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# Research Outline

Title: Quantitative Analysis of Biotic Olfaction and Multi-Perspective Solution based on Embodied Cognition

## 1. Introduction

- i. Motivation of using olfactory sense for Chemical Plume Tracing (CPT) problem
- ii. Objective of the study to find bio-inspired solution to solve CPT problem
- iii. Methodology to realize the objective based on literature review, analysis of natural CPT behavior, modeling of bio-inspired CPT, realization and optimization of bio-inspired model, and experiments for model validation

## 2. Literature review

- i. Research background on CPT and bio-inspired solutions
- ii. The challenges for CPT are identified as spatial temporal variation and intermittency of plume diffusion, nonlinearity of biological systems, and previous studies also suggest localization success rate of CPT and time taken for CPT seems to be a tradeoff
- iii. Problem settlement
  - A) Quantitative analysis of biotic olfaction to understand nonlinearity of natural CPT behavior
  - B) Multi-perspective solution as bio-inspired algorithm on autonomous agents to exhibit efficient CPT. The agent needs to be adaptive to spatial temporal variations of plume dispersal and exhibits good performance in varying environmental conditions

## 3. Quantitative analysis of biotic olfaction to understand its nonlinearity

- i. Identification of biological subject which exhibits efficient olfactory sense as natural instincts, i.e. the male silk moth (*Bombyx Mori*) that finds conspecific female for mating purpose
- ii. Methodology of analysis based on machine learning algorithms, which works in the similar way as the auto-critic method
- iii. Behavior observation system using the Tethered Treadmill System, where the moth is tethered on the experimental system
- iv. Inverse CPT model which consists of Gaussian Mixture Model (GMM) and Echo

State Networks (ESN) is used to estimate CPT state of the silk moth. Stimulus input time is calculated based on the Region of Interest (ROI) model

- v. Evaluation result of the estimation outputs using confusion matrix is used for behavior analysis by changing data for the estimator, i.e. the inverse CPT model
- vi. Analysis results suggest singularity and time-variant biotic CPT of silk moth

#### 4. Multi-perspective solution for bio-inspired CPT

- i. Multi-perspective model based on embodied cognition to improve CPT on autonomous agents
- ii. Solution encompasses interaction among multiple resources to yield complex CPT localization behavior
- iii. Resources such as internal algorithm, embodied intelligence, and environment are identified and they are also commonly referred to as the 'brain', 'body', and 'environment' in embodied cognition
- iv. Internal algorithm includes adaptive behavior and long-lasting stimulus input of the silk moth. The flapping wings and bilateral sensing antennae of this animal contribute to embodied intelligence
- v. The embodied cognition model is simulated in time-variant vision-based plume, which is recorded from the wind tunnel and processed using image subtraction method

#### 5. Realization and optimization of artificial system

- i. The embodied cognition model is realized on physical system to validate the simulation results
- ii. The system is optimized using the Taguchi method, where significance of different variables are identified and improved
- iii. The optimized embodied cognition model is validated in different environments, such as the wind tunnel and indoor environment. Significance of resources is evaluated using the perturbation matrix

#### 6. Conclusions

- i. The experiment results concur with those of the simulation and indicates significance of resources for solving CPT problem
- ii. Multi-perspective solution based on embodied cognition uses real-time interaction of resources to yield complex CPT behavior that is efficient compared to single perspective models