Real–time Analysis of Aerosol Size Distributions with the Fast Integrated Mobility Spectrometer (FIMS)

Daisy Wang (w. yanwang@wustl. edu), Jiaoshi Zhang, Jeremy Buhler, and Jian Wang

Background

Accurate measurement of particle size distributions is essential in aerosol science. The Fast Integrated Mobility Spectrometer (FIMS) has emerged as an innovative tool in this domain. It employs a spatially varying electric field to separate charged aerosol particles by their electrical mobilities. These separated particles are then enlarged through alcohol vapor condensation and imaged in real time by a high-speed CCD camera. FIMS **achieves near 100% detection efficiency** for particles **ranging from 8 nm to 600 nm** with a **temporal resolution of one second**. However, FIMS' real-time capabilities are limited by an offline data analysis process. Deferring analysis until hours or days after measurement makes FIMS' capabilities less valuable for probing dynamic, rapidly changing environments. Our research aims to address this limitation by developing a **real-time data analysis pipeline** for FIMS, allowing for adaptive aerosol measuring, eliminating lengthy delays between data collection and analysis, and boosting FIMS' potential for aerosol research.

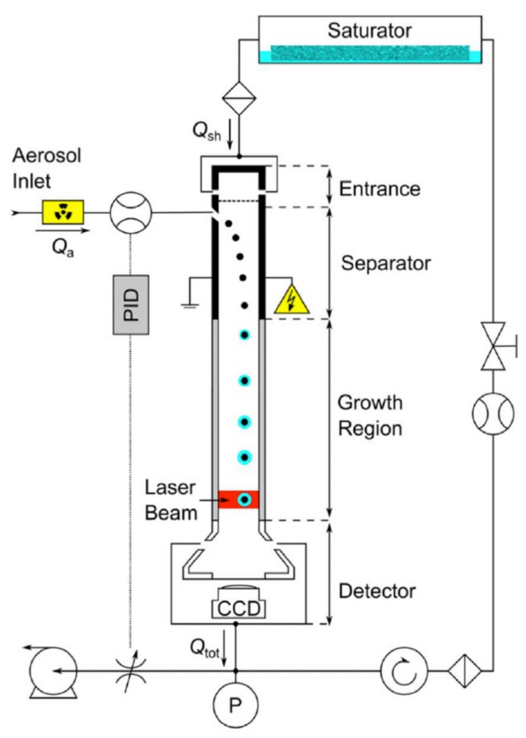

Fig. 1. Schematic of the FIMS (image from Wang, Pikridas, et al. 2017)

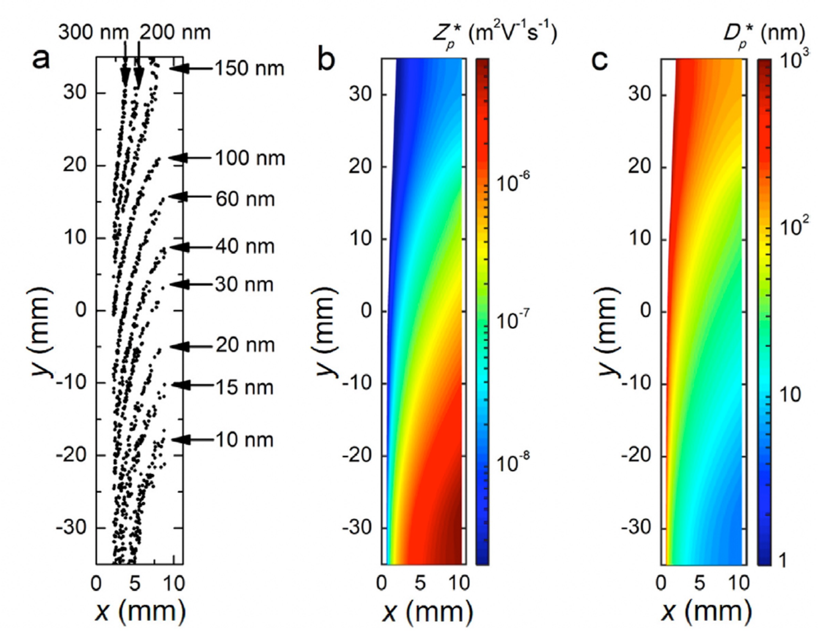

Fig. 2. (a) The FIMS camera-recorded locations of 10–300 nm monodisperse particles within the viewing window after mobility separation and growth. (b) and (c) show maps of instrument response mobility (Z^*p) and diameter (D^*p) derived from particle trajectories and positions at the separator exit simulated using the Langevin equation. (image from Wang, Pinterich, et al. 2018)

Real-Time Design

Our real-time data analysis pipeline for FIMS consists of three main components: **Housekeeping Data Reader**, **Image Processor**, and **Data Inversion Component**. The pipeline is written in C++, making it suitable for deployment even in low-power embedded systems. The design also allows for easy future upgrades like new data types or machine learning integrations.

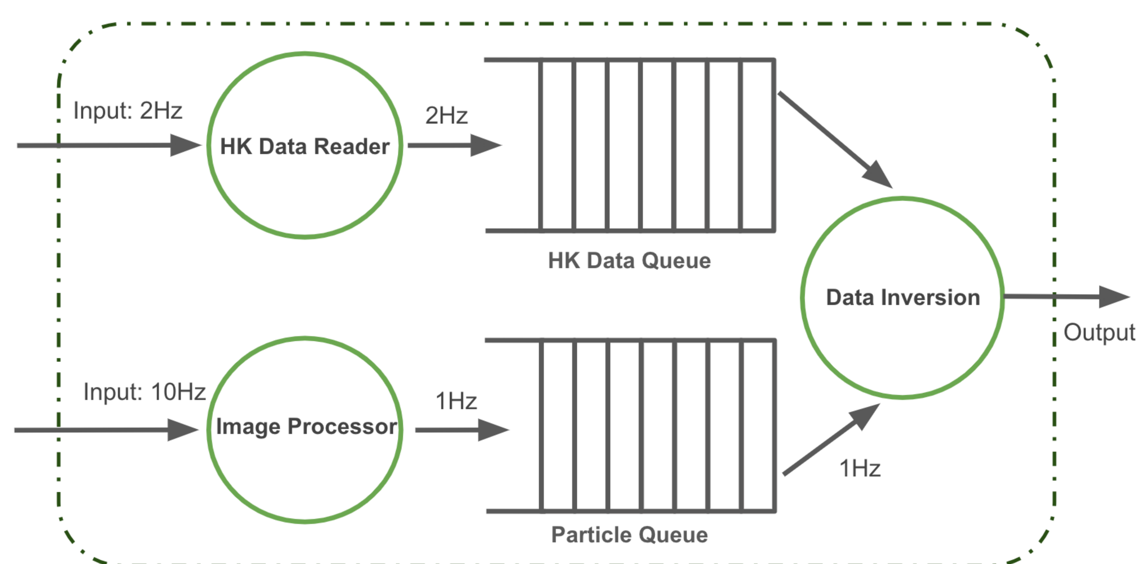

Fig. 3. Queue Model of Real-Time Pipeline for FIMS

Housekeeping Data Reader

- Reads sensor data (temperature, pressure, flow rate, voltage, etc.) collected by the FIMS instrument twice a second
- Parses data into a structured format and pushes the it to a queue for further processing

Image Processor

- Processes images captured at a frequency of 10 Hz from a CCD camera as particles traverse the FIMS detector
- Identifies particles within the images using the OpenCV library
- Calculates each particle's residence time within the instrument to obtain its inlet time
- Bins particles into 1-second intervals by inlet time

Data Inversion Component

- Computes an inversion matrix based on current housekeeping data
- Reads particles from current bin and computes a histogram of particle diameters driven from response mobility
- Uses improved Twomey inversion technique[5] to transform observed particle histograms into reliable size distributions at frequency of 1Hz

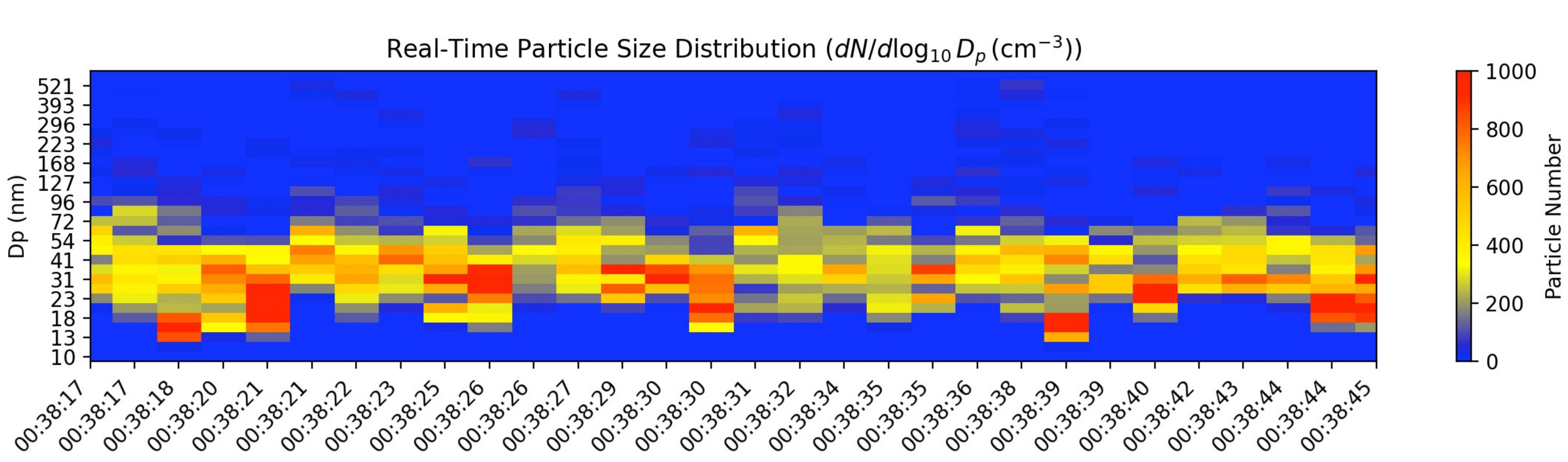

Fig. 4. Real-Time Size Distribution Output (This is an animation that scrolls to the right every second)

Performance

Running Time

- Test platforms:
  - Raspberry Pi 4 (Linux): 1.5 GHz Quad-core ARM Cortex-A72
  - MacBook Pro (macOS): 2 GHz Quad-Core Intel Core i5
  - Desktop PC (Windows): 3.6GHz 12-Core (8P+4E) i7-12700k
- Performance: the pipeline can process an image **within 50ms** and invert count vectors **under 100ms** across all platforms, well below the required update rates of **100ms** and **1000ms**, respectively.

System Latency

- Due to particle **residence time** in the FIMS instrument, a minimum **2.4-second delay** to accumulate particles between image processing and inversion ensures results align 100% with offline methods.
- As technology evolves, future FIMS versions could further reduce the residence time, reducing output delay.

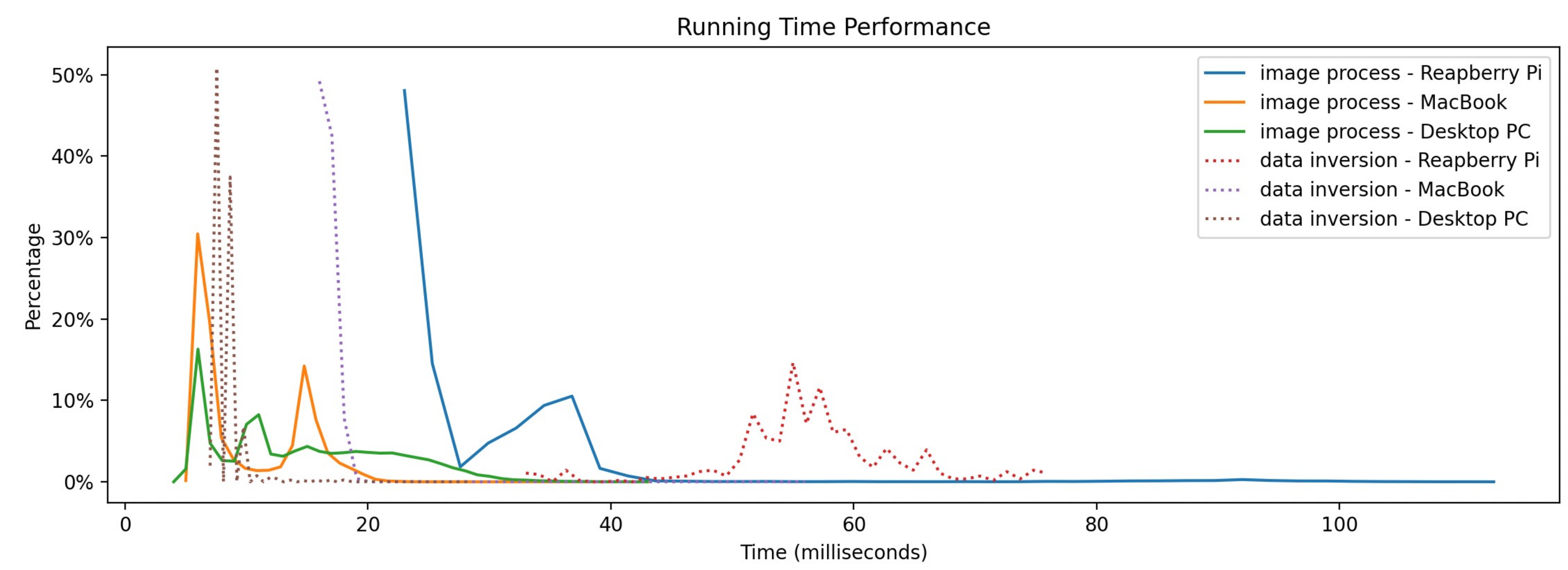

Fig. 5. Running times of analysis pipeline components on different hardware platforms

Average(Milliseconds)	Raspberry Pi	MacBook	Desktop PC
Image Process Time	29.509	11.539	14.661
Data Inversion Time	57.111	17.589	8.665
HK Reading Time	8.28E-05	0	0

Table. 1. Average Running Time on Different Hardware Platforms

Future Work

The main objective for future work is to exploit FIMS' new real-time analytical capabilities for more adaptive, efficient, and reliable aerosol measurement.

Enhance Data Reliability

- Design algorithms for immediate identification and correction of data anomalies when measuring

Optimize Resource Allocation

- Develop algorithms to identify transient and scientifically significant aerosol events
- Implement dynamic measuring path adjustments based on detected data and operational constraints, for deployment on both aircraft and ground vehicles

Machine & Human Teaming

- Integrate a human-in-the-loop model to provide real-time algorithmic suggestions for measurement path adjustments.

References

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