

Conceptualization of Multidimensional Finite Impulse Response (FIR) Filter for Projected Emittance Images-sets

Haider Al-Juboori^{1,*}, Juergen Baehr²

¹ Department of Electronics Engineering and Communications, South East Technological University, Carlow, Ireland

² Deutsches Elektronen Synchrotron – DESY, Zeuthen, Germany.

Abstract. Photoemission in modern high-brightness electron sources is under study at the DESY-PITZ photo injector. The electron source optimization process is under continuous upgrading. The developments in modern digital signal processing provide an opportunity for building intelligent algorithms that implement mathematical methods unattainable by analogue technology which can support the related image of emittance measurements from PITZ system. In this work, we provide an intriguing technique for designing multilayer FIR filters with minimal computing effort. As a result, the filter design is particularly effective at reducing complicated noise and performs quickly and efficiently.

1 Introduction

Development and improvement of high brightness electron sources for Free Electron Lasers (FELs) like FLASH and the European XFEL are carried out in the Photo Injector Test facility at DESY, Zeuthen location (PITZ). At PITZ, the single-slit scan method is used to assess the transverse emittance and phase space [1]. The horizontal and vertical actuators in the Emittance Measurement System (EMSY) include 10 and 50 μm slit masks and YAG/OTR screens for measuring the beam size. The general configuration of the EMSY system is depicted in Figure 1.

In the emittance measurement setup and procedure, intrinsic cuts have been minimized by e.g. using highly sensitive screens, high resolution CCD camera that can help to cover the whole beam distribution. Therefore, the emittance value is called 100% rms emittance. To improve the outputs measurement accuracy, the adaptive filter could be one of the digital techniques that can help to enhance the quality of the noisy images produced by emittance measurements (i.e., boost the measurement quality and then optimization of high-brightness electron sources).

2 Methodology

Figure 1 is a sketch of the whole beamline. Electrons are produced within the RF gun by photoemission and accelerated to energies of up to 6.5 MeV in the booster cavity [1]. A transverse deflecting structure (TDS) is part of the measuring setup for slice emittance shown in Fig. 2a. The vertical deflection at PITZ enables the horizontal plane slice emittance measurement. Fig. 2b depicts a general view of the PITZ beamline between the booster exit and the PST.Scr1. The PITZ TDS is far away from the booster cavity, which causes a long distance between the two existing slit stations (EMSY1 and EMSY2) and the first screen after the TDS: The drift distance from the routine emittance measurement station EMSY1 to PST.Scr1 is 7m, which is a factor of ~ 2 larger than for the projected emittance measurements [1, 2].

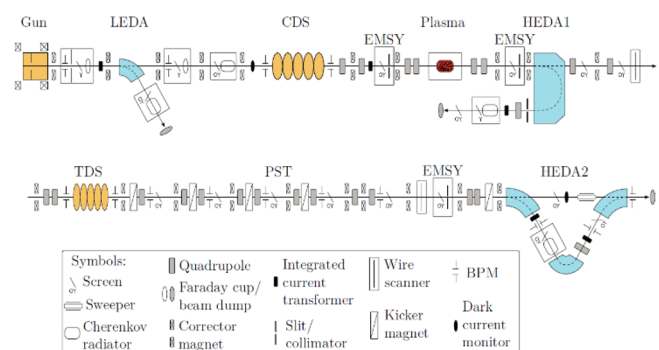


Fig. 1 : The concept of PITZ setup, the gun (top left on chamber) produces the beam, which then moves from left to right [1, 2].

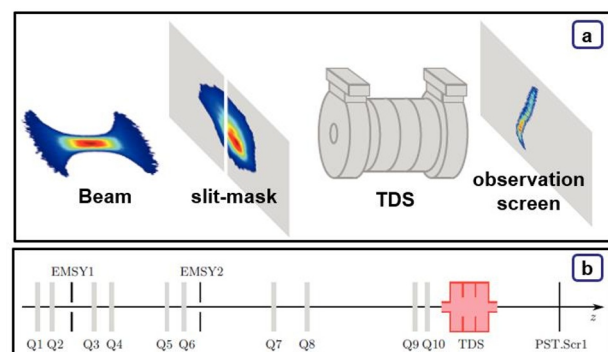


Figure 2: Projected Emittance Measurements (a) Slice emittance measurements are possible when the TDS and the slit scan technique for projected emittance measurement are combined. Although the (slice) emittance measurement is in the horizontal plane, the deflection is vertical. (b) Diagram of the PITZ beamline after the booster [1].

A single-slit scan approach is a primary technique used at PITZ to measure emittance. This technique involves measuring local beam divergence by inserting the slit mask at a specific place within the beam and measuring the transmitted beamlet profile downstream of the slit station. The special computer tool used by PITZ operators for automatic emittance measurements is called "Emittance Measurement Wizard" (EMWiz), as seen in Figure 3a. The multi-layered image-sets are represented

* Corresponding author: haider.aljuboori@setu.ie

by a stack of 2-D images as $I(x,y,z)$, where z refers to the slice number as represented in Fig. 3b. The multidimensional arrays of scalar or vector data are a distinctive feature of volume data sets. Typically, these data are defined using lattice structures that reflect values sampled in three dimensions.

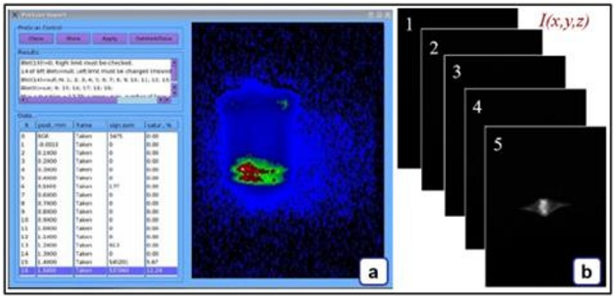


Figure 3: (a) GUI of emittance measurement wizard (EMWiz) software [3], (b) 3-D volumetric images.

3. Efficient Method for Synthesizing FIR Filter

One of the fundamental image processing tools is finite impulse response (FIR) filters. An interesting method was developed for 3D FIR filter design with low computational complexity that can be used for multilayer image sets for projected Emittance Measurements. In this methodology, numerical parameters that correspond to operations with image intensities between 0 and 1 are normalized. Fig. 4 explains the filter efficiency to remove complex and multiple noise effects by convolution of the original image with enhanced one, at two different cut-off frequencies (C_f). Fig. 5 illustrated the centroid of the beam profile before and after applying the designed multilayer digital FIR filter.

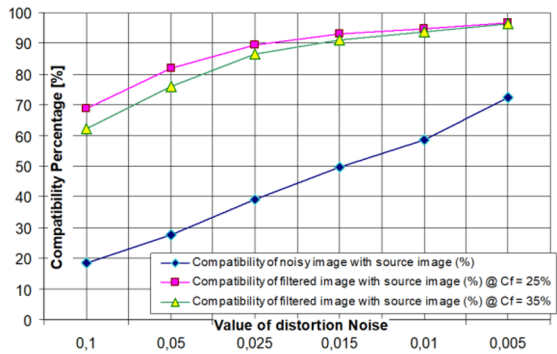


Figure 4: Quality of noise reduction of projected emittance images using FIR filter.

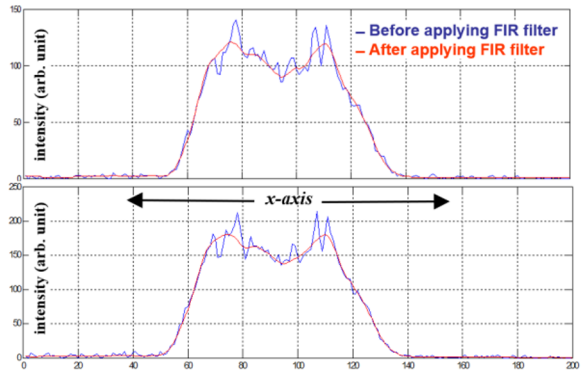


Figure 5: Line profile of two different samples from multilayer projected emittance image-sets.

To further investigate, how the FIR filter of our synthetic image looks, we can generate a 3D view of our accumulator arrays using volume visualization. After applying the FIR filter as shown in Figure 6, the ripples in the projected beam disappeared and the desired intensity distribution was approximately achieved, as illustrated in the bellow 3D view of accumulator arrays. All digital analysis was completed by creating complex codes within the MATLAB digital environment.

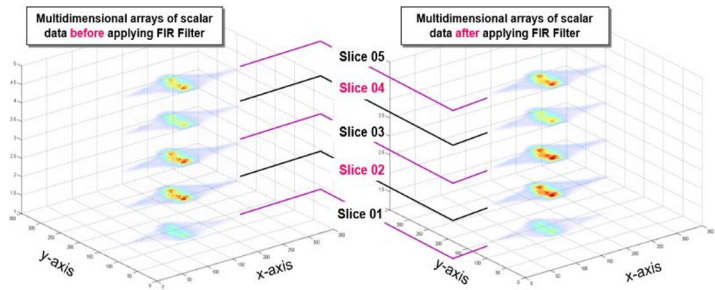


Figure 6: Volume visualization of the multidimensional arrays of emittance measurements.

4. Concluding Remarks

The presented work illustrated an efficient method for 3D digital FIR filter synthesis for projected emittance measurements, as well as simple Volume visualization tools. The recommended FIR filtering method is an accurate, straightforward approximation of the ideal low-pass filter transfer function. The integral Gaussian error function's unique characteristics—a smooth graph without local extrema in the passband and stopband—make it valuable. According to the design requirements, parameter C_f modifies the filter selectivity. As a consequence, the selectivity is increased and the computation time for filter synthesis is decreased. Worth mentioning, the developed concepts might support and serve other promising applications such as multispectral imaging (MSI) which is the method for collecting imagery of a scene or object over numerous distinct wavelength bands and extracting spectral information from that data.

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