Joint Tracking and Recognition of the Locomotion State of *C. elegans* from Time-Lapse Image Sequences

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Abstract

The nematode *Caenorhabditis elegans* (*C. elegans*) is a simple and well-characterized organism used for studying genetic influence at morphological or behavioral levels. To facilitate quantitative analysis of *C. elegans*, we developed a novel and fully automated worm tracking system. Most worm analysis systems in the literature treat worm tracking/detection and locomotion state recognition as two separate tasks, however, our proposed simultaneous tracking and locomotion state recognition model is designed to exploit the synergy between these tasks. This model could deal with worms with complex behaviors such as omega bend, or worms in physical contact. Based on the obtained worm structure and motion state labels, morphological, locomotory, and other others are calculated, which serve as the basis for identifying distinct worm events, classification, event analysis and discovery, and other quantitative analyses of *C. elegans*.

Implementation of Proposed Model

Algorithm: In the model, we employ a Bayesian recursive-computation to compute the posterior density function (pdf), \( p(x_t | z_{1:t}) \), which is the conditional probability of the mixed-state \( x_t \) given all the observations/measures made on the images up to time \( t \), and can be derived as:

\[
p(x_t | z_{1:t}) = \sum_{x_{t-1}} p(x_{t-1}) p(z_t | x_t) p(x_t | x_{t-1})
\]

The dynamics model, \( p(x_t | x_{t-1}) \), can be further decomposed as:

\[
p(x_t | x_{t-1}) = \prod_{i=1}^{n} p(x_{ti} | x_{t-1i})
\]

where \( x_{ti} \) is the locomotion state transition probabilities, which could be automatically trained, or manually set as:

\[
p(x_{ti} | x_{t-1i}) = \begin{cases} F & \text{Forward} \\ R & \text{Reversal} \\ S & \text{SharpTurn} \\ O & \text{OmegaBend} \end{cases}
\]

where \( F, R, S, O \) denote the locomotion state transition probabilities, which could be automatically trained, or manually set as:

\[
p(F | R) = \begin{cases} 0.8 & \text{Forward} \\ 0.1 & \text{Reversal} \\ 0.05 & \text{SharpTurn} \\ 0.05 & \text{OmegaBend} \end{cases}
\]

Interactive Observation Models

Our automated system quantitates features describing the worm shape, motion, events (forward/omega bend), and interaction \( I \) (i.e. output of \( J \) features).

Different from existing tracking systems in the literature which usually treat worm tracking and locomotion stage recognition as two independent tasks, our model proposed here is designed to exploit synergy between the two tasks. The experiments demonstrate that our automated system advances the state-of-the-art with: 1) better performance of tracking intersecting worms and worms with complex behavioral patterns; 2) simultaneous recognition of locomotion labels; 3) new features quantifying worm in terms of its morphology, locomotion, behavioral event and interaction. Our future investigations include: 1) to automatically model worm dynamics, we plan to study worm dynamics in lower dimensionality as in [2], 2) to deal with more complex worm interaction, we will investigate bi-directional tracking or “smoothing” algorithm.

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Reference