# Chemical Plume Detection with Collaborative, Autonomous Sensor Networks

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## Introduction

- Distributed detection in large wireless sensor networks shows strong potential for use in chemical plume detection.
- We assume a gaussian model with a constant release rate and added noise, which is blown by wind parallel to the ground and diffuses as distance from the source increases.
- This research evaluates the relative performance of IDT, FDR, and motion-based detection methods.

$$C(x,y,z) = \frac{Q}{2\pi v \sigma_y \sigma_z}\left(\exp\left(-\frac{(z-h)^2}{\left(\frac{4K_z x}{v}\right)}\right) + \exp\left(-\frac{(z+h)^2}{\left(\frac{4K_z x}{v}\right)}\right)\right)\left(\exp\left(-\frac{y^2}{\left(\frac{4K_y x}{v}\right)}\right)\right)$$

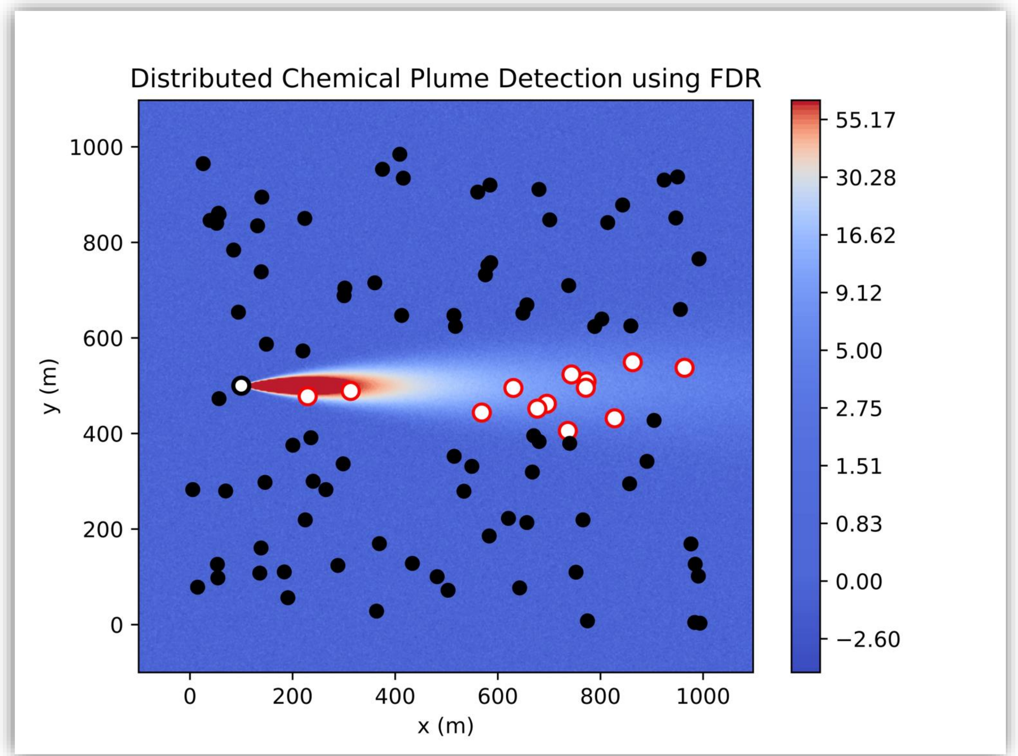


*Figure 1: Chemical Plume Detection Model*

## Detection Methods

**Identical Decision Threshold (IDT):**

- Each sensor uses an identical local threshold.
- Controls the local false alarm rate.

Algorithm:

1. Each node with a measurement above the local threshold $\tau$ determines a local detection.
2. Nodes share their data throughout the network.
3. Each node compares the total number of local decisions to a global decision threshold to reach a global decision.

**False Discovery Rate (FDR):**

- $FDR\ (\gamma) = E\left[\frac{\#\ False\ Detections}{\#\ Total\ Detections}\right]$
- Allows the network to dynamically set local thresholds.
- More liberal in the presence of a signal, and more conservative in the absence of a signal.

Algorithm :

1. Each node computes its local p-value.
2. The $m$ sensors with $p_i > \gamma$ broadcast this decision.
3. All sensors update their thresholds to $\gamma(\frac{N-m}{N})$
4. The $k$ sensors with $p$ greater than the current threshold, and which did not report previously, broadcast.
5. All sensors update their thresholds to $\frac{\gamma(N-m-k)}{N}$
6. Repeat steps 4-5 until no sensors report. The number of remaining sensors is compared against the global threshold.

**Parameter Selection:**

- Optimal FDR and IDT thresholds are determined using optimization of the Kolmogorov-Smirnov distance metric.
- The global threshold (T) is determined by the desired Probability of False Alarm (Figure 3).

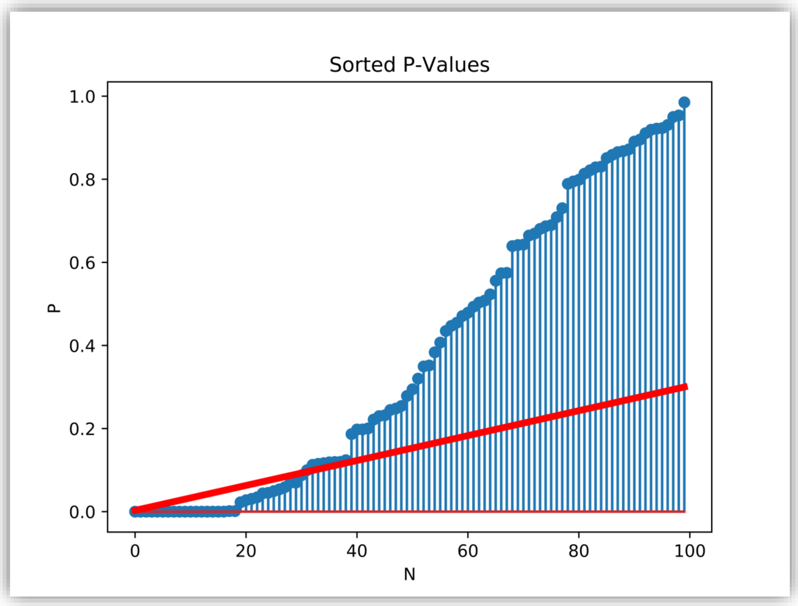


*Figure 2: Sorted p-values*

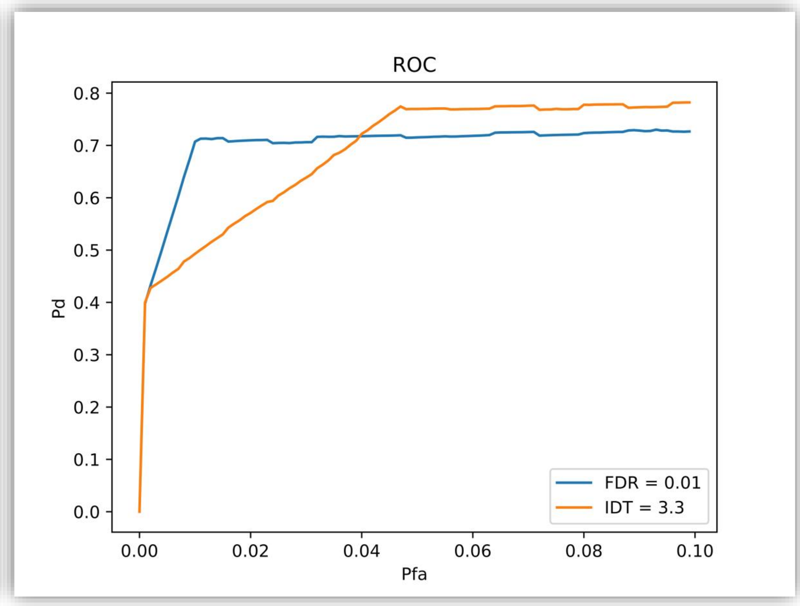


*Figure 3: Receiver Operating Characteristics*

## Performance under Communication Errors

- Each node only needs to send one bit.
- Performance can degrade due to bit errors caused by noise, jamming, or other interference.
- IDT and FDR methods display similar robustness to errors.

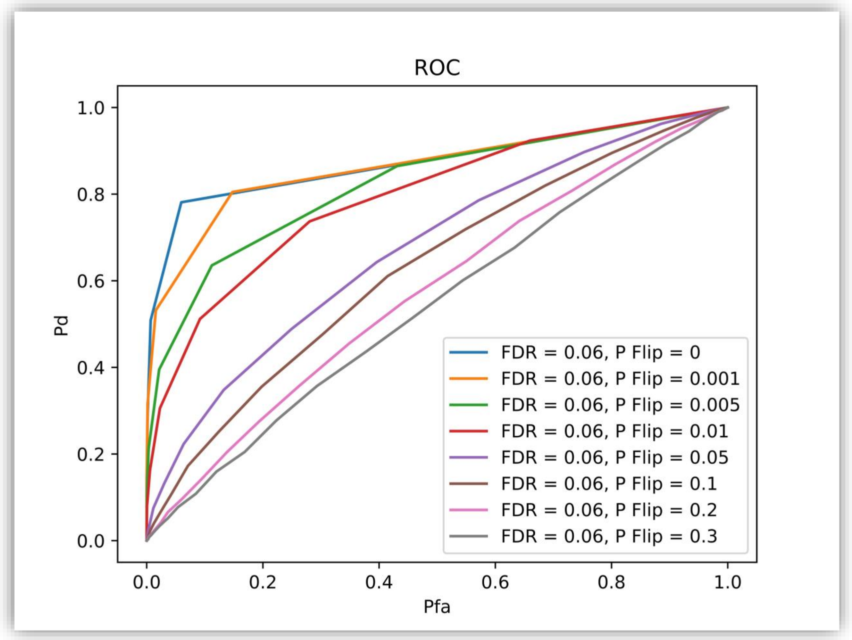


*Figure 4: FDR Performance with Bit Errors*

## Motion-Based Active Sensing

- Significant performance improvements result from simple movement procedures.
- Useful for low signal strength or low sensor density scenarios.

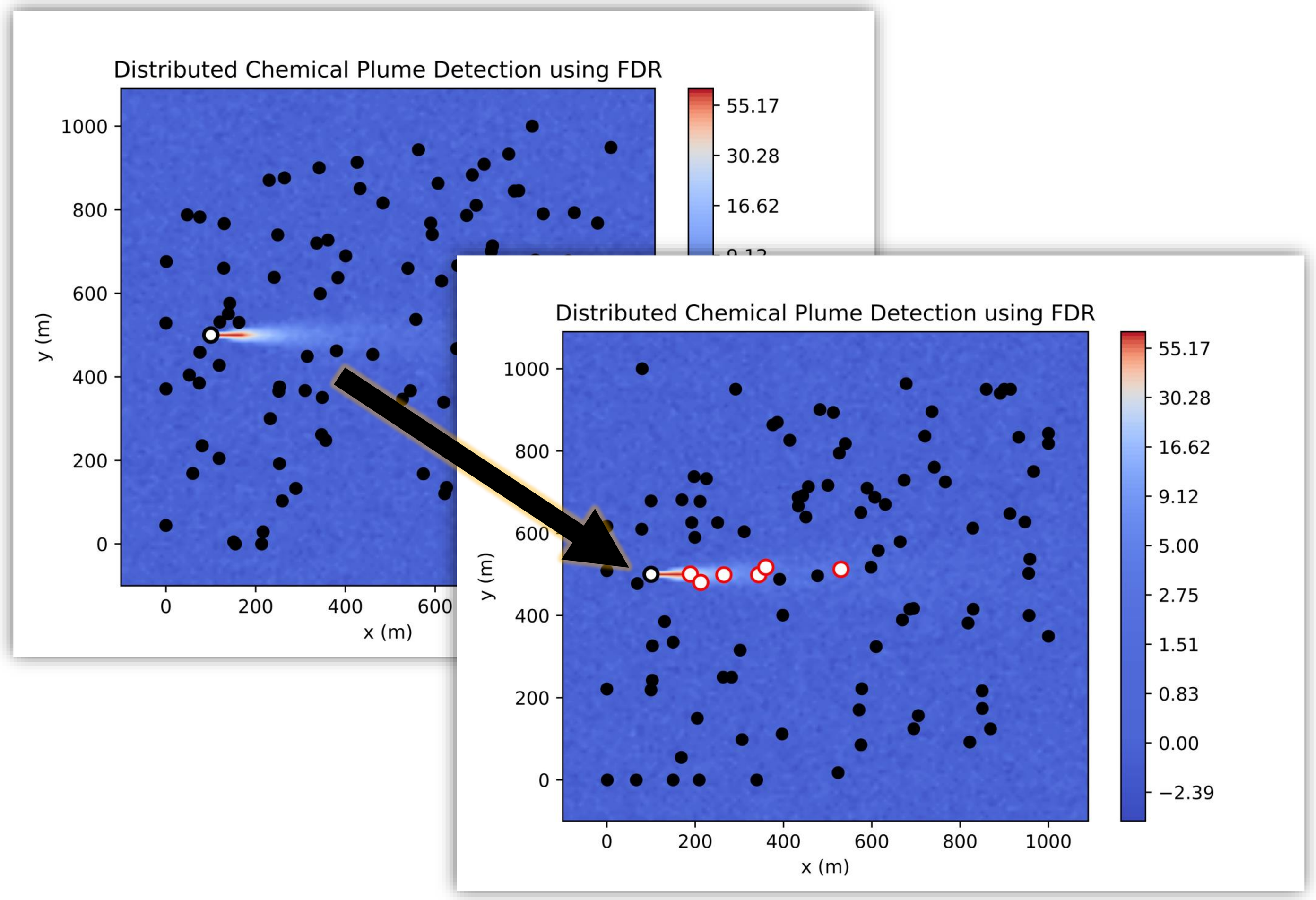


*Figure 5: Before and After Sensor Motion*

Algorithm:

1. All sensors determine their individual detection decision.
2. Sensors detecting no signal move to check the signal value 1m in each coordinate direction.
3. Sensors detecting no signal move 20m in the direction of greatest signal increase in each coordinate direction.

- Over time, non-detecting sensors in the path of the plume will be drawn closer to the location of the source (Figure 5).
- Requires no intra-network communication.
- Significant performance improvements as number of steps increases (Figure 6).

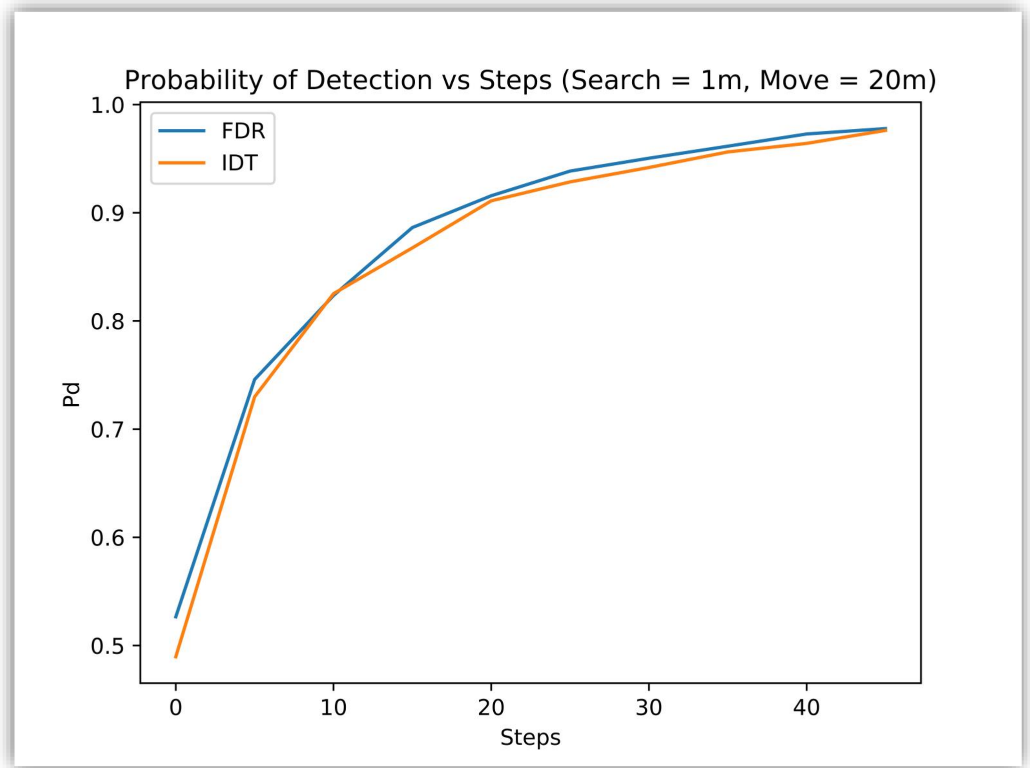


*Figure 6: Probability of Detection vs Motion*

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