

## Supplementary Materials

### Dynamical Boundary Following and Corner Trapping of Undulating Worms

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#### I. MOVIES

List of movies and captions.

- **Movie S1:** A California blackworm moving in a circular chamber is observed to turn and follow the boundary. The frame rate is 1 fps and total time is 450 s. ( $R = 20$  mm;  $l_w = 18 \pm 1.50$  mm). The movie is played at 10 fps.
- **Movie S2:** A California blackworm moving in a square chamber is observed to follow the boundary and get trapped at the corners before escaping over varying internal of time. The frame rate is 1 fps and total time is 600 s. ( $l = 40$  mm;  $l_w = 22 \pm 2$  mm). The movie is played at 10 fps.
- **Movie S3:** A California blackworm moving in a polygonal chamber with concave and convex corners. The worm is observed to follow the boundary but not across the convex corner. It is observed to get trapped at concave corners as also seen in the square chambers. The frame rate is 1 fps and total time is 600 s. ( $l = 40$  mm;  $l_w = 15 \pm 1.8$  mm). The movie is played at 10 fps.
- **Movie S4:** An animation of the simulated self-propelled rod (SPR) model in a circular chamber. The frame rate is 4 fps and total time is 600 s. ( $R = 20$  mm;  $l_r = 15$  mm), The animation is played at frame rate of 40 fps.
- **Movie S5:** An animation of the simulated SPR model in a square chamber. The frame rate is 4 fps and total time is 600 s. ( $l = 40$  mm;  $l_r = 15$  mm), The animation is played at frame rate of 40 fps.
- **Movie S6:** An animation of the simulated SPR model in a polygon chamber. The frame rate is 4 fps and total time is 600 s. ( $l = 40$  mm;  $l_r = 15$  mm), The animation is played at frame rate of 40 fps.

#### II. IMAGE PROCESSING

The system is imaged from above with a DSLR camera Canon Rebel T5i with a 18 megapixel CMOS sensor while the worms are back-lit with a uniform LED array. After the worm acclimatizes over a few minutes, the motion of the worm is recorded over approximately 30 minutes at 24 fps, and the worm is returned back to the holding tank. A representative cropped image is shown in Fig. S1(a). The images are binarized by using a suitable threshold and its complement image is shown in Fig. S1(b) and the entire shape of the worm is tracked using Image Acquisition Toolbox functions implemented in MATLAB. The tracked worm body position superimposed on an image of the worm are shown in Fig. S1(c), and several superimposed snapshots of the worm while moving inside the chamber is shown in Fig. S1(d). We obtain the worm locomotion speed, its orientation, the stroke amplitudes, along with the position of the head and tail from the tracked shape, and use them for further analysis.

The recorded images are pre-processed before they can be used for extracting data. We use the following steps for pre-processing:

1. **Conversion of an image from RGB to gray scale.** The image captured by the camera is in RGB scale. We convert the image to gray scale. Under the applied lighting conditions, the worm appears dark in contrast to the bright background.
2. **Subtracting the background from the image.** To remove the background, we average over all the images to obtain a background image. Each frame is then subtracted from this background image. The resulting difference image has the worm body as bright pixels against a dark background. This results in an image where the worm's body is represented as bright pixels against a dark background.
3. **Binarizing the image.** The gray scale images are binarized using an appropriate threshold. We set the threshold value such that the worm's body pixel value equals 1.

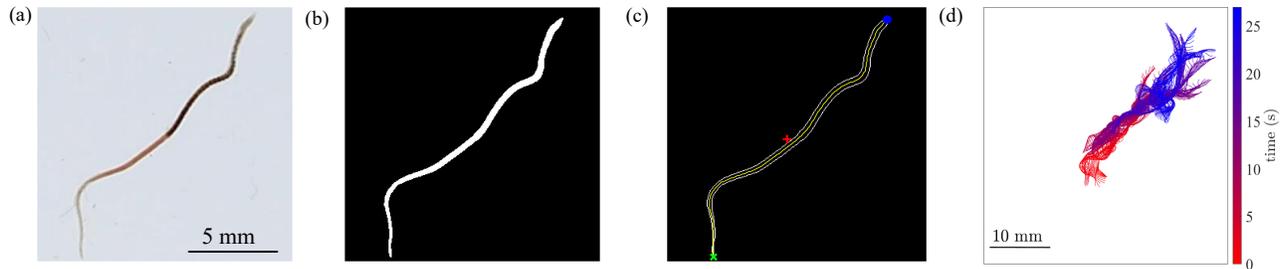


FIG. S1. (a) A closeup image of a California blackworm. (b) The complementary binarized image. (c) Tracked body shape (solid yellow curve) of the worm with head (blue o), centroid (red +) and tail (green x) coordinates. (d) Superimposed snapshots of a worm moving diagonally across a square chamber at 12 frames per second or 83.3 ms time intervals. The color bar represents time.

4. **Cleaning the image.** The noise in the binarized image is removed by determining all the connected objects in the image and choosing the object having the maximum number of pixels which corresponds to the worm body.
5. **Skeletonizing the image.** We then determine the skeleton of the image. The skeleton image is a 2D curved line representing the body shape of the worm.

The position coordinates for the head, centroid and tail of the worm can be tracked from the processed image. Using inbuilt MATLAB operations, we can directly extract the position of the centroid of any segment (in this case, the worm body) present in the image. To track head and tail, we extract and save the endpoints from the images and connect them using the Hungarian tracking algorithm. To track the full body shape of the worm we use the skeleton image and sort its pixel from head to tail using the tracked head and tail coordinates.

### III. CONTOUR LENGTH OF THE WORMS

We measure the mean and standard deviation of the contour length of worm from 10 trials of the experiment. The length is sampled over the total time  $T \approx 30$ , min with time interval  $\Delta t = 1$  second. Overall, the mean length and fluctuation of the worms is  $l_w = 20 \pm 3$  mm.

Experiment No.	Mean length $l_w$ (mm)	Standard deviation (mm)
1	17.2	1.7
2	19.8	2.2
3	20.2	1.8
4	23.3	2.2
5	17.0	1.8
6	19.9	2.0
7	22.9	4.4
8	17.9	2.3
9	19.9	2.2
10	20.3	2.4

### IV. LOCOMOTION SPEED OF THE WORMS

Worm speed is evaluated in the central region away from the boundary, in the boundary region, and at the corners. This analysis includes all relevant events from 10 independent 30-minute trials. Average speeds are computed from position data sampled over a time interval of 2.5 seconds, selected to smooth out fluctuations over two peristaltic body strokes. The measured speeds are as follows.

Centroid speed:

$$\begin{aligned} \text{Center, } v_c &= 0.95 \pm 0.49 \text{ mm s}^{-1} \\ \text{Boundary, } v_c &= 0.82 \pm 0.57 \text{ mm s}^{-1} \\ \text{Corner, } v_c &= 0.47 \pm 0.15 \text{ mm s}^{-1} \end{aligned}$$

Head speed:

$$\begin{aligned} \text{Center, } v_h &= 1.72 \pm 0.65 \text{ mm s}^{-1} \\ \text{Boundary, } v_h &= 1.33 \pm 0.70 \text{ mm s}^{-1} \\ \text{Corner, } v_h &= 0.26 \pm 0.07 \text{ mm s}^{-1} \end{aligned}$$

Thus, we observe that the velocity of both the centroid and the head while confined in the corner is significantly lower than when it is away from the boundaries due to the collisions with the boundaries. Further, it can be noted from the speeds that the head is more motile than the centroid in each region, except in the concave corner.

## V. MEASUREMENTS OF DIFFUSION CONSTANTS

We obtain the translational diffusion constant  $D_t^w$  from the mean square displacement of the worm's center as a function of time interval  $\Delta t$ , given by  $\langle(\Delta r)^2\rangle = 4D_t^w \Delta t$ . The worm's center is obtained by averaging the worm's head and tail coordinates and hence is different from the worm's body centroid. The rotational diffusion constant  $D_r^w$  is similarly determined from the mean square angular displacement, given by  $\langle(\Delta\theta)^2\rangle = 2D_r^w \Delta t$ . Here  $\theta$  is the angle subtended by the line joining tail to head with the horizontal. Plots of  $\langle(\Delta r)^2\rangle$  and  $\langle(\Delta\theta)^2\rangle$  as a function of time interval  $\Delta t$  in the circular chamber are shown in Fig. S2(a) and Fig. S2(b), respectively. Similarly, Fig. S2(c) and Fig. S2(d) show the corresponding plots in the square chamber with side length  $l = 4$  cm. The time interval  $\Delta t = 0.5$  s, over which the mean square displacements grow linearly, is used to fit the data and obtain the two diffusion constants.

Further, the diffusion constant  $D_l^w$  corresponding to the end-to-end distance length  $l_e$  is obtained from the MSF of the worm end-to-end length  $\langle(\Delta l_e)^2\rangle = 2D_l^w \Delta t$  (see Fig. S3). Guided by these measurements, we assume  $D_l = D_l^w = 3.6 \text{ mm}^2 \text{ s}^{-1}$  in performing simulations with the SPR model to include end-to-end length variations. The saturation of the MSF of the worm end-to-end length at long times leads to an estimate of maximum deviation in worm-length  $\langle\Delta l_e\rangle_{\max} \approx 5$  mm. Thus, we set  $l_e^{\min} = 10$  mm and  $l_e^{\max} = 20$  mm

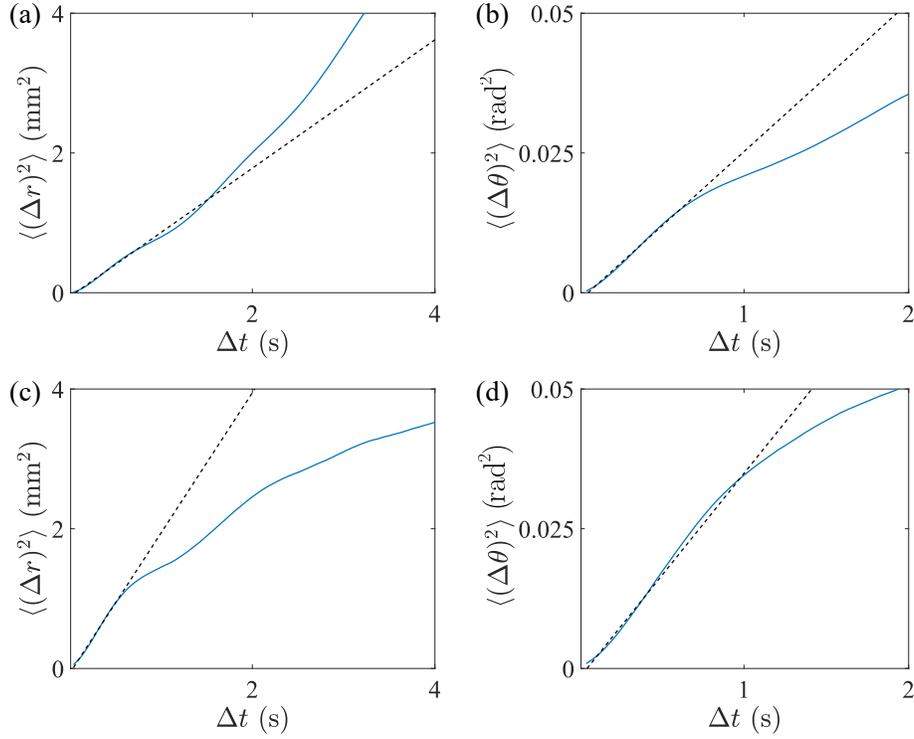


FIG. S2. (a) The mean square displacement versus time interval in the circular chamber ( $D_t^w = 0.22 \text{ mm}^2 \text{ s}^{-1}$ ). (b) The mean square displacement versus time interval in the circular chamber ( $D_r^w = 0.014 \text{ s}^{-1}$ ). (c) The mean square displacement versus time interval in the square chamber ( $D_t^w = 0.5 \text{ mm}^2 \text{ s}^{-1}$ ). (d) The mean square angular displacement versus time interval in the square chamber ( $D_r^w = 0.018 \text{ s}^{-1}$ ). The black dashed line corresponds to the time interval  $\Delta t = 0.5 \text{ s}$  over which the growth is linear.

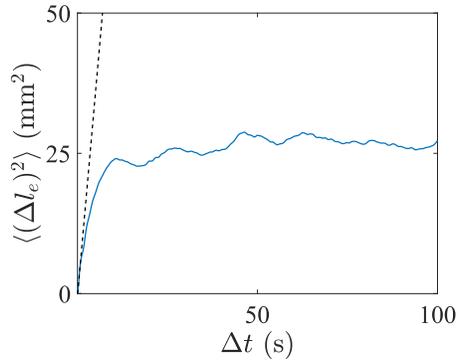


FIG. S3. The mean square fluctuation of the worm end-to-end distance as a function of time. ( $D_t^w = 3.6 \text{ mm}^2 \text{ s}^{-1}$ ). The black dashed line represents the linear fit over time interval  $\Delta t = 0.5 \text{ s}$ . The growth over long times is limited by the worm length and its elongation due to the peristaltic stroke.