Application of canonical polyadic decomposition for ultrasonic interrogation of neural dust grids: a simulation study

Alexander Bertrand[1,2] Dongjin Seo[3] Jose M. Carmena[3,4] Michel M. Maharbiz[3]
Elad Alon[3] Jan M. Rabaey[3]

One of the major engineering challenges in the current 'century of the brain' is the development of chronic neuromonitoring techniques, i.e., devices that allow to monitor the brain 24/7, over a period of 10-20 years or longer. Such a technology would form an important breakthrough for brain-machine interfaces (BMIs), allowing to improve the quality of life of people suffering from debilitating neurological conditions [1, 2]. Recently, a neural recording platform based on a distributed ultrasonic backscattering system has been proposed, referred to as 'neural dust' (ND) [5–7] The ND system, as shown in Fig. 1, consists of a large number of free-floating ND motes (NDMs), which are implanted at 3mm depth in the cortex in a grid with a $<$100 μm pitch. These NDMs measure extracellular action potentials or 'spikes' generated by neurons in their neighborhood. Sub-dural ultrasound (US) transceiver modules, referred to as 'interrogators', are implanted on top of the cortex (without penetrating it), to collect the spike signals recorded by the NDMs. The interrogators send a US carrier wave to the targeted NDM, which then modulates the recorded neural signal onto the reflected carrier. The interrogator then demodulates the reflected wave and sends the result to an external transceiver through near-field electromagnetic communication.

However, since the US communication is based on passive backscattering, all NDMs in the neighborhood of a targeted NDM will also modulate and reflect the US wave, generating substantial interference which prohibits a straightforward interrogation. In [7], we have demonstrated that this interference can be removed by combining transmit (Tx) and receive (Rx) beamforming techniques. However, this approach only allows for a sequential interrogation of the NDMs using time-multiplexing, such that only 10% of the NDM grid can be interrogated within the available number of Tx/Rx time slots (the length of each time slot is lower bounded by the time of flight of the US wave).

In this work, we propose an alternative approach where a few random (non-focal) US beam patterns are transmitted in Tx mode towards the entire grid of NDMs simultaneously, resulting in a grid-wide MIMO source separation problem.

[1]KU Leuven - Dept. Electrical Engineering, Stadius Center for Dynamical Systems, Signal Processing, and Data Analytics.

[2]iMinds Medical IT.

[3]Department of Electrical Engineering and Computer Sciences, University of California, Berkeley.

[4]Helen Wills Neuroscience Institute, University of California, Berkeley.

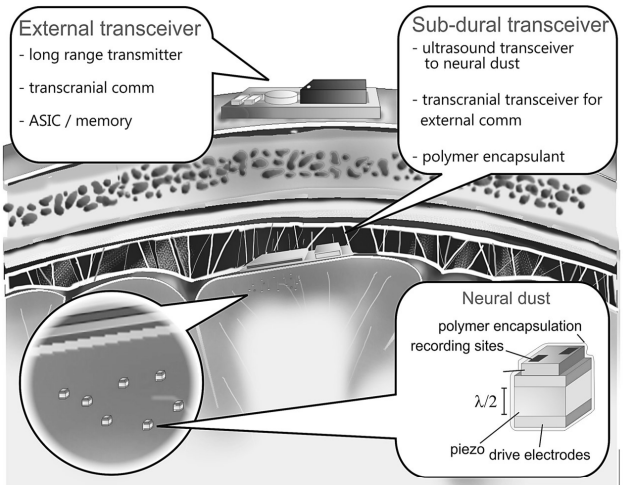

Figure 1: Schematic illustration of the neural dust system.

We then build a 3D-tensor, populated with samples of the demodulated reflected US waves, where the three dimensions consist of the number of channels, the number of time samples of the neural signals, and the number of US beam patterns per sample time. We show that -under certain conditions- a canonical polyadic decomposition (CPD) of this tensor reveals the neural signals recorded by each individual NDM. This allows to read out the entire NDM grid using only a few Tx/Rx time slots, which is validated in a simulation study based on the physical model of the neural dust system described in [5, 7].

References

[1] J. L. Collinger, et al., "High-performance neuroprosthetic control by an individual with tetraplegia," *The Lancet*, Volume 381, Issue 9866, pp. 557-564, 2013.

[2] J. M. Carmena, "Advances in Neuroprosthetic Learning and Control," *PLoS Biol* vol. 11, no. 5: e1001561, 2013.

[3] T. A. Szuts, et al., "A wireless multi-channel neural amplifier for freely moving animals," *Nature Neurosci*, vol. 14, no. 2, pp. 263-269, 2011.

[4] W. Biederman, D. J. Yeager, N. Narevsky, A. C. Koralek, J. M. Carmena, E. Alon, J. M. Rabaey, "A Fully-Integrated, Miniaturized (0.125 mm^2) 10.5 μW Wireless Neural Sensor," *IEEE J Solid-State Circuits*, vol. 48, no. 4, pp. 960-970, Apr. 2013.

[5] D. Seo, J. M. Carmena, J. M. Rabaey, E. Alon, and M. M. Maharbiz, "Neural Dust: An Ultrasonic, Low Power Solution for Chronic Brain-Machine Interfaces," *arXiv*:1307.2196, Jul. 2013.

[6] D. Seo, J. M. Carmena, J. M. Rabaey, M. M. Maharbiz, E. Alon, "Model validation of untethered, ultrasonic neural dust motes for cortical recording", *Journal of Neuroscience Methods*, Vol. 244, Apr. 2015, pp. 114-122.

[7] A. Bertrand, D. Seo, F. Maksimovic, J. M. Carmena, M. M. Maharbiz, E. Alon, and J. M. Rabaey, "Beamforming Approaches for Untethered, Ultrasonic Neural Dust Motes for Cortical Recording: a Simulation Study," *Proc. Int. Conf. IEEE Engineering in Medicine and Biology Society (EMBC)*, Chicago, Illinois, USA, Aug. 2014, pp. 2625-2628.