FireAIDSS: Real-Time and In-Situ Reconstruction of Wildfire Thermofluid Dynamics Through Physics-Constrained Inverse PDE Modeling

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Wildfires pose significant threats to ecosystems and communities worldwide. While visible flames can be readily captured, the underlying thermofluidic processes governing atmospheric fire spread, today the leading cause of fire-related property destruction, remain uncharted. This project presents FireAIDSS, a novel framework for real-time and in-situ computation of thermofluidic wildfire dynamics using sparse data and conservation laws. FireAIDSS consists of a perception module and an action module. The perception module includes a Physics-Informed Attention-CNN model capable of reconstructing and predicting the transient evolution of temperature and velocity fields from sparse observations. The AI model is trained with CFD simulations and a multi-stage curriculum to enhance physical fidelity. The action module comprises an intelligent drone swarm built from low-cost platforms for multi-agent data collection. The two modules are linked by a feedback-based search strategy where predictions of the AI model optimize the next-step motion of the drone swarm, enabling efficient information gathering and rapid convergence to accurate reconstructions. In full-scale experimentation, FireAIDSS achieves an average temperature error of 2.97 K and wind velocity error of 0.08 m/s in a space of 2×2×1 m^3 within 58s, meeting emergency response requirements in accuracy and efficiency. Across 200+ runs, it consistently maintains an update rate of 1.1 FPS and demonstrates collision-avoidance behaviors, highlighting its environmental robustness. As the first system making wildfire dynamics spatiotemporally resolved in real time, FireAIDSS democratizes wildfire intelligence and offers a scalable and cost-effective solution to building wildfire resilience across wildland and urban settings.

Awards Won:

Third Award of $1,200