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Path guided motion synthesis for *Drosophila* larvae

Key words: Motion synthesis of mollusks; Dynamic pose dataset; Morphological analysis; Long pose sequence generation

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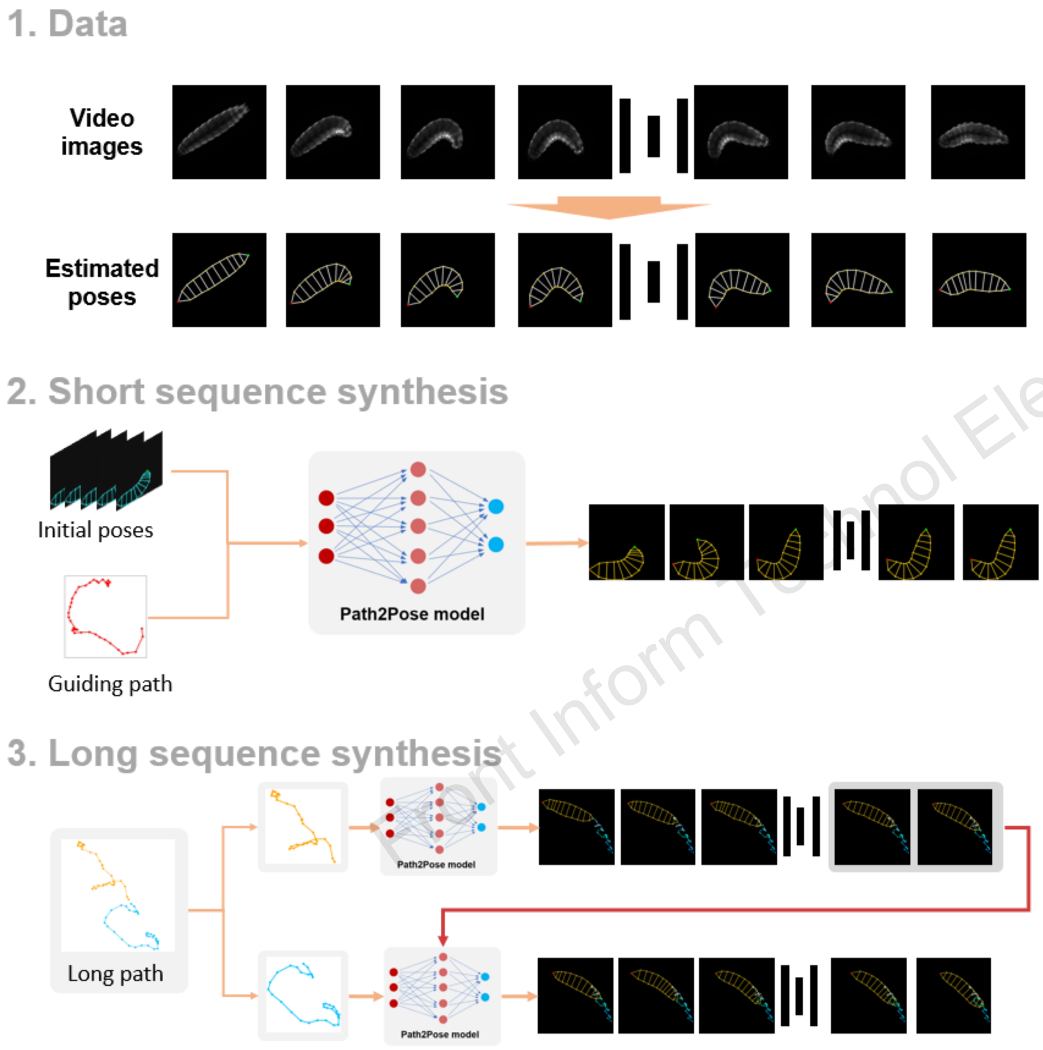
Motivation

- Animals interact with the environment mainly through a variety of motions. Modeling the motion dynamics and synthesizing the realistic motions of animals have great significance in many industrial applications, such as computer animation, game production, and biomimetic robots.
- Compared with mammals, especially humans, few studies on the motion synthesis of mollusks have been reported.
- The high degrees of freedom and deformability of mollusks pose significant challenges for motion synthesis tasks.

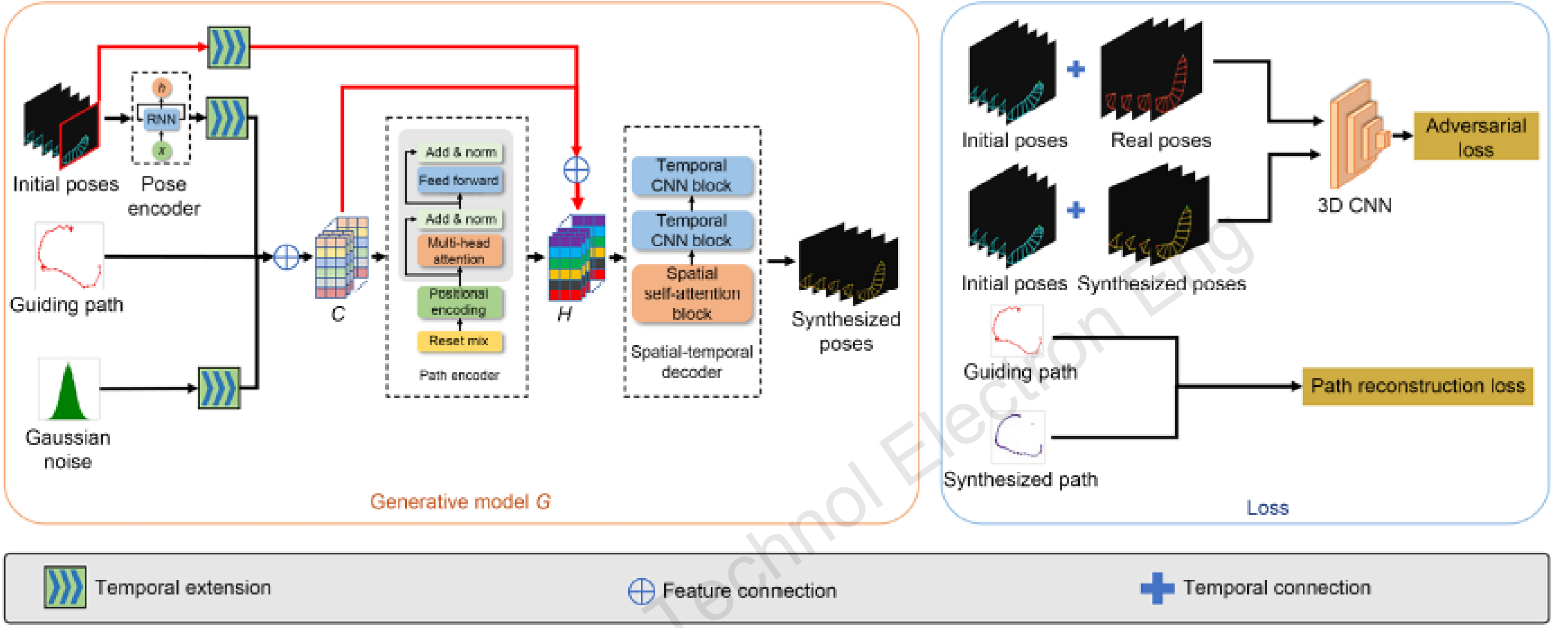
Method



Pipeline of the Paper

- Construct a large-scale pose dataset of *Drosophila* larvae for model training.
- Propose a basis sequential generative model to synthesize short-time motions based on the initial poses and guiding path.
- Perform a long-time motion synthesis via recursive concatenation.

Path2Pose model



- ☐ Generative model
  - ☐ Input: initial poses, guiding path, Gaussian noise
  - ☐ Output: short synthesized poses (35 frames)
  - ☐ Pose encoder: RNN
  - ☐ Path encoder: self-attention model
  - ☐ Spatial-temporal pose decoder: AttnCnNet
    - ☐ Spatial decoder: self-attention model
    - ☐ Temporal decoder: CNN

- ☐ Loss
  - ☐ Discriminator

$$\min_{D} \mathcal{L}(D) = \mathbb{E}_{\boldsymbol{R}\sim p_{\text{real}|\boldsymbol{P}_{\text{ini}},\boldsymbol{X}_{\text{g}}}}\left(D(\boldsymbol{R})-1\right)^2 + \mathbb{E}_{\boldsymbol{z}\sim p_{\text{norm}}} D(G(\boldsymbol{z}|\boldsymbol{P}_{\text{ini}},\boldsymbol{X}_{\text{g}}))^2$$

  - ☐ Generative model

$$\min_{R} \mathcal{L}(G) = \mathbb{E}_{\boldsymbol{z}\sim p_{\text{norm}}}(D(G(\boldsymbol{z}|\boldsymbol{P}_{\text{ini}},\boldsymbol{X}_{\text{g}}))-1)^2 + \alpha\mathbb{E}_{\boldsymbol{F}_t\sim G(\boldsymbol{z}|\boldsymbol{P}_{\text{hist}},\boldsymbol{X}_{\text{g}})}\left\|\boldsymbol{X}_{\text{g}}-\boldsymbol{F}_t\right\|_2,$$

DLPose dataset

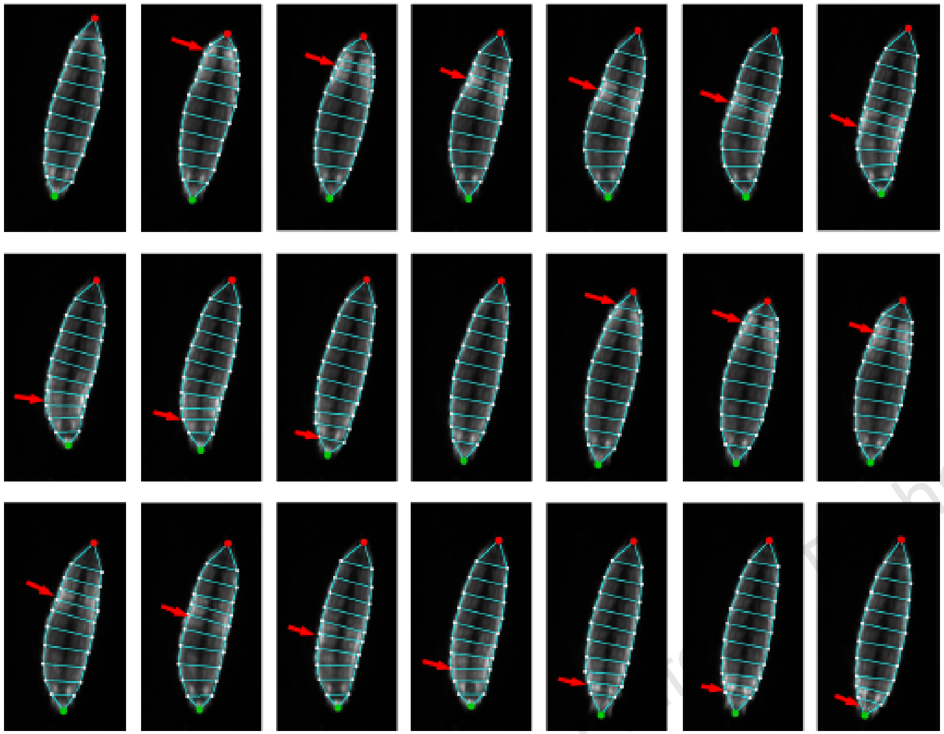


Fig. 3 An estimated pose sequence in the DLPose dataset. Raw video images of 2000×2000 pixels are cropped to 330×624 pixels for demonstration. The pose sequence depicts a *Drosophila* larva moving forward with the peristaltic wave (red arrow) passing through its body periodically. The peristaltic wave propagates from the tail (red point) to the head (green point) in a crawling cycle

- We recorded videos of 51 *Drosophila* larvae with a total length of 5.1 h.
- We finally obtained 61 644 frames of video images, which were divided into 165 clips.
- Each frame of larval poses is composed of 22 keypoints, divided the body into 11 segments.

Short pose sequence synthesis

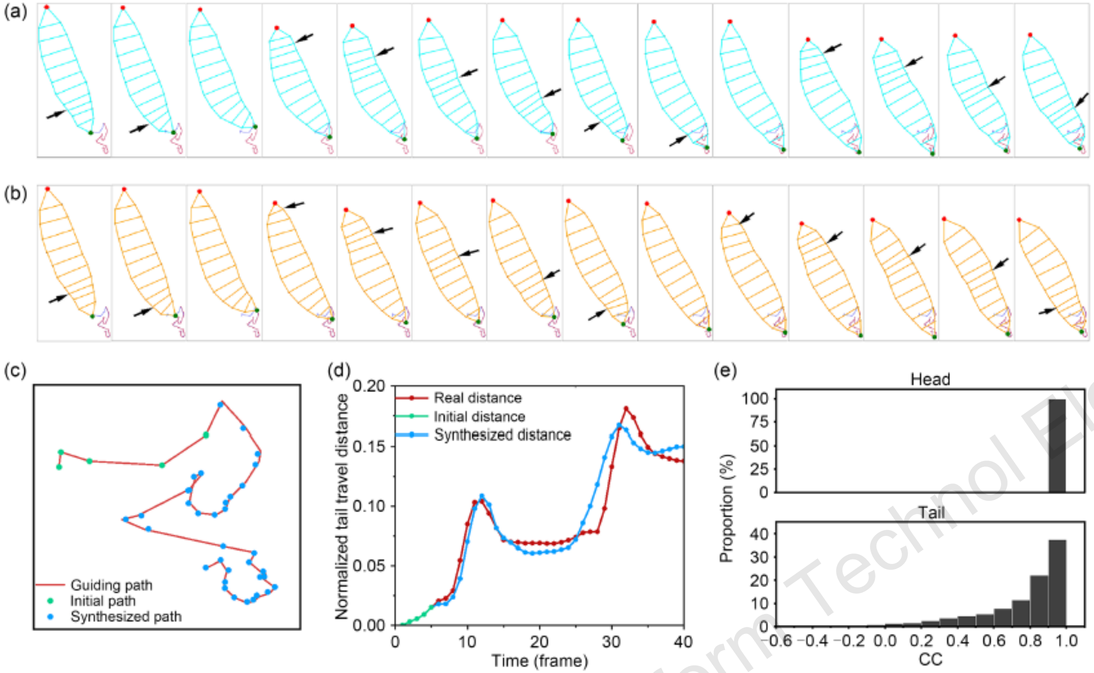


Fig. 4 Comparison between the real and the synthesized pose sequences: (a) a pose sequence from the DLPose dataset, the arrow indicating the position of the peristaltic wave; (b) synthesized pose sequence with the same initial poses and the guiding path; (c) comparison between the guiding path (red line) and the synthesized head movement path (blue dots), the green dots representing the initial path; (d) tail travel distance normalized by larval body length during forward locomotion; (e) Pearson correlation coefficient (CC) distribution of the travel distance for the head (top panel) and the tail (bottom panel)

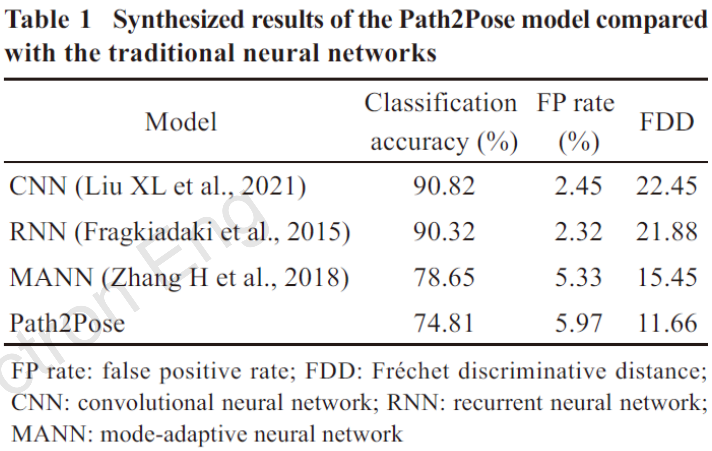


Table 1 Synthesized results of the Path2Pose model compared with the traditional neural networks

Model	Classification accuracy (%)	FP rate (%)	FDD
CNN (Liu XL et al., 2021)	90.82	2.45	22.45
RNN (Fragkiadaki et al., 2015)	90.32	2.32	21.88
MANN (Zhang H et al., 2018)	78.65	5.33	15.45
Path2Pose	74.81	5.97	11.66

FP rate: false positive rate; FDD: Fréchet discriminative distance; CNN: convolutional neural network; RNN: recurrent neural network; MANN: mode-adaptive neural network

- ☐ The synthesized larval poses are similar to the real data in terms of body shape, peristaltic wave, head movement path, and tail travel distance.

- ☐ Compared to traditional models, the Path2Pose model has lower classification accuracy, higher false positive (FP) rate and lower Fréchet discriminative distance (FDD), which indicates its synthesized samples are more similar to the real data.

Long pose sequence synthesis

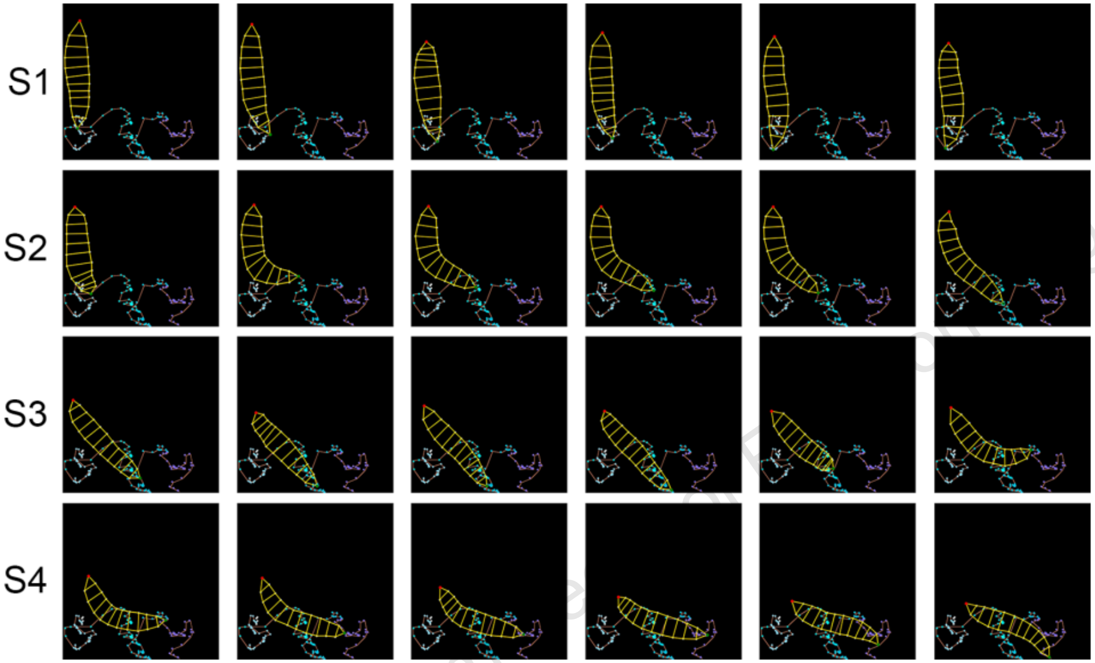


Fig. 6 A long pose sequence composed of four recursively synthesized segments. The head movement paths of individual segments are labeled by different colors

- The synthesized long pose sequences, joined with several short segments, can depict complicated and continuous motions of *Drosophila* larvae, such as tuning and forward locomotion.

Long pose sequence synthesis

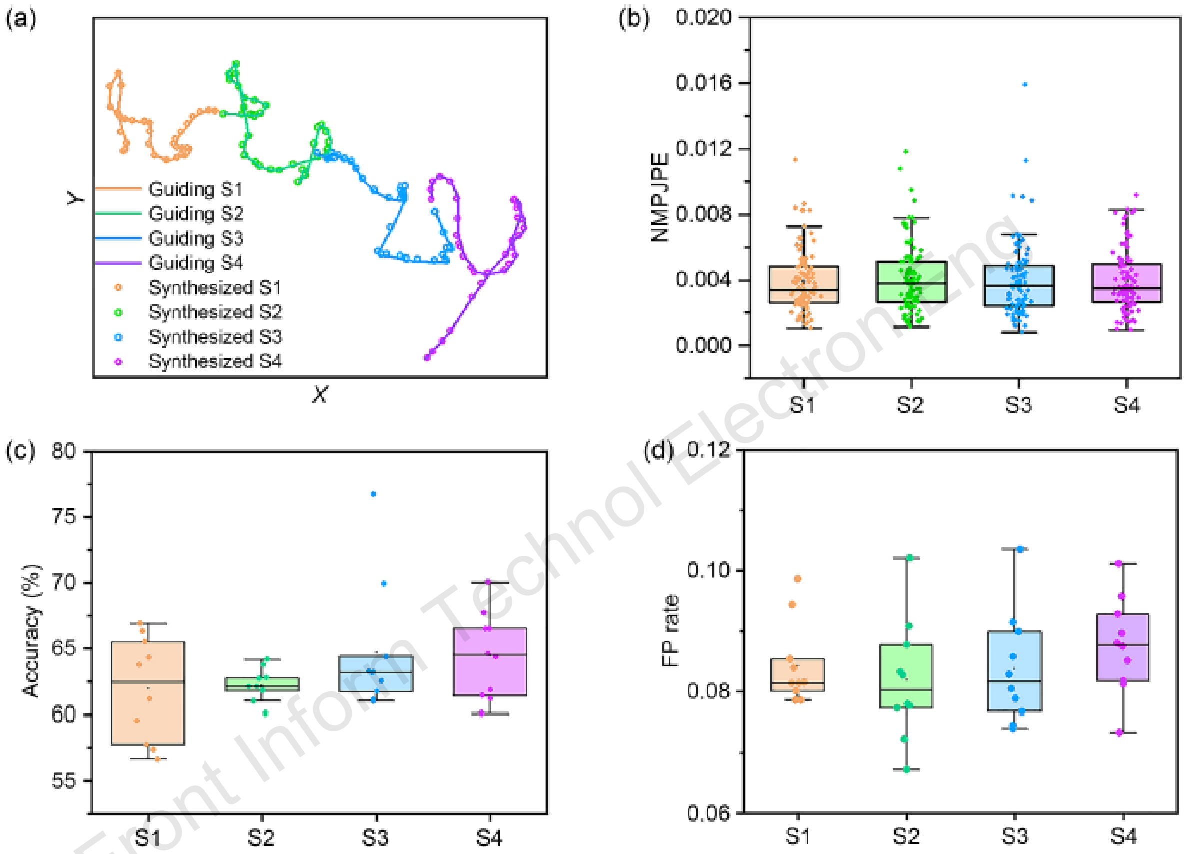


Fig. 7 Error accumulation analysis of long pose sequence synthesis: (a) guiding path (line) and synthesized head movement path (dots) of a long pose sequence consisting of four joined segments; (b) normalized mean per-joint position error (NMPJPE) of the head movement path for four joined segments; (c) classification accuracy of four joined segments; (d) false positive (FP) rate of four joined segments

- There is no significant accumulative error across joined segments in terms of larval head movement path and similarity to the real data.

Conclusions

- We construct a large-scale dynamic pose dataset of *Drosophila* larvae to support model training.
- We propose a Path2Pose model to synthesize the short pose sequence given the initial poses and the guiding path sampled from the dataset. The synthesized pose segments can be joined end-to-end to obtain long-time motions.
- The evaluation analysis results show that the Path2Pose model synthesizes highly realistic *Drosophila* larval motions in terms of morphology and achieves better performance than the traditional models.

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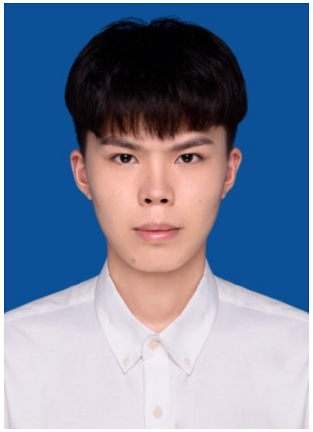

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