Outfitted Electrical Mobility Spectrometer with Spatial Coded Aperture Mask for Accurate Size Distribution Measurement of Aerosol Nanoparticles

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Introduction

- Application of nanoparticles classification and measurement is ubiquitous in scientific and industrial fields. Accurate size distribution measurement of a wide spectrum of polydisperse nanoparticles is quite challenging. Brownian motions of ions and ultrafine particles, along with non-uniformity of charge distributions account for this difficulty.

- Electrical Mobility Spectrometer (EMS) is an instrument which classifies particles according to their electrical mobility. Electrical mobility is the result of interaction of drag force on the particles and electric body force. When charged particles classified due to their mobilities and landed along the classifier cylinder, their charge is transferred to the electrometers through electrodes. Size distribution of injected particles can be interpreted by data reported via electrometers.

- The classifier contains two concentric cylinders with high electric potential difference. Charged particles travel in-between, and due to mass to charge ratio, land on the detectors and transfer their charges. Detectors are identical electrode rings placed sequentially along the axial direction on the outer cylinder. Fig. 1. Schematically illustrates the typical of EMS integrated with a corona charger.

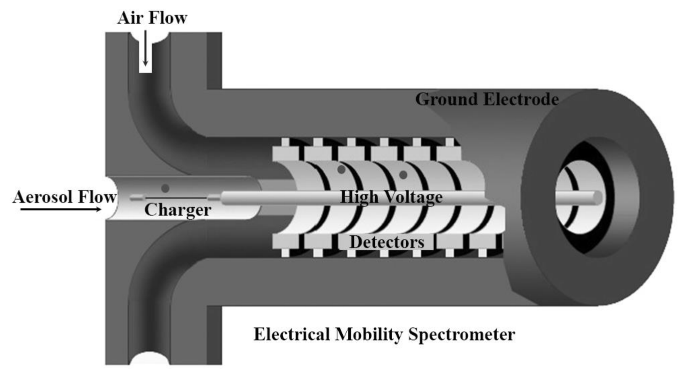


Figure 1. Schematic view of an Electrical Mobility Spectrometer (EMS). Corona charger is installed upstream and the flow is provided with clean sheath air before entering the measurement zone.

- In this study, instead of one cylinder, two eccentric cylinders with different sizes were used inside the outer cylinder to add another component to the electric force influencing the charged particles. Instead of electrode rings, different configuration of detectors was used on the outer cylinder to report angular variations of data, as well. Aerosol inlet is a Fig. 2 depicts the proposed geometry, with hybrid triangular prism and hexahedron mesh.

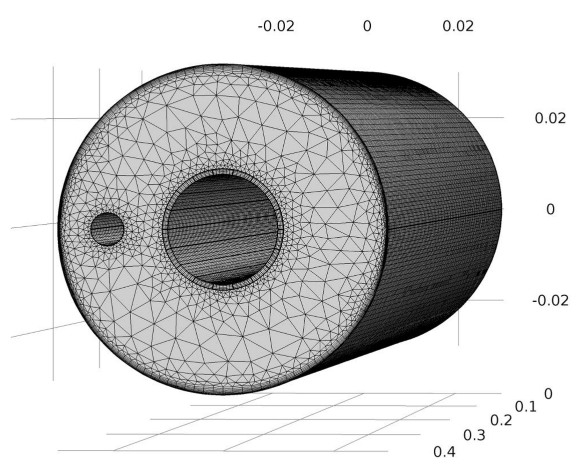


Figure 2. Proposed geometry of the classifier with hybrid grid.

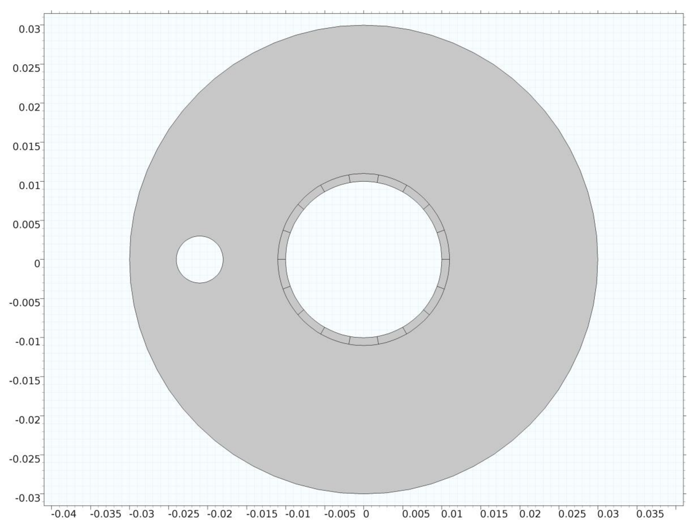


Figure 3. Aerosol inlet around the central high-potential rod

- Since aerosol inlet is a narrow ring with 1 mm width and relatively large radios around the central rod (shown in Fig. 3), resolution of angular data reported by detectors is much lower than axial data, because angular variation of starting points of injected particles makes the landing points deviated with a great extent. The problem was solved by implementing a one-dimensional coded aperture mask in the aerosol inlet and encoding the starting points in angular direction.

Coded Aperture Masks and Encoding Aerosol Inlet

- Coded-aperture masks are spatial or temporal patterns, incorporated in detection of high-energy radiations, molecular spectroscopy and regular photography. Role of the masks is to improve throughput and signal to noise ratio, by means of encoding the extra information made by patterns, into the injected stream of particles or photons.

- The spatial masks are grids, gratings, or other patterns of materials which block or unblock light, or any other information in a known pattern. Using computer algorithms, properties of the encoded source can be deduced. Patterns are constructed in various ways like randomly generated patterns or according to Hadamard or Walsh matrix. Various patterns can be seen in Fig. 4.

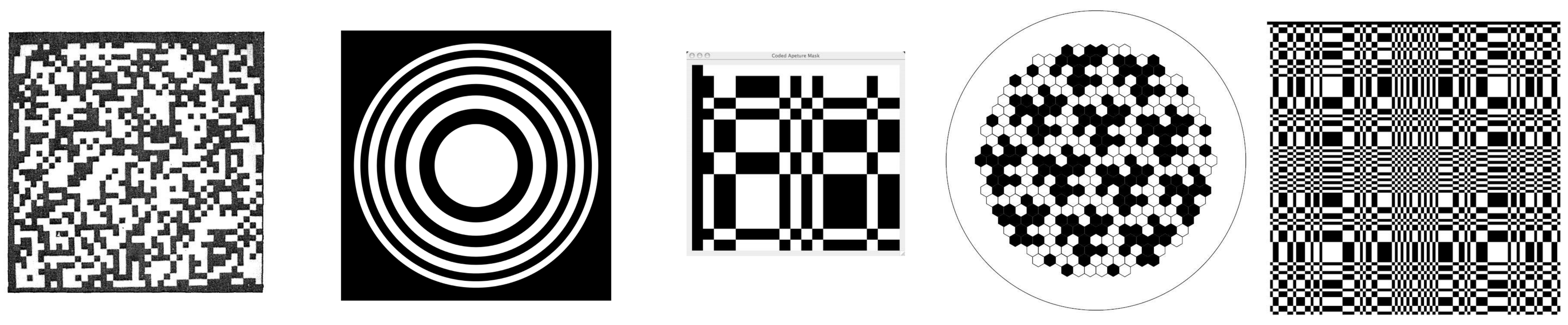


Figure 4. Examples of spatial coded masks. (2D codes)

- This study introduces another application of the coded masks in Electrical Mobility Spectrometers (EMSs), to improve accuracy of size distribution measurements of aerosol nanoparticles. By this method, aerosol inlet is encoded with random binary numbers. One for blocked section and zero for unblocked section. Bellow, some encoding patterns for inlet.

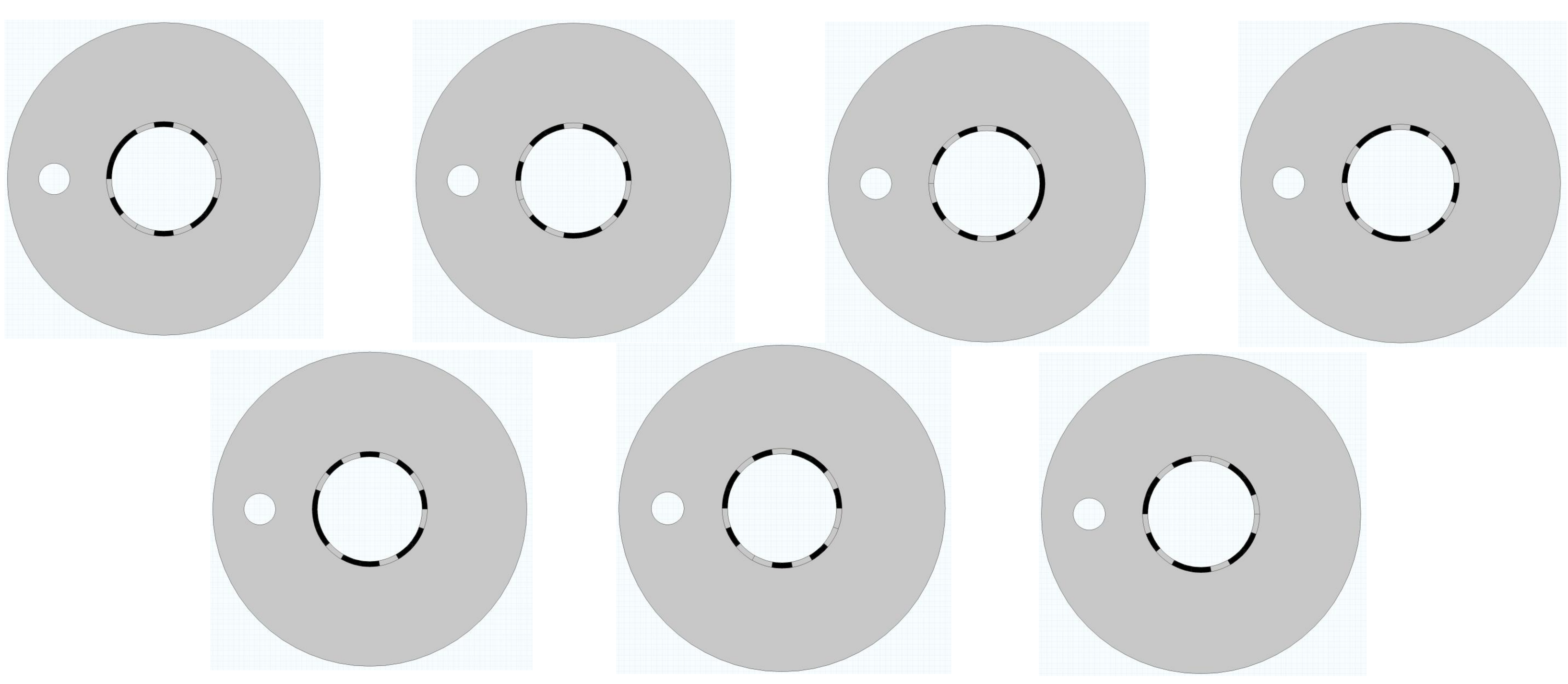


Figure 5. Examples of coded inlet. . (1D codes)

Steps and Methods

1- Numerical simulation of Corona discharge in the charger to estimate space charge density in the charging chamber. This includes Maxwell's equations, charge transport equation, Navier-Stokes and continuity equations.

2- Numerical simulation of aerosol charging due to Diffusion and Brownian motions using birth-and-death theory and estimation of charge distributions on injected particles.

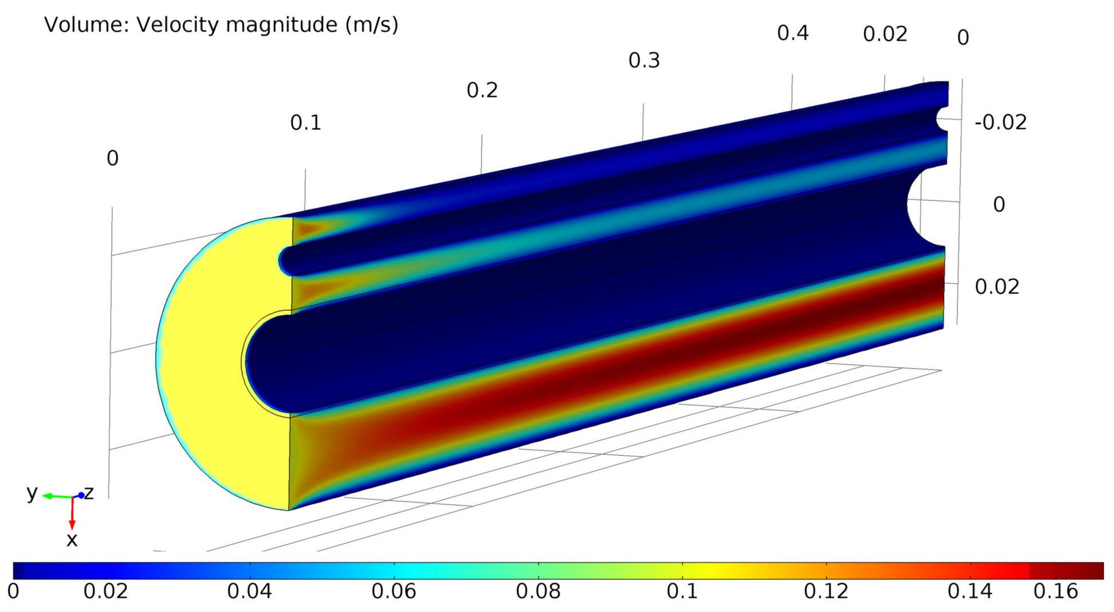
3- CFD simulation of EMS and particle tracking in the classifier to map landing positions of particles holding different number of charges and to obtain the map of charges (or currents) transferred to the electrometers from which transfer matrix of the instrument can be obtained.

4- Different coded aerosol inlets are used and the corresponding transfer matrices are obtained. Entropy of the transfer matrices predicts the accuracy of size distribution measurements.

5-Configuration of electrodes means physical location of electrodes under the map of currents. Different configuration means different vector, transferred and reported by electrometers. Using GA, random electrode configurations are produced to obtain corresponding transfer matrices. The objective is to find a matrix with highest possible rank and maximum entropy.

CFD Simulation and Particle Trajectories

Fig. 6 shows the velocity and electric field and electric potential components generated by two high potential electrodes and the grounded cylinder of the classifier. In Fig. 7 trajectories of 1000 particles (300nm) of average charge is depicted, while no encoding mask is used. Fig. 8 shows trajectories using a coded inlet.



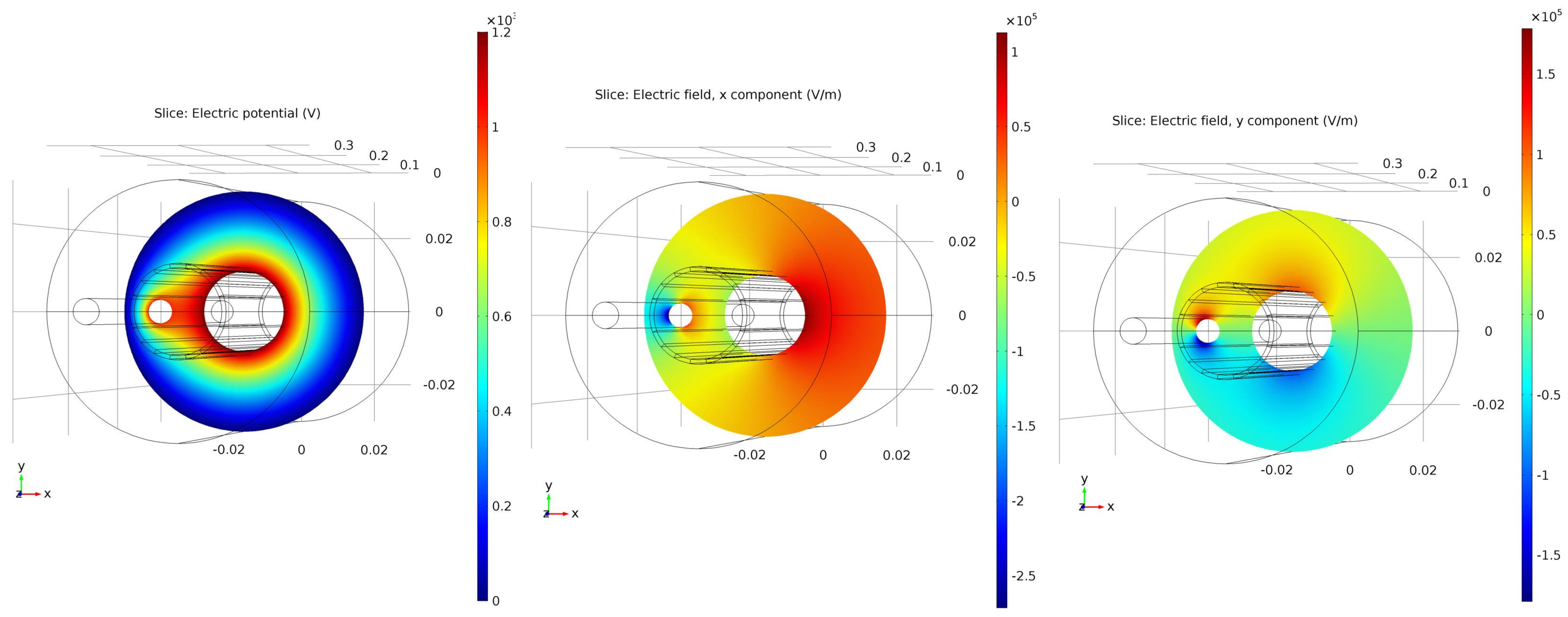


Figure 6. Velocity field, Electric field and Electric potential components

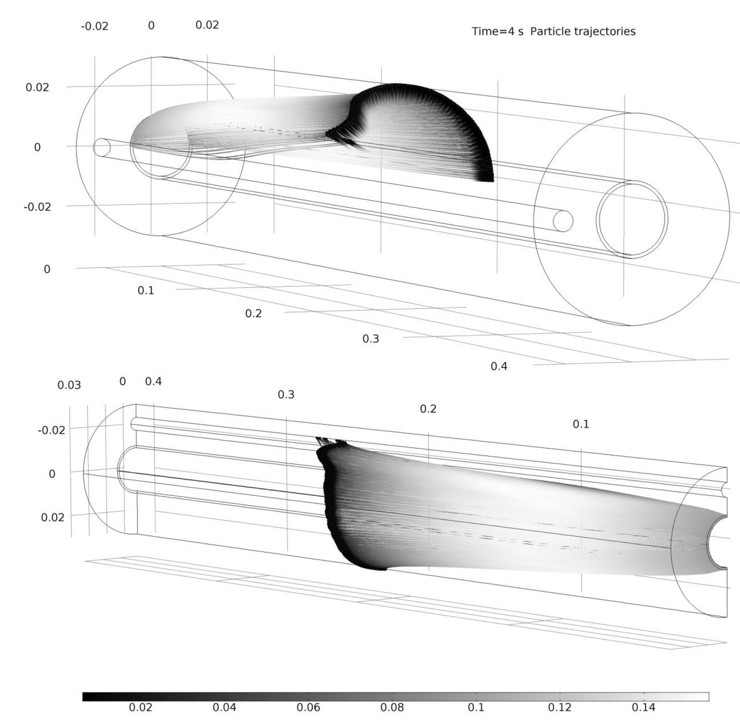


Figure 7. 1000 Trajectories of 300nm particles

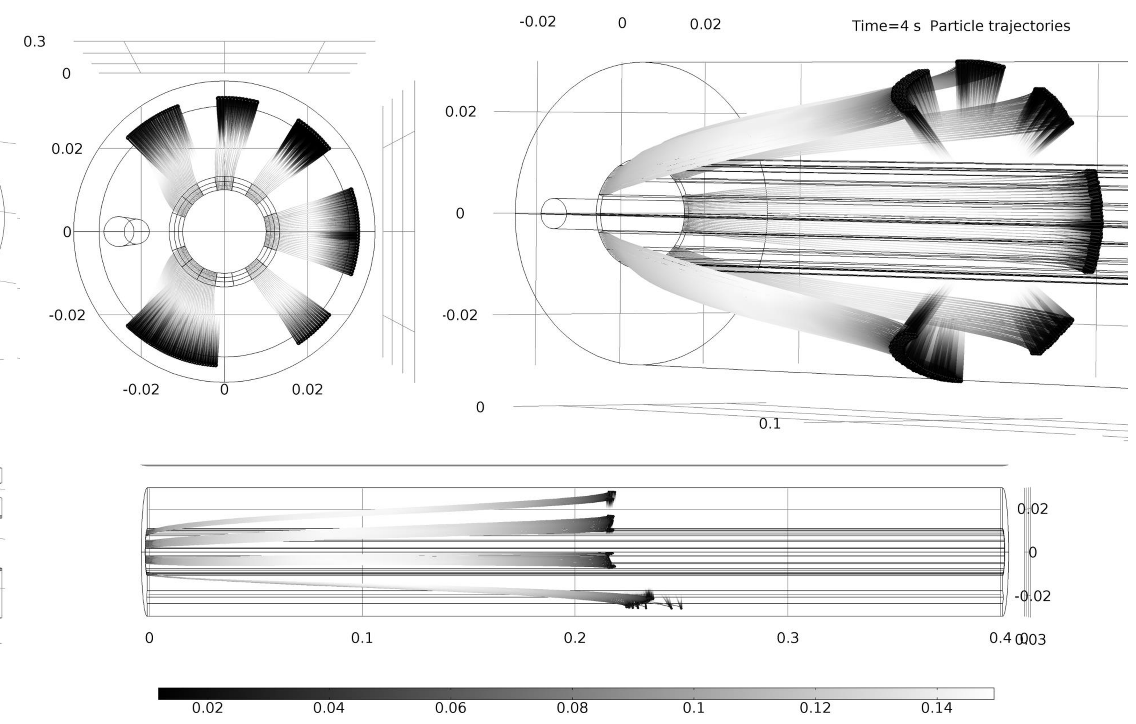


Figure 8. Coded trajectories

Transfer Matrices, SVD, Entropy and Accuracy of Data Interpretation

The ability to predict size distribution depends on the transfer matrix ($\boldsymbol{F}$) of the instrument which is obtained by means of calibration. Fig. 9 and Fig. 10 compare characteristics of transfer matrices of a classifier with and without coded masks and 14 channels (electrodes). Difference in orthonormal eigenvectors of $\boldsymbol{F}^{\mathrm{T}}\boldsymbol{F}$ shown in Fig. 9. Singular values of $\boldsymbol{F}$ by which the entropies are extracted are shown in Fig. 10. Having more and higher singular values means the amount of information latent in $\boldsymbol{F}$ is higher, entropy is higher, and therefore the classifier potentially reports more accurate size distributions.

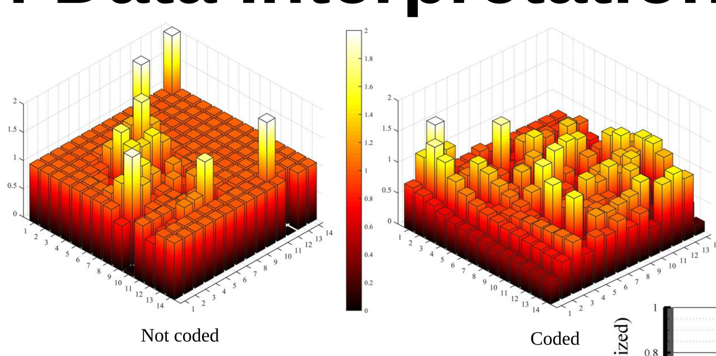


Figure 9. Orthonormal eigenvectors of $\boldsymbol{F}^{\mathrm{T}}\boldsymbol{F}$

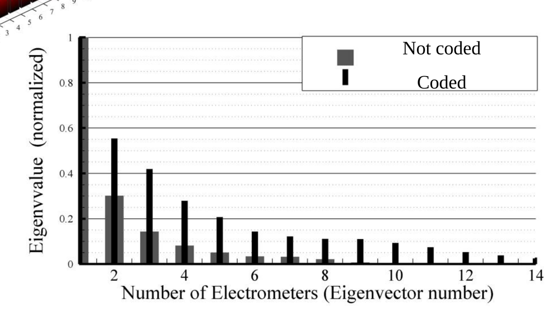


Figure 10. Singular values

Conclusions

An EMS integrated with a corona charger was proposed and simulated using Computational Fluid Dynamics (CFD). Tracking particles inside the classifier, gave the signals (charges) transferred by particles, upon which an appropriate configuration of detectors was obtained. The setup with coded mask led to a transfer matrix with higher entropy and rank, by which more information about the size distribution of injected particles can be transferred. Furthermore, encoding also helped for eliminating background noise, caused by propagation and diffusion of unwanted ions (generated in the charger) through the classifier, by generating a transfer matrix with higher rank and entropy.

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