Fast Inference Methods for Parallelized Diffuse Correlation Spectroscopy Enabled by SPAD Arrays

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Diffuse correlation spectroscopy (DCS) is an optical technique that allows for non-invasive measurements of tissue perfusion, particularly cerebral blood flow [1]. In DCS, a long coherence laser is used to illuminate a tissue sample. The backscattered light coming out of the sample forms a dynamic speckle pattern, and the temporal autocorrelation function (ACF) of the speckle can then be analyzed to quantify the movement of red blood cells. Traditional detection strategies in DCS consist of using one to several single-pixel SPADs to sample one speckle per detector before calculating independent ACFs and subsequently averaging them together. Recent hardware developments in SPADs, however, have enabled "parallelized DCS", where many independent measurements of the speckle field can be captured simultaneously on a compact SPAD array [2]. To keep up with the increasing amounts of data throughput offered with this technique, new methods for data analyses must be developed.

Previous works have applied neuromorphic data processing to SPAD arrays in the form of spiking neural networks [3]. In the DCS context, we employ a technique likewise originally developed for neural data analysis – particle filters for state estimation from (Poissonian) point process models. Specifically, we explore whether these methods can allow us to fully translate the parallelized detection scheme offered by SPAD arrays to both computational speedups as well as faster sampling. The SPAD array detections each follow a doubly stochastic Poisson process with time-varying rate parameter described as the stochastic differential equation:

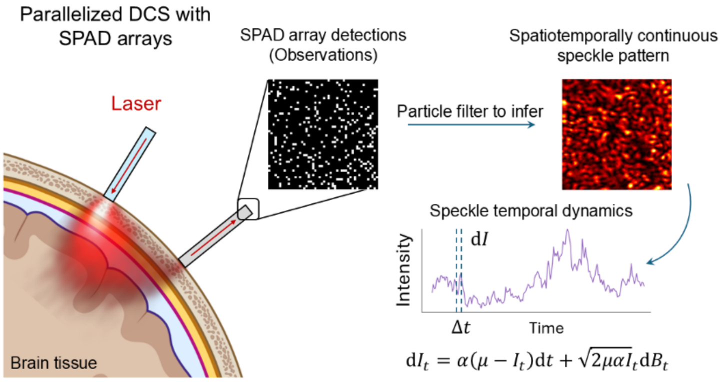

Fig. 1. *In DCS, a laser illuminates a tissue sample, and the spatiotemporally continuous speckle pattern gets discretized in the detection process into photons. We propose a particle filtering method which can infer the speckle pattern from the discrete events to subsequently obtain fast signal extraction.*

$$\mathrm{d}I = \alpha(\mu - I)\mathrm{d}t + \sqrt{2\alpha\mu I}\mathrm{d}B_t$$

Where I is the detected intensity, α is the mean-reversion parameter (and desired value to infer), μ is the mean, and B_t is Brownian motion. This knowledge allows to design a particle filter using Bayesian optimization techniques to estimate α even after the discretization of I. We plan to present initial results from this algorithm and discuss its advantages when working with SPAD array data.

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References

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