Understanding *Polypterus Senegalus* Walking Locomotion from its Center of Mass Displacements

Laura Paez[a], Kamilo Melo[a], Emily Standen[b], Auke Ijspeert[a]
[a]Biorobotics Laboratory, EPFL Lausanne, Switzerland
{*laura.paez, kamilo.melo, auke.ijspeert*}*@epfl.ch*
[b]Comparative and Evolutionary Biomechanics Lab, University of Ottawa, Canada
estanden@uottawa.ca

1 Introduction

Polypterus Senegalus is an elongated body fish capable of moving in water as well on land. During terrestrial locomotion, its pectoral fins have a similar role as a limb on other primitive terrestrial animals. Understanding the mechanical strategies used by *Polypterus* during walking locomotion can lead to provide hints on how the elongated bodies of fishes evolved and adapted to move on land [1].

The terrestrial movement of *Polypterus*, is called axial-appendicular-based locomotion [2]. This fish exhibits a contralateral gait that involves the movement of the whole body. It is a combination of undulatory movements along the body and the use of pectoral fins in order to generate thrust [3]. For our biomechanical analysis, the Center of Mass (CoM) is a key parameter. We consider the CoM displacement as the resultant of the whole body motion. Fig.1 shows snapshots of a video of a *Polypterus* walking. The red dots show the location of the CoM at diferent stages of the locomoton, while the black dashed line describes the displacement between the two snapshots. *Polypterus* uses the whole body in order walk.

Fig 1 shows how the body of the *Polypterus* has to change constantly from a C-shape facing upwards (top) to a C-shape facing downwards (bottom). This gait seems high energy consuming and rather inefficient as forward propulsion. In view of this, we are motivated to investigate the next conjecture:

Polypterus maximizes the forward CoM displacement while minimizing the CoM lateral deviation during walking.

2 CoM calculation

The CoM trajectory was calculated using an estimate of the mass distribution of the animal, combined with the position of the centerline of the body in sequences of images taken from videos of the animal executing the gait.

Centerline of the body: it was calculated using digital image processing. A skeleton algorithm was applied to each frame of the motion video, in which the body shape was reduced to a thin version of it. Applying a second order polynomial fit to this reduction, we obtain a center line function that represents the body shape Fig.2a.

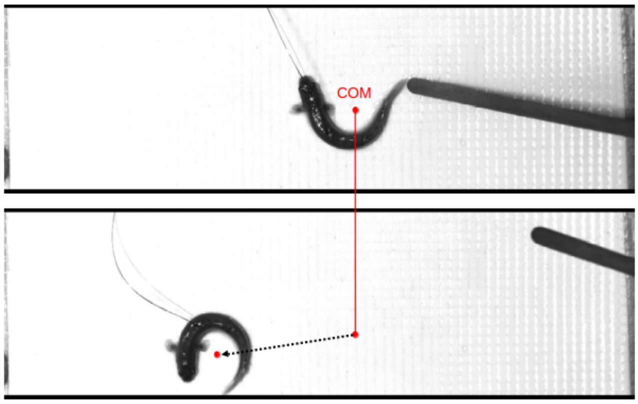
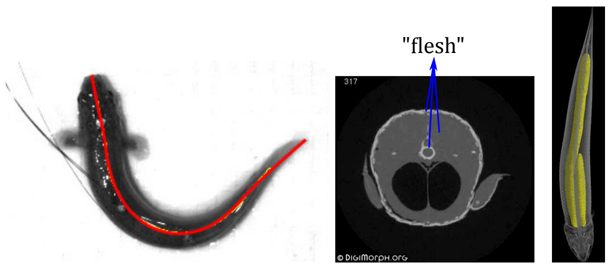


Figure 1: Snapshots of a video of a *Polypterus* walking, showing the displacement of the CoM (black dashed line). On top, the body of the fish in an initial time, on bottom, the same body after certain time.

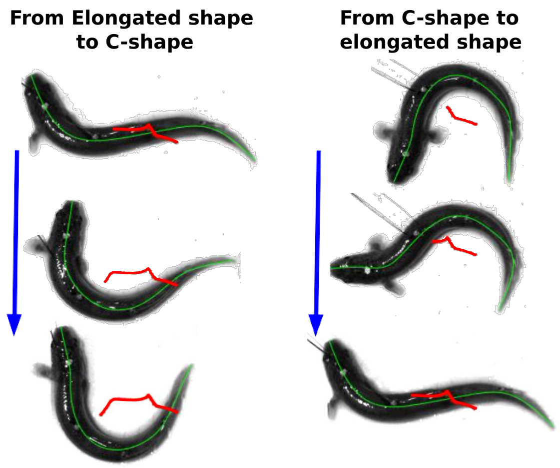
Mass distribution: It was obtained using a coronal plane X-ray CT scan sweep [4]. From the scan video, the area representing the ”flesh” was quantified in each frame. Fig.2b left side, shows an example of a quantified frame. The pixels different than black (i.e white and gray tones) are assumed to be ”flesh”, while the black pixels were not taken into ac-



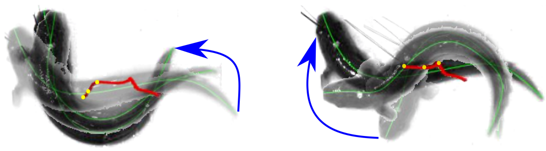
(a) Resultant centerline calculation of the *Polypterus* (red line)

(b) CT-scan of *Polypterus*. Left, cross sectional view. Right, top view [4]

Figure 2: Tools used in order to calculate the CoM.



(a) Step by step sequence



(b) The steps are overlapped.

Figure 3: Resultant sequence of the CoM displacement.

count. In this example is possible to visualize the area of the lungs. In this case the lungs area were subtracted from the body area. The distance between each frame (i.e. slice) is provided along with the video. Having the area of the cross-section of the body (i.e. slice) and the distance between each slice, gives an estimation of the volume of that part of the body. By doing the aforementioned process to the whole video is possible to get the estimation of the volume (thus the mass considering a uniform body density) of the whole body.

The volume of the "slice" was calculated with a *Polypterus* of specific dimensions (V_{scan} volume slice of the fish of the scan). Those dimensions were geometrically scaled to the dimension of the *Polypterus* used during the center of line calculation (v_{fish} volume slice of the original fish), as follows:

$$V_{scan} = v_{fish}(l/L)^3 \tag{1}$$

With l as length of the original fish and L the length of the fish used in the scan. Having the volume along the body and the centerline information the CoM was calculated as follows:

$$x_{cm} = \frac{1}{V_{total}} \sum_{i=1}^{n} v_i x_i \quad y_{cm} = \frac{1}{V_{total}} \sum_{i=1}^{n} v_i y_i \tag{2}$$

Where V_{total} is the total volume of the fish, v_i the scaled volume of the "slice" and x_i, y_i are the x and y position of the centerline, respectively.

3 Analysis and results

The results can be seen on fig 3. During motion, the *Polypterus* presents two main shapes: a C-shape (i.e. the

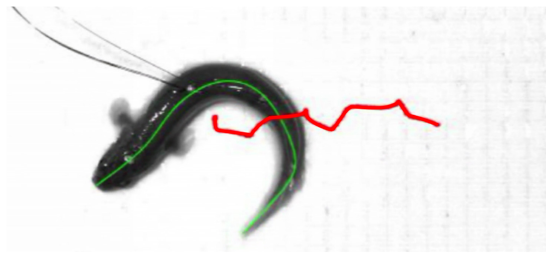


Figure 4: Final CoM trajectory.

body is curved into an arc with the tail close to the head) and an elongated shape. The transition between shapes (i.e. from C to elongated to C shape) corresponds to half gait cycle. Following the example on fig 3a, from C to elongated shape the fish plants its right fin representing the first half of the stance phase. The left fin lifts and the forward displacement is produced (i.e CoM shows high forward displacement). The tail works as an anchor to help to generate thrust and as the left fin lifts, the body reduces friction. From elongated to C-shape, the anchoring preparation is produced. The body does not produce forward displacement and head and tail are lifted. It is produced in short time and moves the CoM sideways. This transition, represents the second half of the stance phase for the right fin. The final CoM trajectory can be seen on fig 4 (in red).

4 Conclusions

Final assessment of the CoM trajectories reveal that the forward displacement can be up to four fold the lateral one. This suggest that the large body bending is produced to minimize the energy expenditure in the locomotion and keep a straight overall displacement in various steps. With this results, the conjecture has been supported. However, it is important to mention that there are sources of error in the calculations: in the CT-Scan if the lungs have air or not can change the results. The fitting curve of the centerline has an error. And the density was assume to be flesh, nonetheless the internal parts of the body can have different densities.

5 Acknowledgements

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