

Pressure Sensor Data Analysis: Can We Teach Computers to Detect Jumps?

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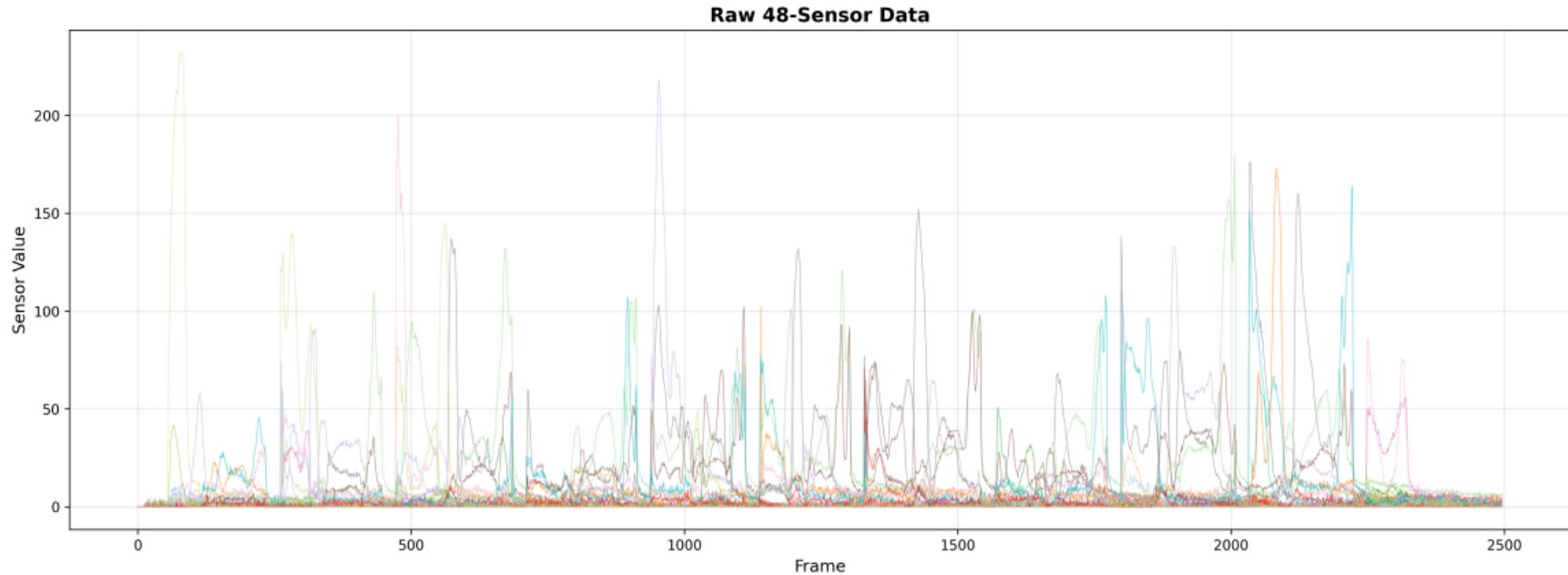
* Submitted in partial fulfillment of the requirements for the Bachelor of Science degree

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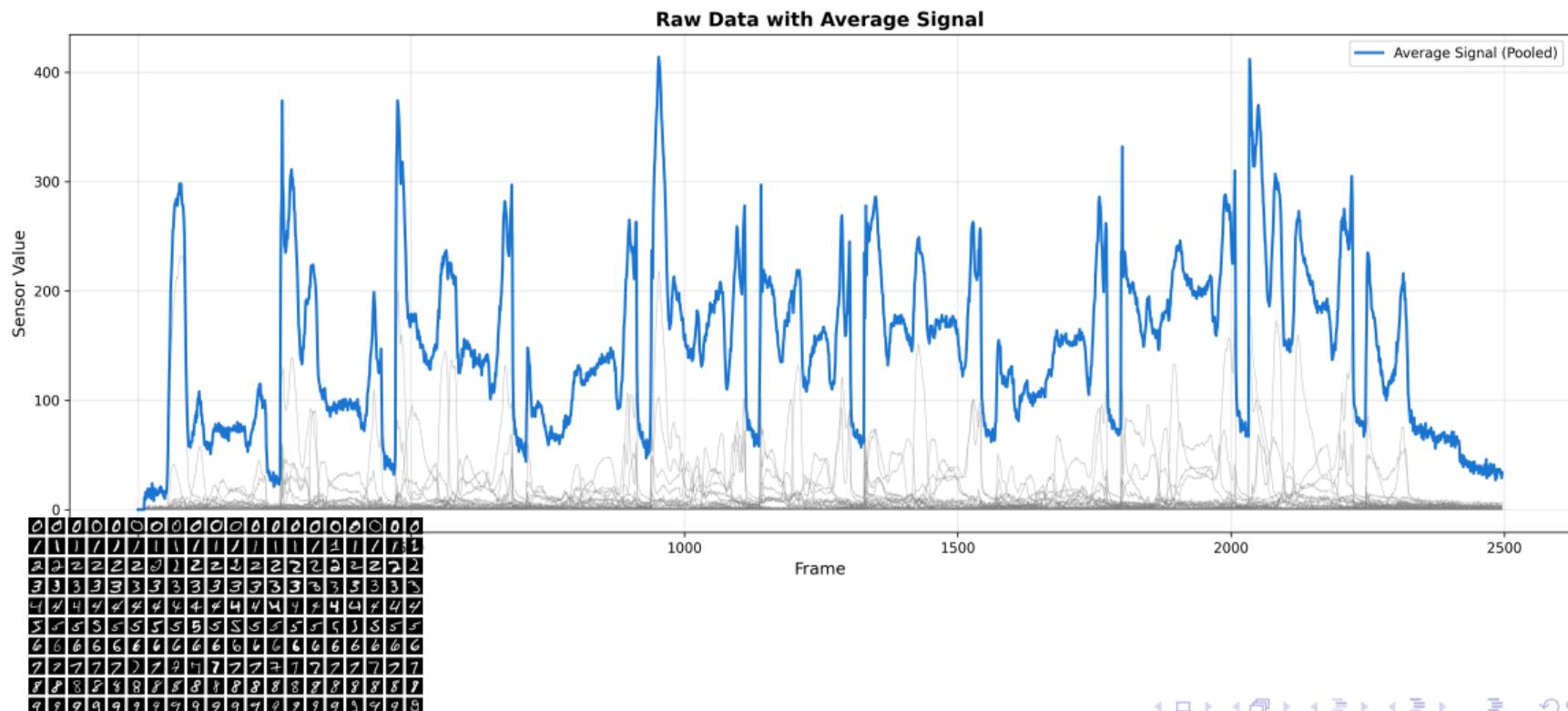
Motivation

- Athletic training has become increasingly data-driven
- Three key steps: (1) data collection, (2) analysis, (3) translating insights
- **Challenge:** Can we teach computers to do step 2 of this process?
- **Raw Data:** Ground reaction forces collected from a 48-sensor pressure plate (50 Hz)

Raw 48-Sensor Data



Raw Data with Average Signal



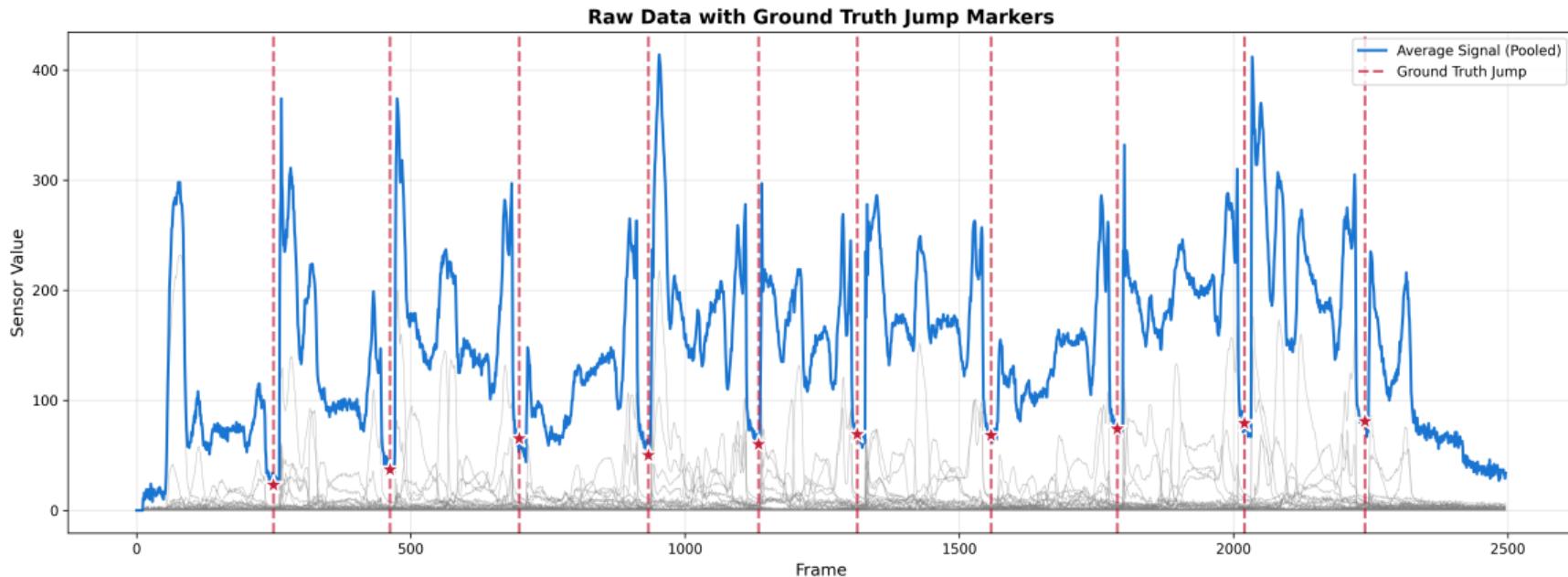
Human Intuition for Analyzing Jumps

Vertical jumps exhibit a characteristic signature:

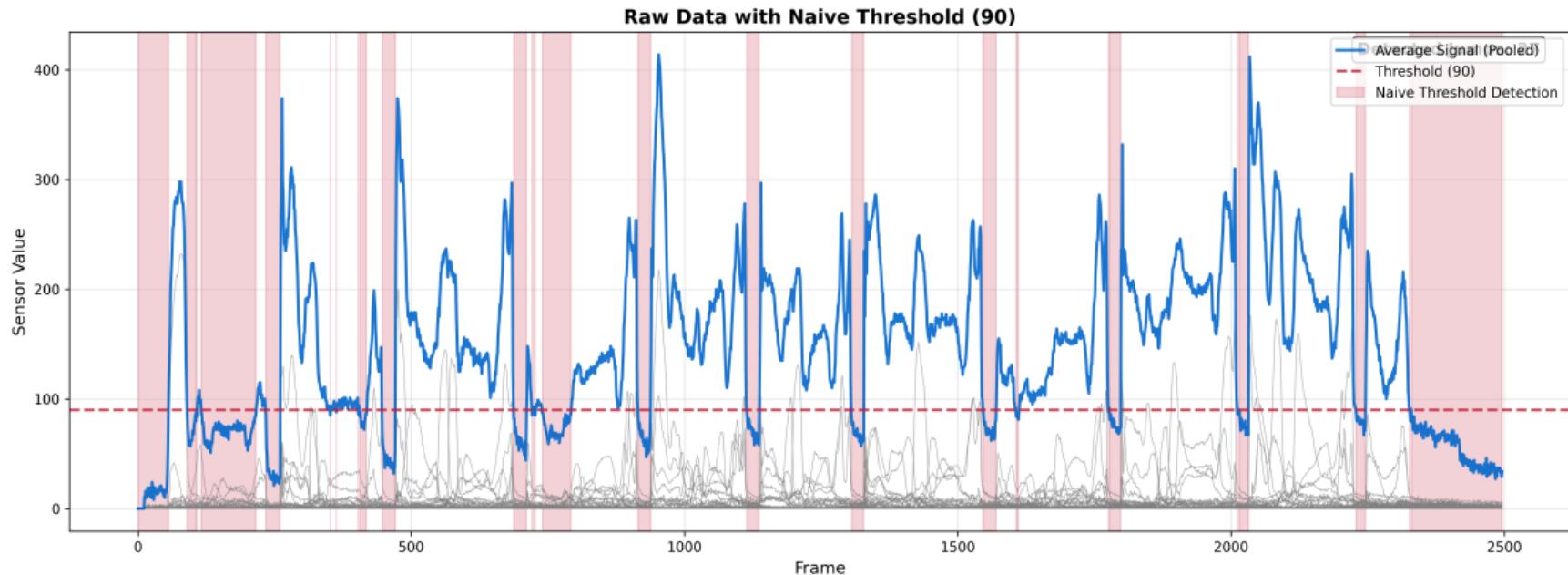
- ① Force build-up during countermovement and propulsion
- ② Rapid unloading at takeoff
- ③ Near-zero force while airborne
- ④ Rapid reloading at landing

Challenge: While patterns are visually obvious to humans, automated detection in noisy real-world conditions is difficult.

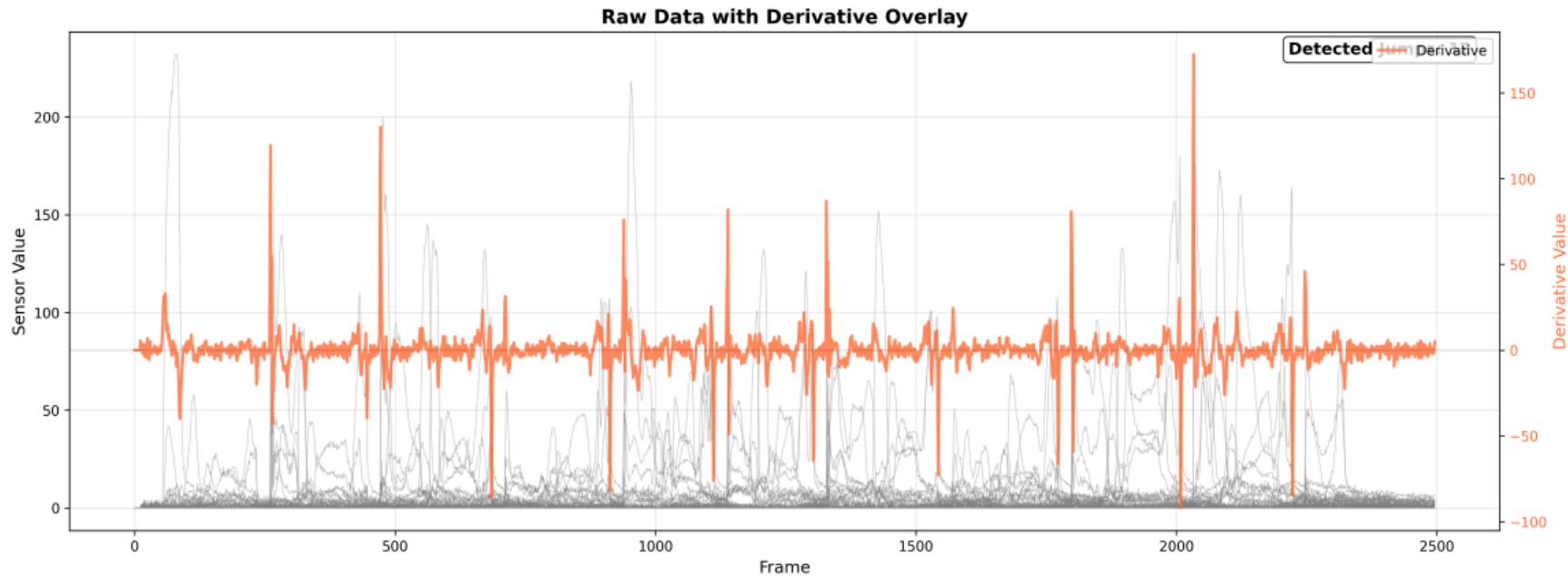
Raw Data with Ground Truth Jump Markers



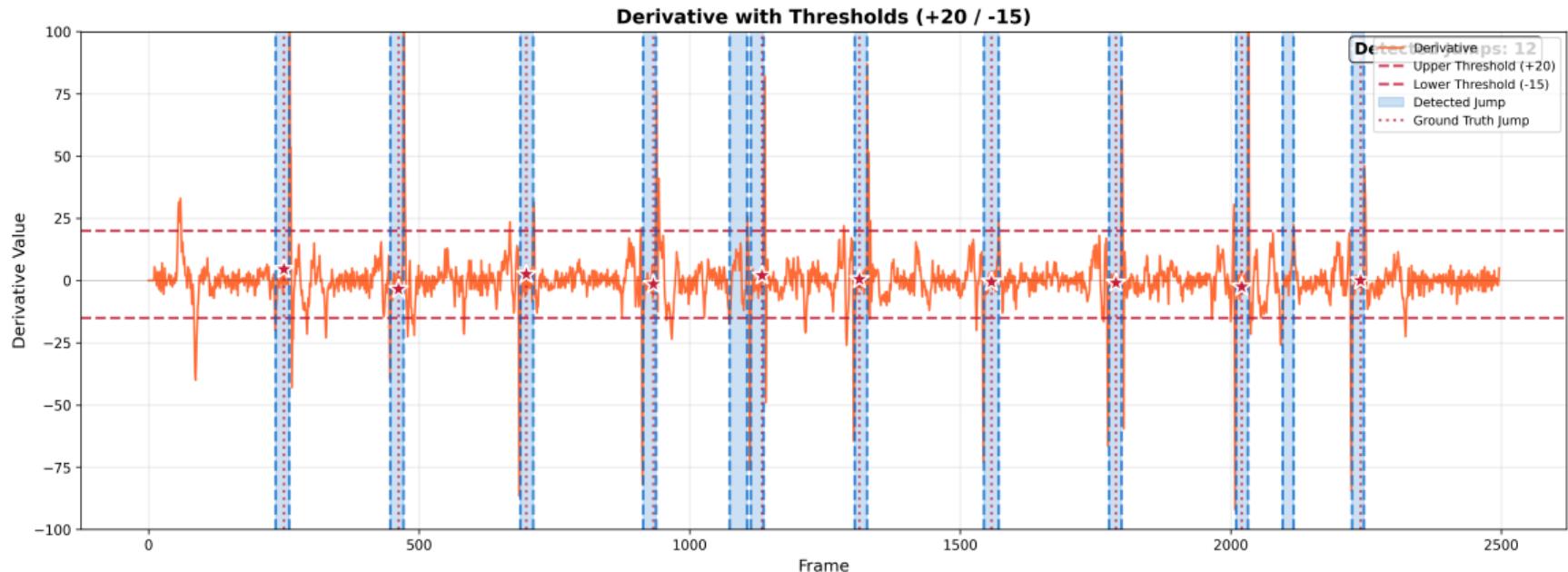
Naive Threshold Detection (Threshold = 90) (21 Jumps Detected!)



Raw Data with Derivative Overlay



Derivative-Based Detection (Thresholds: +20 / -15) (13 Jumps Detected)



Threshold Algorithm:

- Identifies flight periods when force falls below threshold θ
- Binary mask: $m_{\text{threshold}}(t) = 1$ if $\bar{d}(t) < \theta$
- Filtered by physics constraints: $t_{\min} \approx 0.2$ s, $t_{\max} \approx 1.2$ s

Derivative Algorithm:

- Detects paired takeoff and landing events in derivative signal
- Upper threshold: $d'(t) > \theta_{\text{upper}}$ (landing)
- Lower threshold: $d'(t) < \theta_{\text{lower}}$ (takeoff)
- Validated by in-air threshold: $\bar{d}(t) < \theta_{\text{air}}$ during flight

Both algorithms operate in $O(T)$ time, enabling real-time mobile deployment.

All Algorithms & Parameters to Optimize

Algorithm	Brief Description	Parameters to Optimize
Threshold	Identifies flight periods when force falls below threshold. Binary mask filtered by physics constraints.	Threshold θ , derivative threshold δ , minimum flight time t_{\min} , maximum flight time t_{\max}
Derivative	Detects paired takeoff and landing events in derivative signal using upper/lower thresholds, validated by in-air threshold.	Upper threshold θ_{upper} , lower threshold θ_{lower} , in-air threshold θ_{air} , minimum flight time t_{\min} , maximum flight time t_{\max}
Correlation	Template matching on derivative signal using configurable buffer encoding jump signature (preparation, transition, jump phases).	Buffer size B , negative frames w_{neg} , zero frames w_{zero} , positive frames w_{pos} , correlation threshold θ_{corr}
Hybrid	Combines threshold-based takeoff detection with derivative-based landing detection. Pairs takeoff events with landing events.	Takeoff threshold θ_{takeoff} , landing derivative threshold θ_{landing} , in-air threshold θ_{air} , minimum flight time t_{\min} , maximum flight time t_{\max}
Ensemble	Combines multiple algorithms (threshold, derivative, correlation, hybrid) through weighted voting on binary condition indicators.	Weights for 11 condition signals, score threshold, minimum flight time t_{\min} , maximum flight time t_{\max}

Scoring Each Algorithm: Loss Function

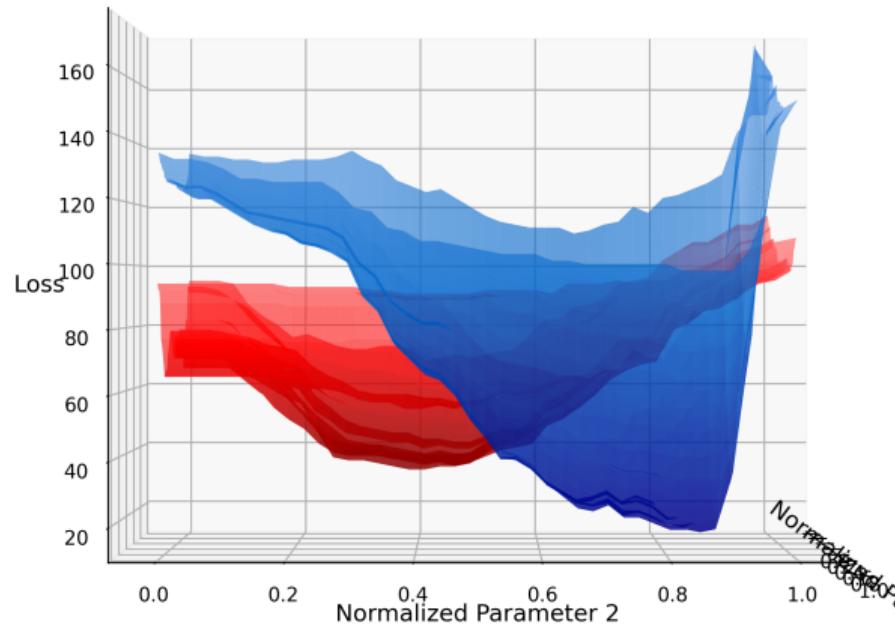
Loss Function:

$$L(\theta) = \text{FP}(\theta) + \text{FN}(\theta)$$

- **False Positives (FP):** Detected jumps without corresponding ground truth markers
- **False Negatives (FN):** Ground truth markers not captured by any detected jump

Manual Tagging: All jump events manually annotated in dataset

Means of Optimization: Grid Search Initial Parameters



Two-Dimensional Grid Search: Threshold: $\theta \in [90, 300]$, $\delta \in [0, 100]$ (40 values each); Derivative: $\theta_{\text{upper}} \in [0, 100]$, $\theta_{\text{lower}} \in [-100, 0]$ (40 values each)

Langevin Monte Carlo Sampling Optimization

Methodology: Stochastic optimization technique inspired by Langevin dynamics for efficient exploration of high-dimensional parameter spaces.

- **Metropolis-Hastings acceptance criterion:** Accepts parameter changes that decrease loss, or probabilistically accepts increases based on temperature
- **Temperature schedule:** Initial temperature 10.0 with exponential decay rate 0.9995 per iteration
- **Escape from local minima:** Temperature schedule enables exploration beyond immediate improvements
- **Comprehensive optimization:** 10,000 iterations for multi-parameter optimization across all algorithms

Advantages over grid search:

- Computationally feasible for high-dimensional spaces (e.g., 5+ parameters)
- Efficiently explores parameter space without exhaustive enumeration
- Finds optimal configurations that minimize loss function $L(\theta) = \text{FP}(\theta) + \text{FN}(\theta)$

Results

Algorithm	Loss	Parameters Optimized
Threshold Derivative	107	$\theta, \delta, t_{\min}, t_{\max}$
Correlation Hybrid	28	$\theta_{\text{upper}}, \theta_{\text{lower}}, \theta_{\text{air}}, t_{\min}, t_{\max}$
Ensemble	229	$B, w_{\text{neg}}, w_{\text{zero}}, w_{\text{pos}}, \theta_{\text{corr}}$
Landing Derivative	72	$\theta_{\text{takeoff}}, \theta_{\text{landing}}, \theta_{\text{air}}, t_{\min}, t_{\max}$
	30	Weights (11), score threshold, t_{\min}, t_{\max}
	34	$\theta_{\text{landing}}, \text{offset}, \text{window}, \theta_{\text{air}}, t_{\min}, t_{\max}$

Final Model Selection & Deployment

Optimized Parameters:

- $\theta_{\text{upper}} = 17.71$, $\theta_{\text{lower}} = -15.19$, $\theta_{\text{air}} = 183.04$
- $t_{\min} = 0.19$ s, $t_{\max} = 0.60$ s

Implementation:

- JavaScript implementation for real-time processing
- Deployed in **Vault One** mobile application
- $O(T)$ complexity enables real-time mobile deployment
- Used by trainers and athletes for immediate feedback



Thank You



Flight Time: Pressure vs. Camera

