **2)** the deceleration mechanism. A simulation will first be made, and as a stretch-goal, a prototype will be assembled.

2. Formulation of the problem

The primary goal is to deliver a payload, such as an egg to some height unharmed using a robot that is bio-inspired. The problem is broken up into two parts. The first part is to find a way to rapidly ascend updward. The second part is to implement a *reasonable* deceleration. These two subproblems use two different mechanisms, one inspired by the flea for take-off and one inspired by the hummingbird for landing.

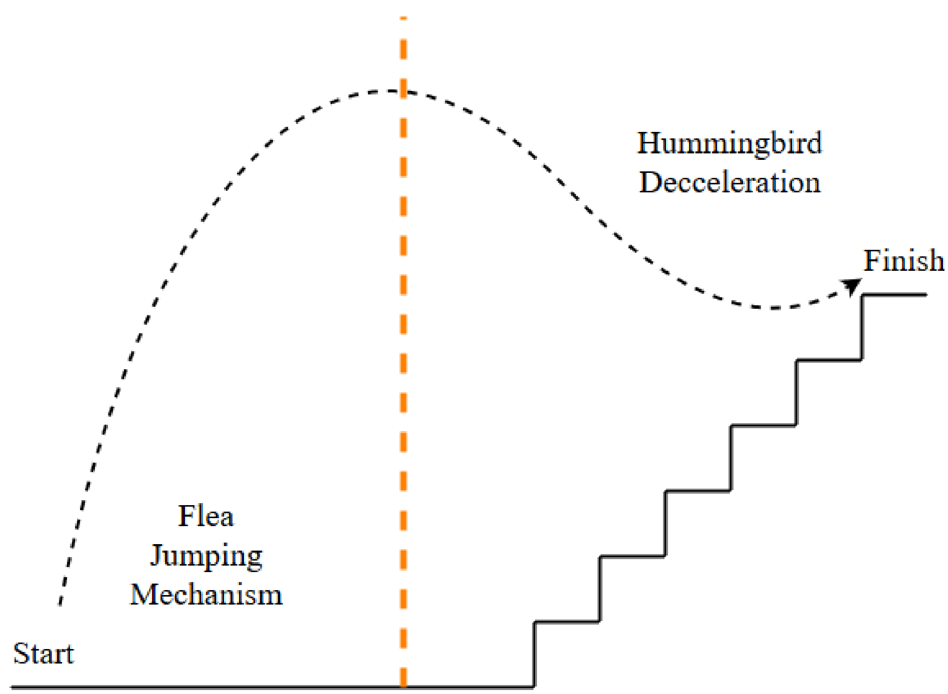


Figure 1: This is a visual representation of the goal of delivering an egg to the top of a staircase. The orange line separates the two different mechanisms into their respective roles for the trajectory of the payload.

2.1. Acceleration Mechanism

As shown in **Figure** 1, the jumping mechanism will be used to achieve substantial height for the payload delivery. In order to draw inspiration from how a flea uses its energy to jump so high, energy usage will be explored in relation to payload mass as well as maximum height. A flea can jump many times its own height, but it is small in mass, approximately 45mg (Bennet-Clark and Lucey, 1967, p. 63). Fleas have a ratio of mass to jump height and energy density. For a larger robot, a similar ratio could be achieved if energy density is proportionally higher to account for the larger mass. The larger mass is in part introduced by the need to carry an egg, which a flea does not have.

It should be noted here that there is no path planning associated with the jumping mechanism. There may be an initial jump angle relative to the ground, but guiding the egg to the desired location is dealt with in the second part of the robot design. The proposed design for the jumping mechanism is shown in **section** 4.

2.2. Deceleration Mechanism

This second part of the problem is associated with the bio-inspiration of a hummingbird. Hummingbirds are able to rapidly decelerate from specifically a diving trajectory. Assuming a substantial height is reached, this deceleration mechanism will be deployed to guide the egg to it's desired location safely. Wings will be used to realize this behavior. The design for this is shown in **section** 4.

3. Method of solution

The flea-inspired leg is the primary focus of the vertical take-off mechanism. It is treated as a two-link planar robot leg. The forward and inverse kinematics are discussed here, followed by the free-body diagram.

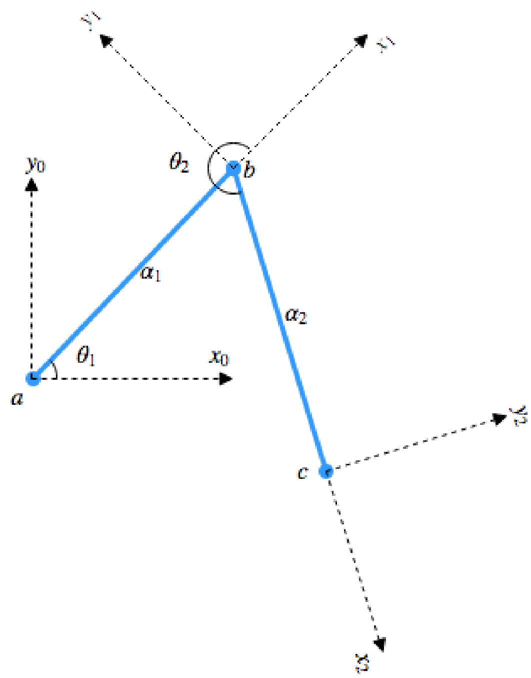


Figure 2: Model for a planar, two-link, robot leg.

Forward Kinematics:

$$x = x_2 = \alpha_1 \cos\theta_1 + \alpha \cos(\theta_1 + theta_2) \tag{1}$$
$$y = y_2 = \alpha_1 \sin\theta_1 + \alpha \sin(\theta_1 + theta_2) \tag{2}$$

The resulting **orientation matrix** is as follows:

$$\begin{bmatrix} x_2x_0 & y_2x_0 \\ x_2y_0 & y_2y_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta_1+\theta_2) & -\sin(\theta_1+\theta_2) \\ \sin(\theta_1+\theta_2) & \cos(\theta_1+\theta_2) \end{bmatrix} \tag{3}$$

Inverse Kinematics:

$$\theta_1 = \tan^{-1}\left(\frac{y_{des}}{x_{des}}\right) - \tan^{-1}\left(\frac{\alpha_1 \sin\theta_2}{\alpha_1 + \alpha_2 \cos\theta_2}\right) \tag{4}$$
$$\theta_2 = \cos^{-1}\left(\frac{x_{des}^2 + y_{des}^2 - \alpha_1^2 - \alpha_2^2}{2\alpha_1\alpha_2}\right) \tag{5}$$

The inverse kinematics represents the angles, θ_1, θ_2 of the two-link leg to be functions of a desired position, (x_{des}, y_{des}). When controlling the acceleration of the robot's mass upwards, the inverse kinematics will be used to command a position of the end of the robot leg at various time steps. A desired acceleration can be incorporated into a feedback loop, which is discussed further.

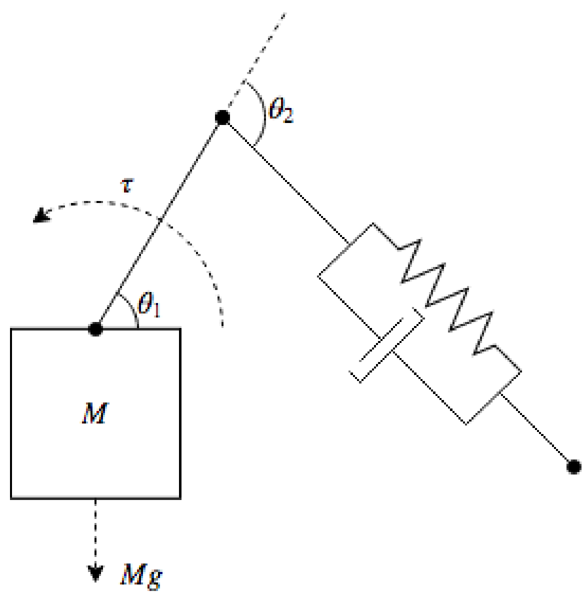


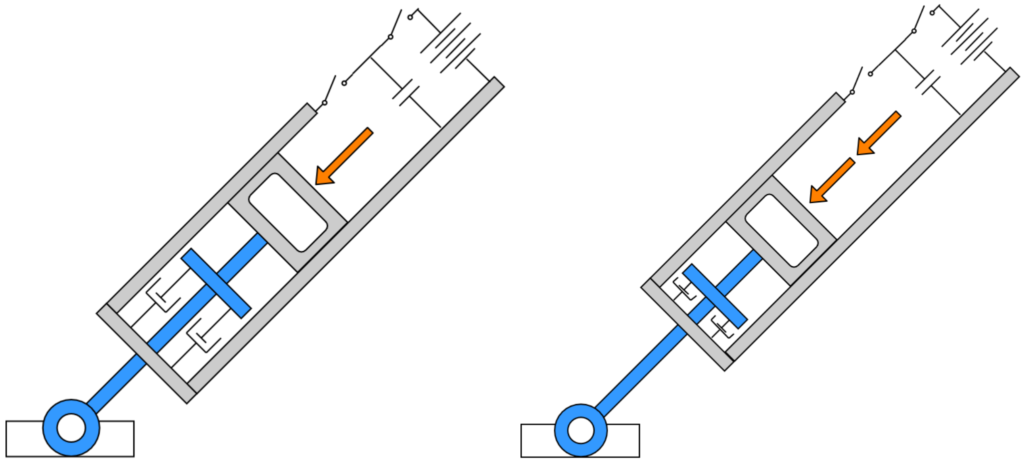
Figure 3: Free-body diagram of the FleaSlug robot

The simulation will look at a number of physical aspects of the robot, but will focus on two main things. The first is energy usage and finding a similar method to store comparable energy density in a small robot. The discharge rate of the energy used to propel the robot upward will be simulated. The second is the flight of the robot. The wing design, air resistance, and lift will be simulated.

Once the simulation is completed, a stretch goal for this project will be fabricate and construct the robot based on the simulation. A simple 8-bit microcontroller will be used to control the robot, its wings, the jumping mechanism, and possible safety features.

4. Implementation

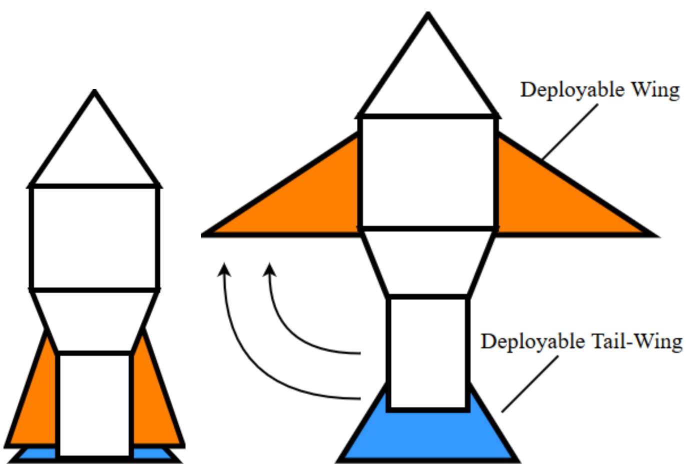
Both the jumping mechanism and wings for deceleration will be outlined here. This section shows possible designs for the robots mechanisms.



(a) Compressed jumping mechanism (b) Extended jumping mechanism

Figure 4: Example of a chart

The mechanical implementation for the flea-inspired jumping mechanism is shown in **Figure** 4. To achieve the necessary energy density, a small battery and a large capacitor will be used. The capacitor allows for large quantities of charge to be discharged rapidly. The current will flow through the armature, pushing the piston-like leg (blue) out. The micro-controller mentioned in **section** 3 will control the flow of current and capacitor charging and discharging.



(a) Folded wings (b) Extended wings

Figure 5: Example of a chart

Figure 4 shows the deployable wings. The wings must be folded at first to maximize the height. When the wings are folded air resistance is less and the jumping mechanism can propel the robot higher. The on-board micro-controller will control the timing of the wings and when the are deployed.

5. Numerical results and discussions

When numerical results are prepared, they will be shown here. The acceleration over time, the velocity over time, the position over time, and other information will be graphed and compared to the simulation if the physical robot is constructed.

References

Bennet-Clark, H.C., Lucey, E.C.A.. THE JUMP OF THE FLEA: A STUDY OF THE ENERGETICS AND A MODEL OF THE MECHANISM. Journal of Experimental Biology 1967;:18.