Reconstruction algorithm for sub-second X-ray tomographic microscopy of liquid water dynamics in polymer electrolyte fuel cells

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Summary: Sub-second X-ray tomographic microscopy is a powerful tool to gain understanding of water dynamics in fuel cells during operation. Reconstruction of these sparse, limited signal-to-noise ratio dynamic datasets requires advanced algorithmic solutions. We propose an extension of rSIRT-PWC [1] to difference sinograms, so minimizing time-consuming and error prone manual labor.

1. INTRODUCTION

Fossil fuels are the foundation of our global energy system. Their expected future reduced availability and detrimental effect on climate challenge mankind to seek for alternative energy sources. Polymer Electrolyte Fuel Cells (PEFC) are a key technology in future decarbonized energy systems, but improvements in efficiency, performance, durability and cost are still needed. Sub-optimal water management is a major limiting factor for increasing the power density of PEFC.

Sub-second X-ray tomographic microscopy of PEFC [2] is key to visualize and quantify the liquid water dynamics in the gas diffusion layers (GDL), the key component regulating water management. The adverse sensitivity of PEFC to X-ray radiation and the limited signal-to-noise ratio at the short scanning times required for the investigation of PEFC during transient operation represent major challenges. Advancements in the experimental setup, in particular exploiting a heated fluid rotary union and a new high quality custom-made macroscope at the TOMCAT beamline at the Swiss Light Source [3], have made operando imaging of fuel cells with 0.1 s scan time per volume reality (Fig. 1 a). The ongoing development of iterative reconstruction algorithms will push the reconstructed image quality even further for improved analysis of the water dynamics during fuel cell operation.

2. RECONSTRUCTION ALGORITHM: rSIRT-PWC WITH DIFFERENCE SINOGRAMS

Van Eydhoven et al. [1] have introduced an iterative CT reconstruction algorithm designed for imaging fluid flow through porous materials. The region-based SIRT algorithm (rSIRT) with intermediate piecewise constant function estimation (PWC) assumes that a time-varying object can be divided into static and dynamic regions using corresponding masks. Each time step can be reconstructed separately with a SIRT algorithm using the corresponding sparse data. The static areas can instead be reconstructed using data from all time steps and subsequently extracting the relevant voxels by applying the static region mask, leading to a high quality reconstruction. In a second step, for each voxel in the dynamic region a piecewise constant (PWC) function is fitted through the time sequence to suppress noise and further improve the image quality. The final reconstructed images are obtained by merging the static and dynamic reconstructions at each time step.

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The rSIRT-PWC algorithm has shown excellent results both on simulated and neutron data, especially in terms of robustness to sparse data sets [1]. However, creating a mask to separate static and dynamic regions in case of time resolved fuel cell applications is currently time-consuming and a challenging task due to the complexity of the object and poor signal-to-noise ratio (Fig. 1 a). Inaccuracies in the mask such as overlaps with the dynamic region lead to imprecise quantification of water dynamics.

We propose a rSIRT-PWC algorithm combined with difference sinograms, where a sinogram of the fuel cell in dry state is used to isolate the dynamic changes from operando sinograms at each time step. By using the difference sinograms, dynamic changes can be reconstructed directly without the static regions, or subsequently merged together with the dry state reconstruction to gain a combined image of the static parts and water dynamics of the fuel cell. Through this approach no masks are needed, reducing pre-processing and manual labor prior to reconstruction as well as possible inaccuracies.

3. RESULTS AND OUTLOOK

The proposed rSIRT-PWC algorithm with difference sinograms has been tested on a dynamic fuel cell phantom designed to mimic the actual structure of a double-channel fuel cell. The performance of the modified algorithm has been compared to FBP (Fig. 1 b): rSIRT-PWC with difference sinograms has shown strongly improved and stable image quality. The proposed algorithm is currently being tested on operando fuel cell time series data, collected in November 2018 at the TOMCAT beamline at the Swiss Light Source, with promising first results.

We will discuss the algorithm performance and its robustness in particular for the reconstruction of sparse datasets, with noisy and inhomogenously angularly distributed projection images, data limitations occurring in time resolved tomographic experiments. The proposed algorithm is not only suited for fuel cell applications, but can be used for any system where a dry scan can be acquired posterior (or prior) to the studied dynamic processes, making it applicable to a variety of time resolved imaging studies.

References

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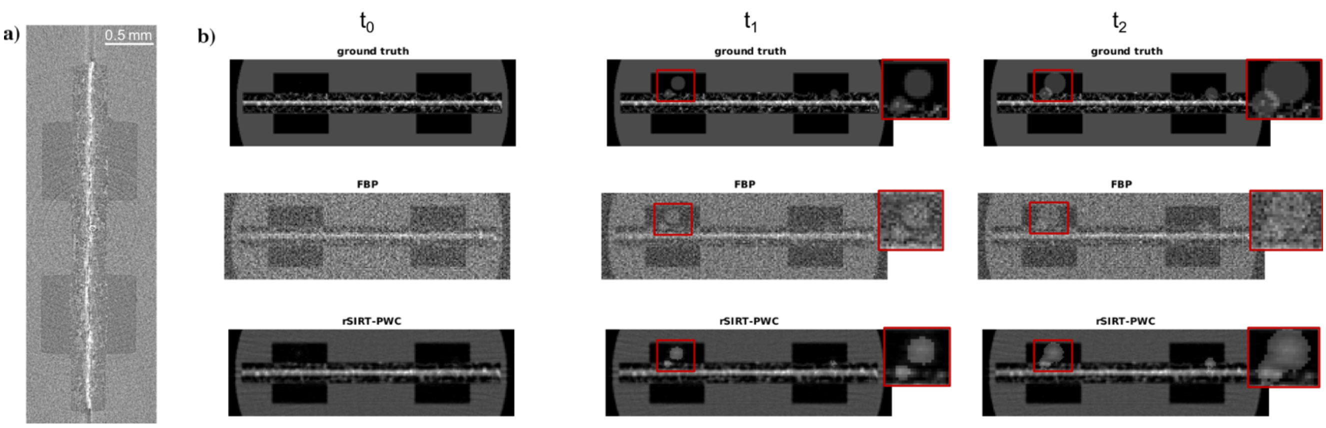

Figure 1: (a) Tomographic slice of a fuel cell (0.1 s scan time). Due to the low signal-to-noise ratio and the object complexity, the creation of a precise static mask is a challenge. (b) Comparison of the reconstructions of a dynamic fuel cell phantom over three time steps (left to right) obtained with FBP and the proposed rSIRT-PWC algorithm with difference sinograms. The simulated phantom has three water droplets developing over time.