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Research paper

Selection of Filtering Method for Accurate Bunch Length Measurement at Synchrotron Radiation Source

Monika Jain[1]*, Rahul Saxena[2]

[1]*Manipal University Jaipur*
[2]*Manipal University Jaipur*
**Corresponding author E-mail: rahulsaxena0812@gmail.com, monikalnct@gmail.com*

Abstract

The measurement of the object parameters present in an image is a difficult task because the image not only contains the objects information but a noise is also associated with the image. The type of noise present in the image depends upon the various parameters like sensors, transmission signal and surrounding conditions. In this paper, we are studying the special type of images of electronic particles (visible light of electromagnetic radiations captured at different beam currents produced by synchrotron radiation source), these images contain visible part information of radiation called bunch. In these images our main aim is to calculate the bunch parameters but due to different light condition and other factors the captured images of bunch is found to be noisy and it causes great loss of bunch information in the image. The image filtering in those kinds of images should be done in such a way that the filter should identify the noisy pixels present in the image and remove them while retaining the original information of the bunch image, for precise measurement of this bunch present in an image appropriate filtering method and filter size is chosen. This paper discusses the test results of bunch parameters by applying various filters and appropriate filter is chosen based upon the measured test results.

Keywords: *Synchrotron radiation source, bunch parameters, noise, particles*

1. Introduction

The circulating electrons are emitting the synchrotron radiation from mid-IR to soft x-ray at synchrotron radiation source. From this radiation visible light is extracted and captured called bunch. Figure 1.1 shows the bunch captured from synchrotron radiations. The bunch parameters are important for scientists to understand the particles nature. But the captured image not only contains the beam information but there is also noise associated with the bunch as shown in Fig. 1.1.

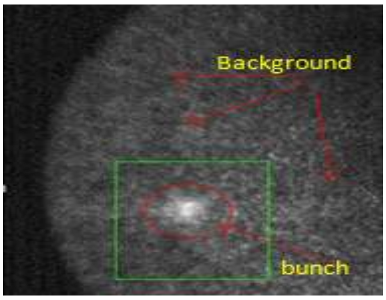

Fig. 1.1: Bunch captured from synchrotron radiation source

2. Literature survey

2.1 Synchrotron radiation source:

A synchrotron radiation source (SRS) is a source of electromagnetic (EM) radiation which is artificially produced for scientific and technical purposes by specialized particle accelerators, mainly by accelerating electrons [9]. These components supply the strong magnetic fields perpendicular to the beam which is needed to convert the high-energy electron energy into desired electromagnetic radiation. The basics of particle accelerator are based on acceleration of charged particles, which radiates while bending in their moving path [8]. Major applications of synchrotron radiation are in materials science, biology, medicine and condensed matter physics etc. A large fraction of experiments using synchrotron light involve probing the structure of matter from the subnanometer level of electronic structure to the micrometer and millimeter level. Fig 2.1 below shows the synchrotron radiation emitted by charged particle. We capture the visible part of this radiation and apply some filtering techniques to it.

Major steps involved in finding parameters

1. Acquisition of online image of electron beam (only visible part)
2. Enhance the quality of images through image processing techniques like filtering, thresholding, morphology and segmentation etc.
3. Measurement of beam parameters such as bunch length and bunch separation of electron beam at different light conditions.

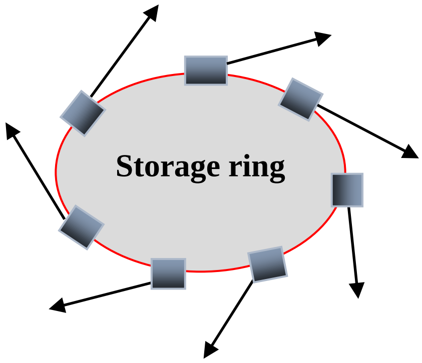

Fig. 2.1: Synchrotron radiation emitted by the charged particle at SRS, Electron beam revolving in storage ring

distribution. The PDF of Gaussian random variable is given by following equation and curve shown in Figure 2.3.

$$p_G(z) = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\frac{(z-\mu)^2}{2\sigma^2}}$$

2.2 Image processing

After acquiring the electron pulse image, the next step is image processing and its analysis. The pulse image during the acquisition, transmission is generally corrupted by noise. The detection of bunch and measurement of bunch are difficult in noisy image. Therefore, it is very important to get the improved image from the corrupted image without loss of features of the image. Figure 2.2 shows the fundamental steps involved in image processing. Noise is a random variation of image density [2]. Noise can attach with the image during image capture, transmission etc. Images are often degraded by noises. Noise removal is an important task in image processing. To select the appropriate denoising filter it is necessary to have the knowledge about the noise present in the image. There are various types of filters available such as Gaussian filter, median filter, mean filter etc. Different noise models like Gaussian noise, salt and pepper noise, speckle noise. Fig. 2.2 shows various kinds of noise present in the image.

Gaussian noise

The term normal noise model is the synonym of Gaussian noise. This noise model is additive in nature [5] and follow Gaussian distribution. In this type of noise, each pixel in the noisy image is the sum of the true pixel value and a random, Gaussian distributed noise value. The noise is independent of intensity of pixel value at each point. It is a major part of the read noise of an image sensor that is of the constant level of noise in the dark areas of the image. This noise has a probability density function [pdf] of the normal shown in fig. 2.3.2.

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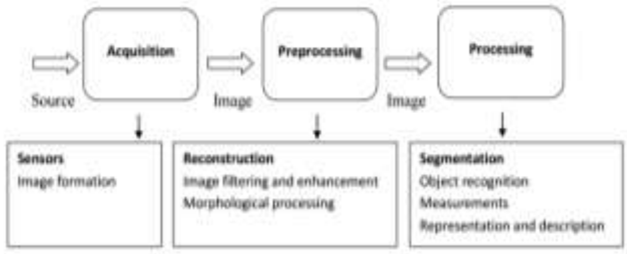

Fig. 2.2: Block diagram showing fundamental steps involved in image processing

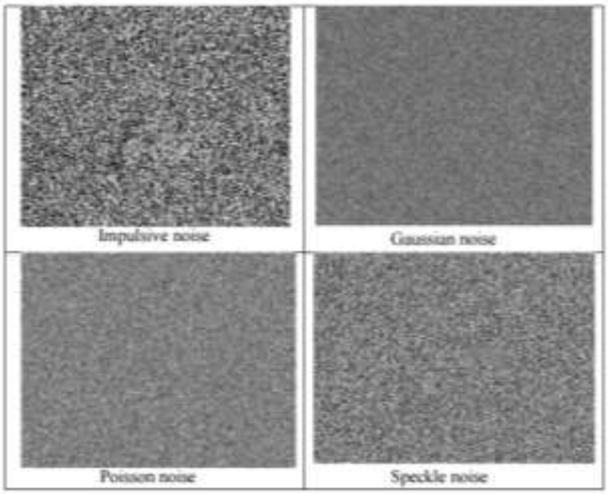

Fig. 2.3.1: Photographs showing various types of noise present in an image

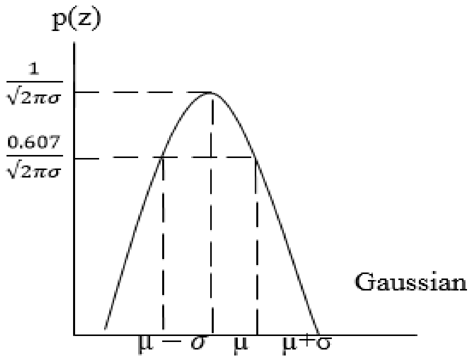

Fig. 2.3.2: PDF of Gaussian noise

Noise can attach with the image during image capture, transmission etc. Images are often degraded by noises. transmission is generally corrupted by noise. The detection of bunch and measurement of bunch are difficult in noisy image. Noise removal is an important task in image processing. To select the appropriate denoising filter it for removing these kinds of noises, image filtering is used. Image processing operations implemented with filtering include smoothing, sharpening, and edge enhancement. Filters are used to remove noise from digital image while keeping the details of image preserved [3]. It is a neighborhood operation, in which the value of any given pixel in the output image is determined by applying some algorithm to the values of the pixels in the neighborhood of the corresponding input pixel. A pixel's neighborhood is some set of pixels, defined by their locations relative to that pixel [4]. Filtering image data is a standard process used in almost all image processing systems. The choice of filter is determined by the nature of the task performed by filter and type of the data. The working of filter is shown in Figure 2.4

Fig. 2.4: Corrupted image filtered by the filter g (x, y) =Corrupted image f (x, y) =Filtered image

3. Selection of optimum filter

For choosing the optimum filter for bunch images, the histogram of bunch images is calculated. The measured histogram of image noise of light pulse is found to be normally distributed in nature, so Gaussian filter is selected for the filtering of image. For selecting the suitable filter size, three filters of different size are taken and bunch length is measured. The filter which gives the optimum result is chosen for preprocessing of image. For choosing the appropriate filter size steps involved are:

Steps involved (in filter selection)

- A bunch image of fixed size is generated
- Induced Gaussian noise of different density into the bunch image
- Gaussian filter of different size is applied on the bunch image and noisy bunch image.
- Measure the bunch length from both the bunch image and noisy bunch image.
- Check the beam size accuracy/ measurement errors of the beam image and noisy image.
- Check the beam size accuracy/ measurement errors of the beam image and noisy image.

Suitable filter is chosen based on measured results.
The choice of filter is determined by the nature of noise present in image. For choosing the appropriate filter, we have measured bunch length using Gaussian filter of different size i.e. 3×3, 5×5, 7×7 on original image as well as some generated noisy images. The experimental results are shown in Table 3.1. It was observed that although fitting of Gaussian profile improves at higher filter size but, image data loses its basic information. Gaussian 3×3 filter gives the minimum standard deviation value and it gives the optimum results in measuring the bunch length and removing noise from the light pulse image, so it is chosen for the filtering operation in image processing software. Figure 3.2 shows the images after applying Gaussian filter of different filter size on bunch images of beam.

4. Calculation of beam parameters after applying filtering operation

The bunch length represents the length of longitudinal distribution of the electrons inside the bunch. Bunch length is important for the desired use of synchrotron radiation source. For accurate measurements of the bunch length, Gaussian filter of 3×3 size is applied and bunch centroid is calculated from image. Bunches are extracted as shown in Figure 4.1 from the filtered image through boundary coordinates and centroid is calculated. A horizontal row is selected from a centroid and the pixel intensity is measured as shown in Figure 4.2. The intensity values obtained are in bell shape in nature so Gauss fitting is done on the measured values. Bunch length is measured from the standard deviation value of Gauss fitting of bunch as shown in Figure 4.3 [1].

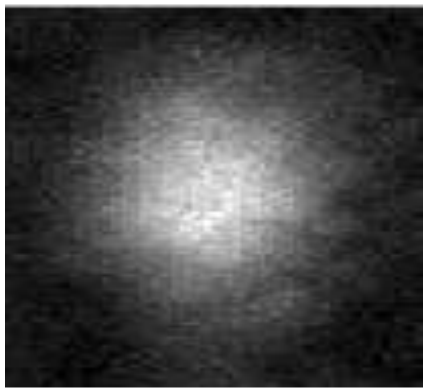

Fig. 4.1: Extracted bunch from the filtered image

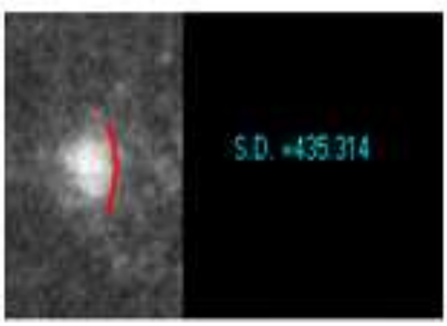

Fig. 4.3: Measurement of bunch parameters from the image

Gauss fitting equation

It uses the iterative general Linear Square method to fit data to a Gaussian curve in a form described by the following equation

$$f = a \times exp\left(\frac{(x-\mu)^2}{2\sigma^2}\right) + c$$

here x is the input sequence **X**, a is **amplitude**, μ is **center**, σ is **standard deviation**, and c is **offset**. This VI finds the values of a, μ, σ, and c that best fit the observations (**X**, **Y**) [6]. Figure 4.3 describe the Gauss fitting curve using least square method

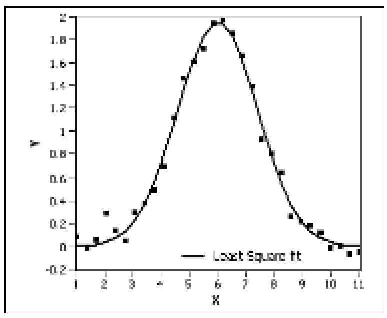

Table 3.1 Bunch length measure after applying Gaussian filter

Image	RMS	Beam size (Pixels)	3×3 Filter		5×5 Filter		7×7 Filter	
			RMS	Size (Pixels)	RMS	Size (Pixels)	RMS	Size (Pixels)
Original Image	0.915	24.847	0.932	21.121	0.945	28.241	0.965	28.758
Noise densi-	0.770	26.644	0.942	22.772	0.959	26.642	0.973	28.987

ty of 0.02								
Noise density of 0.04	0.707	20.000	0.901	20.664	0.951	27.001	0.969	29.013
Noise density of 0.06	0.597	25.959	0.768	20.081	0.953	24.566	0.970	27.546
Noise density of 0.16	0.469	20.168	0.768	20.092	0.944	27.508	0.963	30.660
Noise density of 0.36	0.106	161.266	0.331	20.133	0.348	15.255	0.713	11.017
Standard Deviation				1.046 Pixels		4.869 Pixels		7.405 Pixels

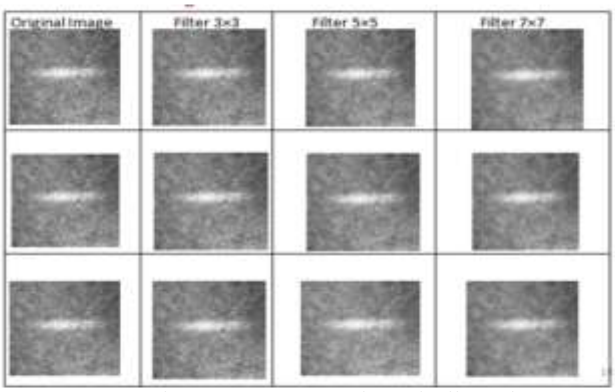

Fig.3.2: Images after applying Gaussian filter of different filter size

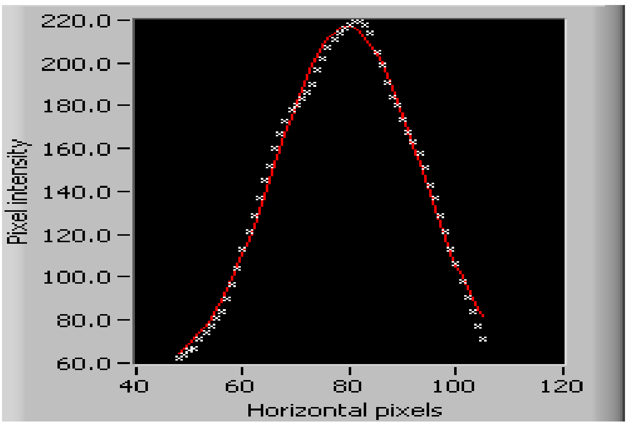

Fig. 4.2: Observed data of intensity values of centroid

5. Testing

In order to test our filtering method we have generated some images and results are analyzed about accurate measurement. We have used software name called object maker which generates images of objects by varying intensity, noise, standard deviation etc. After generating these images we have applied 3*3 filter and bunch length is measured accordingly. The measured results shows the variation of 1 pixels. This means our filtering method filters the images by retaining its actual information. The measured results are shown below.

5.1 By varying intensity

Object length is measured by varying **intensity** and keeping object length, noise standard deviation, and noise mean value of object image constant. The measured object length is shown in Table 4.1.1.

5.2 By varying noise

Object length and object separation is measured by varying noise standard deviation and keeping intensity, object length, object separation, noise mean value of object image constant. The measured object length and object separation is shown in Table 5.2

Table 5.1: Measured results by varying intensity

Theoretical intensity (au)	Theoretical object length (px)	Measured object length (px)
5	10	9.93
10	10	9.96
20	10	10.13
40	10	10.03
80	10	10.04
100	10	10.02
150	10	10.01
200	10	10.12
250	10	10.03
		10.03 ±0.06

5.4 Results after varying intensity of object and adding noise of fixed proportion

We have created the noisy object image with mean value 100 (px) and standard deviation of 1 (px), after varying intensity of this noisy image and keeping all the parameters of object fixed. The measured object length is shown in Table 5.4

Table 5.2: Measured results by varying noise

Theoretical intensity (au)	Theoretical object length (px)	**Noise Standard deviation (px)**	Measured object length (px)
100	10	**0**	10.06
100	10	**0.1**	10.16
100	10	**0.25**	10.23
100	10	**0.5**	10.09
100	10	**1**	10.17
100	10	**2**	10.3
100	10	**5**	10.44
100	10	**10**	10.45
100	10	**20**	10.6
			10.27±0.18

Table 5.3: Measured results by varying intensity and noise

Theoretical intensity (au)	Theoretical object size (px)	Noise Standard deviation (px)	Measured object size (px)
50	10	0.5	10.07
		1	9.96
		5	9.64
		10	10.65
100	10	0.5	10.11
		1	10.06
		5	9.76
		10	9.93
200	10	0.5	10
		1	10.17
		5	9.88
		10	10.21
			10.03±0.25

6. Conclusion and Future Scope

Based on the different testing on images Gaussian filter of 3×3 size is chosen for image filtering and preprocessing on these kinds of images. It gives the accuracy of 1 pixel. After filtering on images, bunch parameters are measured. The length of electron bunches in a storage ring is an important parameter for both synchrotron radiation users and accelerator physicists [7]. More advanced filtering method can be applied in the future. Further, to improve the quality of image fitting more image processing functions can be tried on the image.

Table 5.4 Measured results by varying intensity of noisy object

Theoretical intensity (au)	Theoretical object length (px)	Width Standard deviation (px)	Measured object length (px)
10	10	1	10.39
			12.4
			10.82
20	10	1	10.7
			9.43
			10.11
40	10	1	10.72
			9.74
			9.99
80	10	1	10.68
			10.04
			9.67
100	10	1	10.15
			10.19
			10.22
150	10	1	10.59
			10.09
			10.15
200	10	1	9.99
			9.19
			10.01
			10.25±0.64

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