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Efficient sensorimotor cues for training a glider to soar autonomously

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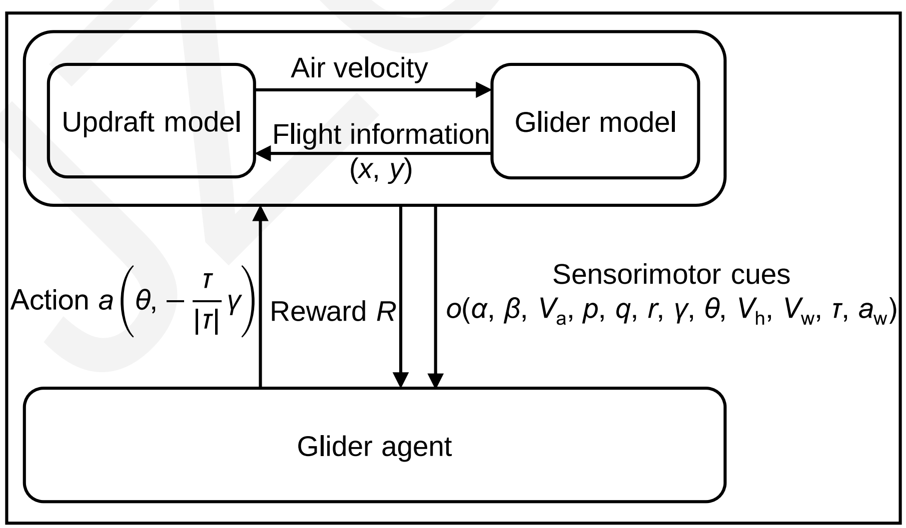
Motivation & Methodology

Motivation:

- Migratory birds utilize atmospheric updrafts for energy-efficient long-distance flight.
- Goal: Enable unmanned gliders to achieve autonomous soaring by learning optimal sensorimotor strategies.

Methodology: RL-based Simulation Framework

- Algorithm: Twin Delayed Deep Deterministic Policy Gradient (TD3).
- Environment: Round updraft model (Gaussian distribution).
- Agent: Learns to map sensorimotor cues (Input) to control actions (Output) for maximum energy harvesting.



Candidate Sensorimotor Cues

■ **Systematic Investigation (12 Candidates):**

To find the most efficient soaring strategy, 12 potential cues were selected and analyzed.

■ **Categories:**

•**Flight State Cues (9 types):**

- •V_a (Airspeed), V_h (Vertical velocity), p,q,r (Angular velocities), α, β, θ, γ (Attitude angles).
- •Obtained by onboard sensors.

•**Environmental Cues (3 types):**

- •a_{w} (Vertical updraft acceleration).
- •V_{w} (Vertical updraft velocity).
- •τ (Spanwise updraft velocity difference).
- •Challenging to measure directly; require estimation.

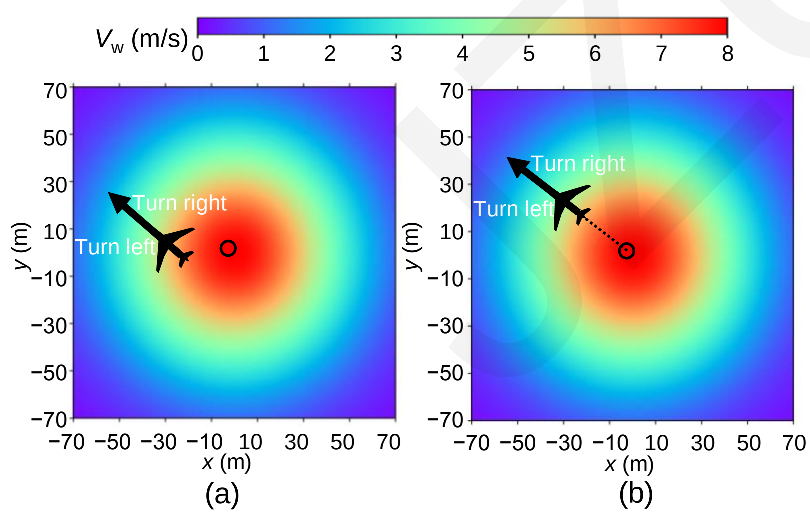
Key Finding I: Single Cue Efficiency & Mechanism

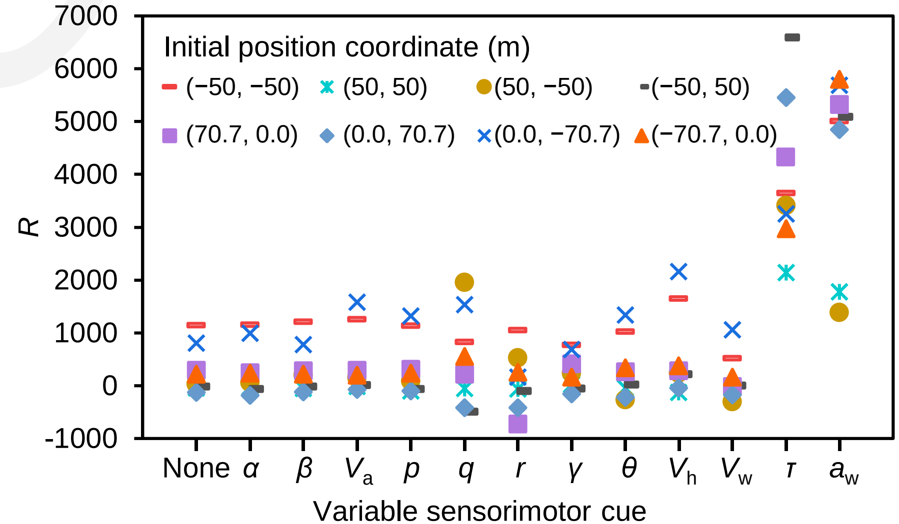
Result 1: The "Best" Independent Cues

- Comparisons (Fig. 10) revealed that only a_{w} and τ can independently guide the glider to soar.
- Other cues (e.g., attitude, airspeed) failed in the single-cue test.

Result 2: Why τ is critical? (Mechanism Analysis)

- Limitation of a_{w} : It only indicates updraft *strength* changes, leading to directional ambiguity (don't know left or right).
- Advantage of τ : It indicates the lateral gradient (V_{left} - V_{right}), providing direct directional guidance towards the updraft center.





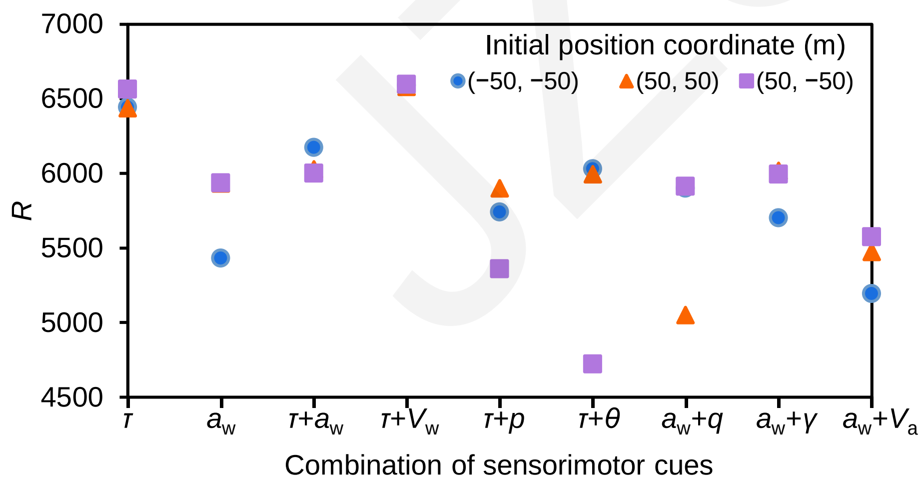
Key Finding II: Optimal Strategy & Verification

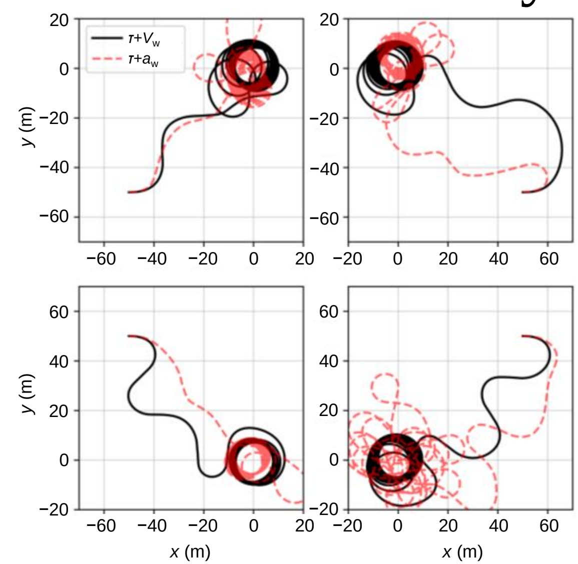
Optimal Combination:

- $\tau + V_w$ (Spanwise velocity difference + Vertical updraft velocity) achieved the highest energy gain.
- Outperformed the $\tau + a_w$ combination in stability and centering capability.

Trajectory Visualization:

- $\tau + V_w$: Perfectly circles around the updraft center.
- $\tau + a_w$: Shows eccentric trajectories with lower efficiency.





Conclusions

- **Summary:**
- Platform: Established a high-fidelity reinforcement learning simulation for autonomous soaring.
- Key Insight: Identified a_{w} (Acceleration) and τ (Spanwise Difference) as the most critical features for updraft perception.
- Optimal Strategy: The combination of $\tau + V_{\mathrm{w}}$ is identified as the most efficient strategy for long-endurance autonomous flight.
- **Significance:**
- Provides theoretical guidance for sensor selection on intelligent gliders.
- Demonstrates that sensing lateral gradients (τ) is key to efficient centering behavior.