Supporting Information

CMOS Potentiometric FET Array Platform using Sensor Learning for Multi-Ion Imaging

Nicolas Moser,[†,¶] Chi Leng Leong,[‡,¶] Yuanqi Hu,[†] Chiara Cicatiello,[†,‡] Sally Gowers,[‡] Martyn Boutelle,[*,‡] and Pantelis Georgiou[*,†]

†*Dept. of Electrical and Electronic Engineering and Institute of Biomedical Engineering, Imperial College London, SW7 2AZ, United Kingdom*

‡*Dept. of Bioengineering, Imperial College London, SW7 2AZ, United Kingdom*

¶*These authors have contributed equally to this work as first authors.*

E-mail: m.boutelle@imperial.ac.uk; pantelis@imperial.ac.uk

Supporting information includes additional information on membrane characterisation, drift and step-by-step output of the learning algorithm.

Table of contents

Membrane Characterisation with ISEs

We constructed solid-state ISEs. Briefly a silver electrode was coated with PEDOT.PSS using a cyclic voltammetry deposition. The ISE mixtures described in the main text were then coated onto the surface, and the electrodes conditioned overnight by storage in an aCSF solution. Fig. S1 illustrates the sensitivity measured with the ISEs prior the ISFET array characterisation for each membrane, respectively 57.78 mV/dec (potassium), 56.44 mV/dec (sodium) and 25.79 mV/dec (calcium).

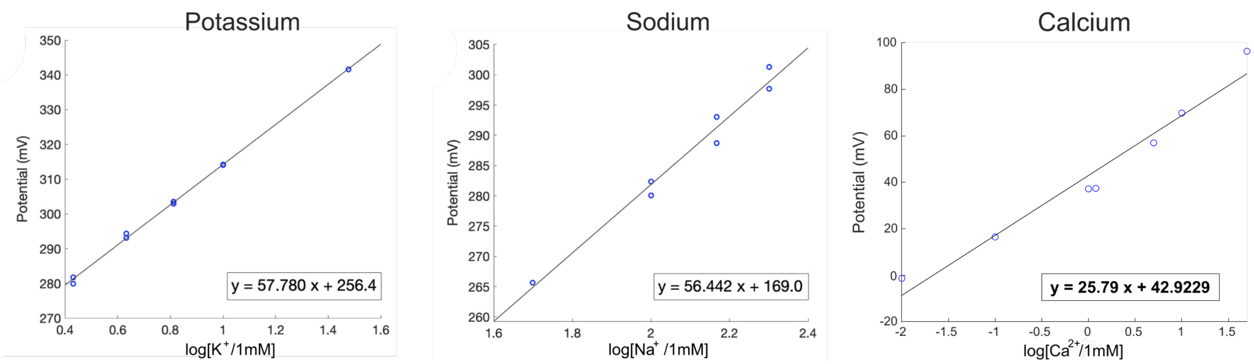

Figure S1: Membrane characterisation with ISEs.

Device Lifetime

We provide data supporting that the lifetime of the sensing device. Fig. S2 shows the response curves of sensors exposed to a potassium-selective membrane for a decade change in potassium (2.8-28 mM) on Day 1 and Day 5 of experimentation. When not in use, the devices are kept in aCSF. The direct array output signal is approximately 207 mV/dec and 205 mV/dec for each day, which amounts to respectively 54.8 mV/dec and 54.2 mV/dec sensor sensitivity. This illustrates that the membrane still adheres to the surface and the encapsulation has not failed.

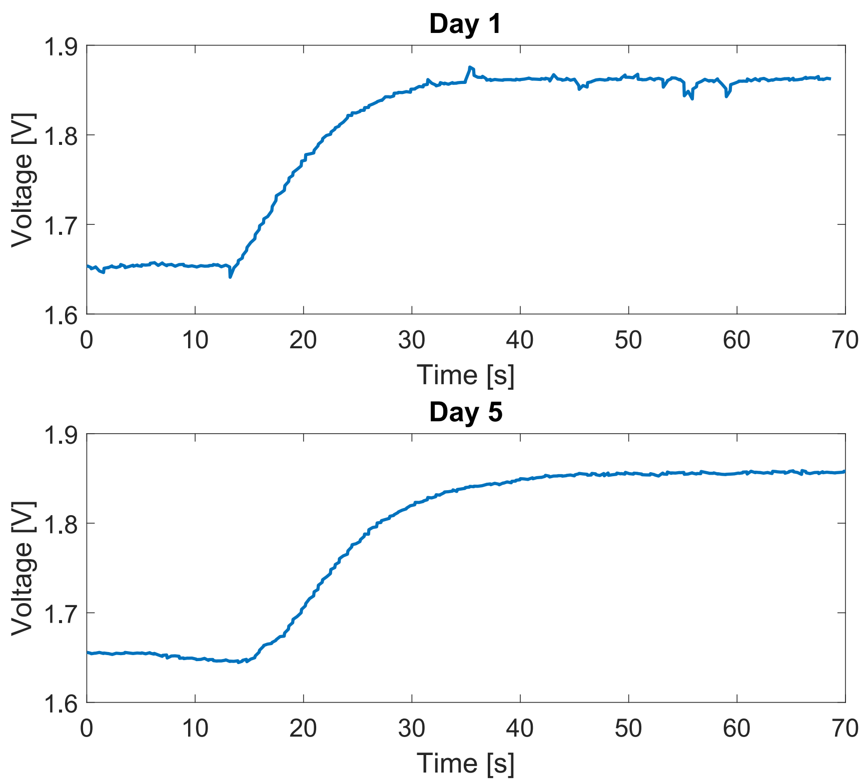

Figure S2: Characterisation of device lifetime. The potassium output response is measured on Day 1 and Day 5 of experiments.

Learning Algorithm

First we describe the identification of active pixels using a reference electrode voltage step (**Fig. S1**), then we demonstrate the spatial filtering of the last frame of the array for each ion experiment (**Fig. S2**), we apply k-means clustering to identify the sensing regions corresponding to the membranes (**Fig. S3**) and we add spatial correlation with DBSCAN (**Fig. S4**).

Reference Electrode Voltage Step

Performing a reference electrode voltage V_{ref} step change on the whole array allows to 1) identify possible pixels which have been covered by epoxy during encapsulation and 2) extract the accurate gain of each sensing front-end pixel. Following a 100 mV step in V_{ref}, we find an average of 3.78 V/V based on sensor attenuation and pixel gain and highlights that all the sensors are active.

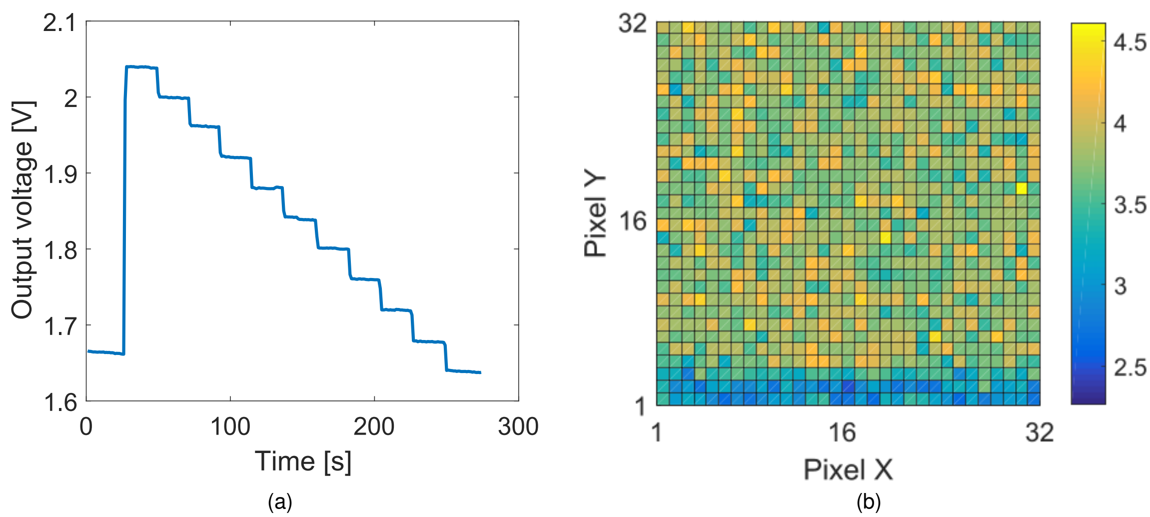

Figure S3: Sampling of pixel gain as initial electrical calibration of the sensors. (a) Average output voltage of the array with a single V_{ref} step of 100 mV and multiple steps of 10 mV and (b) Mapping of the gain of all pixels.

Moving Average

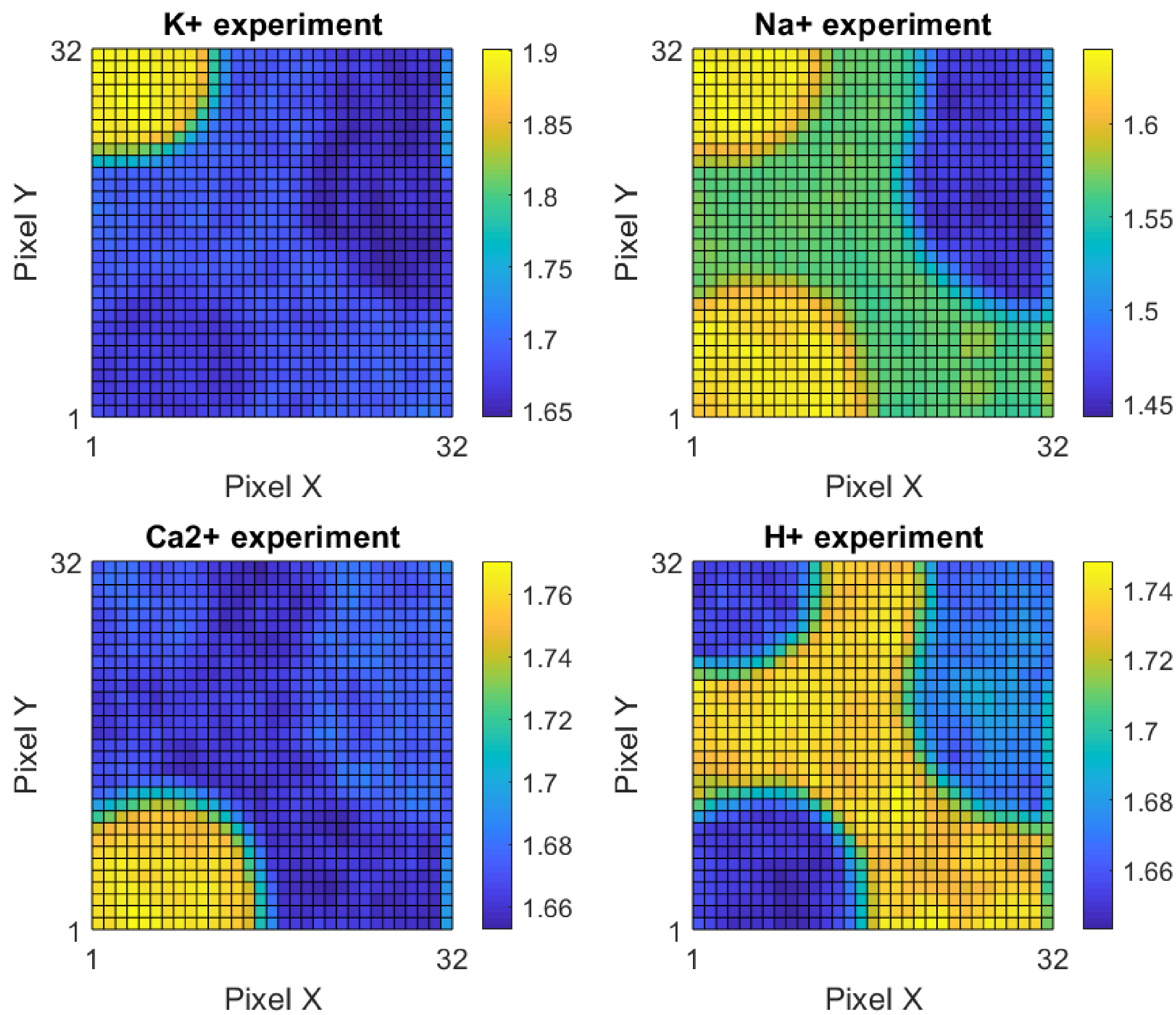

Figure S4: Last frame of each ion calibration experiment spatially filtered using a three-neighbour moving average method.

K-Means Clustering

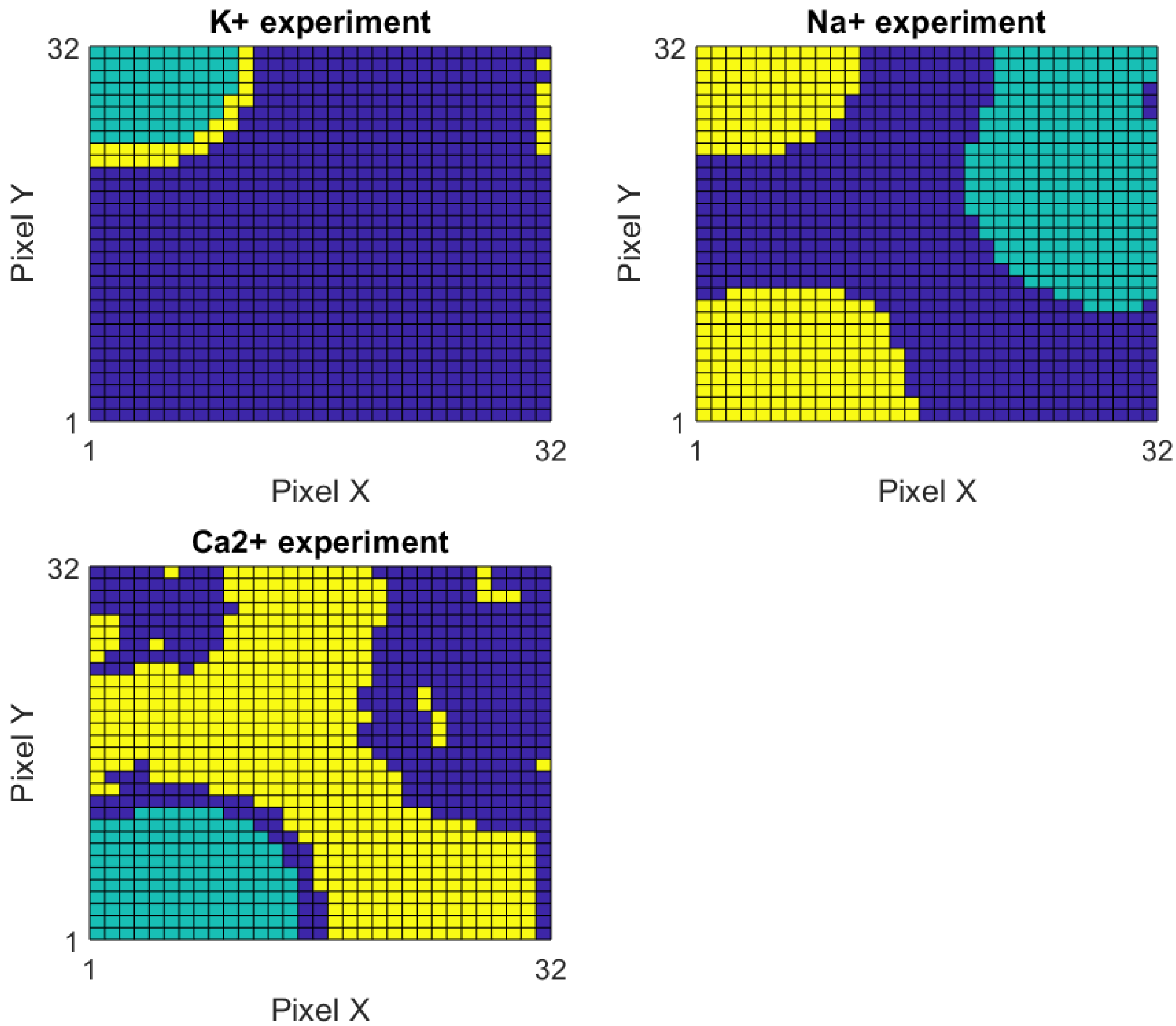

Figure S5: K-means clustering (N=3) applied to the last frame of each ion calibration experiment. The colours indicate levels classified depending on the voltage output.

DBSCAN

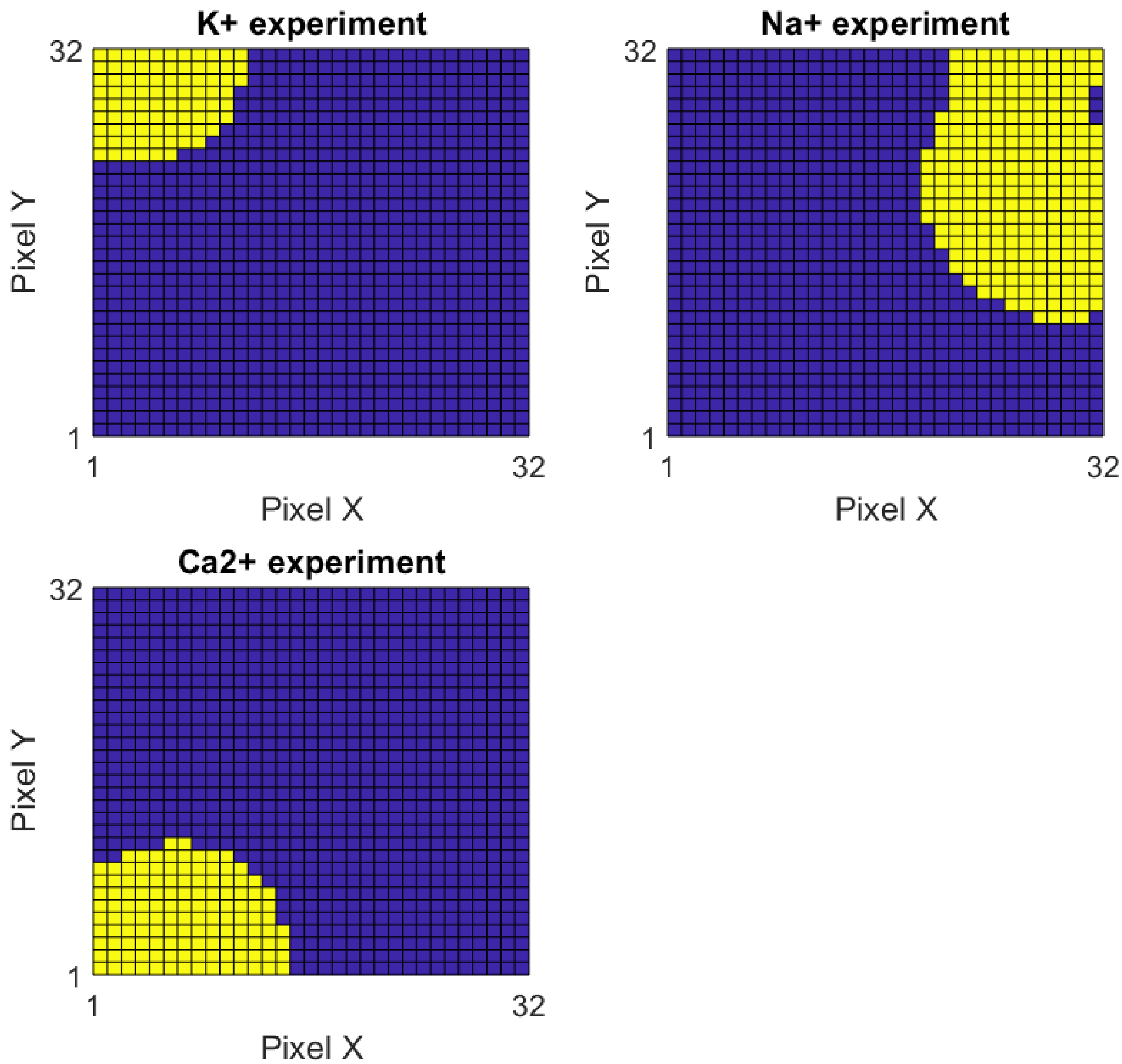

Figure S6: DBSCAN applied to the k means clustering to eliminate spatial outliers. The pH region is then identified by as the pixels who are not present in the first three ionic clusters.

Multi-Ion Imaging Videos

We include videos of experiments referred to in the manuscript to illustrate the multi-ion imaging capabilities of the sensor array. All videos included as supplementary data are marked with a time stamp and played at 2x speed. A colour bar is included to show the output scale in V. They are as follows:

- **MultiIonImaging_aCSF_Sol4_2x** : Mixed experiment illustrating multi-ion imaging in **Fig. 2(a)** (aCSF - Sol 4).
- **MultiIonImaging_Calibration_K+_2x** : K^+ calibration experiment.
- **MultiIonImaging_Calibration_Na+_2x** : Na^+ calibration experiment.
- **MultiIonImaging_Calibration_Ca+_2x** : Ca^{2+} calibration experiment.
- **MultiIonImaging_Calibration_H+_2x** : H^+ calibration experiment.