Application of Hidden Markov Models in an Autonomous Fish Feeding System Using Computer Vision and IoT

Problem Statement

Feeding in aquaculture plays a pivotal role in fish growth, operational costs, and ecological balance. Manual feeding methods are often inefficient and imprecise, leading to overfeeding or underfeeding, both of which negatively impact water quality and fish health [1]. A key challenge lies in identifying the optimal feeding time, which is influenced by internal (hidden) states of fish such as hunger, activity, and stress states that cannot be observed directly.

Proposed Solution

This capstone project presents an **Autonomous Fish Feeding System** that integrates **Computer Vision** and **IoT sensors** to monitor the fish and environmental conditions in real-time. To infer latent behavioral states like “hungry” or “satiated,” the system utilizes a **Hidden Markov Model (HMM)**, a statistical model widely used for sequential pattern recognition in uncertain domains [2]. The HMM provides a structured probabilistic framework to estimate hidden states from observed features, enabling the system to make intelligent feeding decisions.

Observations and Features

The model uses the following **observable (emission) features**:

- Fish activity levels (e.g., motion, clustering behavior) extracted from underwater video streams using computer vision.
- Environmental parameters (e.g., temperature, pH, turbidity, dissolved oxygen) collected via IoT-based sensors.
- Feeding history and timestamps (e.g., time since last feeding, duration of previous feeding).
- Circadian factors such as light intensity and time of day.

These features are measurable at regular intervals and form the **emission sequence** used by the HMM to infer hidden behavioral states.

Type of HMM Task

This system falls under an **unsupervised HMM framework** where the **hidden states**—such as Hungry, Satiated, and Inactive are not known a priori but are inferred through patterns in sensor data. Since the model attempts to estimate latent behavior from sequences of noisy observations, this is best described as a **hidden state decoding and parameter learning task** [2][3].

Training Algorithm

a. Known Parameters at Initialization:

- Observed emission sequences from the environment.
- Hypothesized number of hidden states (e.g., 3 behavioral states).
- Heuristic or uniform initialization of transition and emission probabilities.

b. Unknown Parameters to Be Learned:

- **State transition probabilities**: Likelihood of moving from one internal state to another.
- **Emission probabilities**: Probability of observing a sensor pattern given a particular state.
- **Initial state distribution**: The probability of beginning in each hidden state.

Training is conducted using the **Baum Welch algorithm** (an Expectation Maximization method), while **Viterbi decoding** is applied to infer the most likely hidden state sequence [2].

Parameter Updates

The HMM training algorithm will update:

- **Transition matrix (A)**: Models the dynamics of behavioral change (e.g., from Hungry → Satiated).

- **Emission matrix (B)**: Represents the likelihood of observing specific features under each state.
- **Initial state distribution (π)**: Probabilities over the starting behavioral condition.

These updates allow the system to generalize behavior from observational sequences over time [2][3].

By integrating HMMs into the autonomous fish feeding system, the model can make **probabilistic, informed feeding decisions** based on inferred behavioral states rather than arbitrary thresholds. This results in improved feeding efficiency, reduced waste, and better alignment with sustainable aquaculture goals [1][4].

References

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