Document Number: K45-B60046
Rev E02 : April 1, 2024

X-ray Flat Panel Sensor Application Manual

Read this manual carefully before using this product.
Keep this manual handy so that you can easily refer to it when needed.

HAMAMATSU
PHOTON IS OUR BUSINESS

Introduction

Thank you for purchasing a Hamamatsu Photonics Flat Panel Sensor (hereafter referred to simply as the “sensor”). Please read this application manual carefully before using the sensor. This document shows how to improve the image quality of the sensor and important notices when incorporating it into applications. Before handling the sensor, read this manual and the instruction manual carefully, and make sure to understand the contents so you can use it safely.

Contents

1. Image Correction

The raw image captured by the sensor contains dark offset irregularities, x-ray sensitivity non-uniformity, and scratches on the scintillator material. Also, spatial non-uniformity in the exposure dose of the x-ray source can also cause non-uniformity in the shading image. Make sure to do image correction to remove these components.
Also, the sensor degrades due to long-term exposure to x-rays, resulting in increased dark offset output and decreased sensitivity. Therefore, acquire new reference images regularly according to your required image quality.
Do imaging of the reference image under the same conditions (tube voltage, tube current, filter, exposure, frame rate, scan mode, gain) as when acquiring the object image. Also, the dark offset output fluctuates depending on operating temperature and time elapsed after turning on the power supply. Therefore, it is able to acquire highly accurate images by acquiring dark images for correction for each imaging, then doing image correction. If it is difficult to acquire for each imaging, then consider the frequency according to the required image quality.
The content of this chapter describes the typical correction method. In order to improve image quality, consider appropriate image correction according to required image quality.

The basic image correction procedure is as follows.

(1) Reference x-ray image and dark image acquisition (regularly)

(2) Object x-ray image and dark image acquisition (every imaging)

(3) Execution of dark correction

(4) Execution of shading correction

(5) Execution of defect line correction

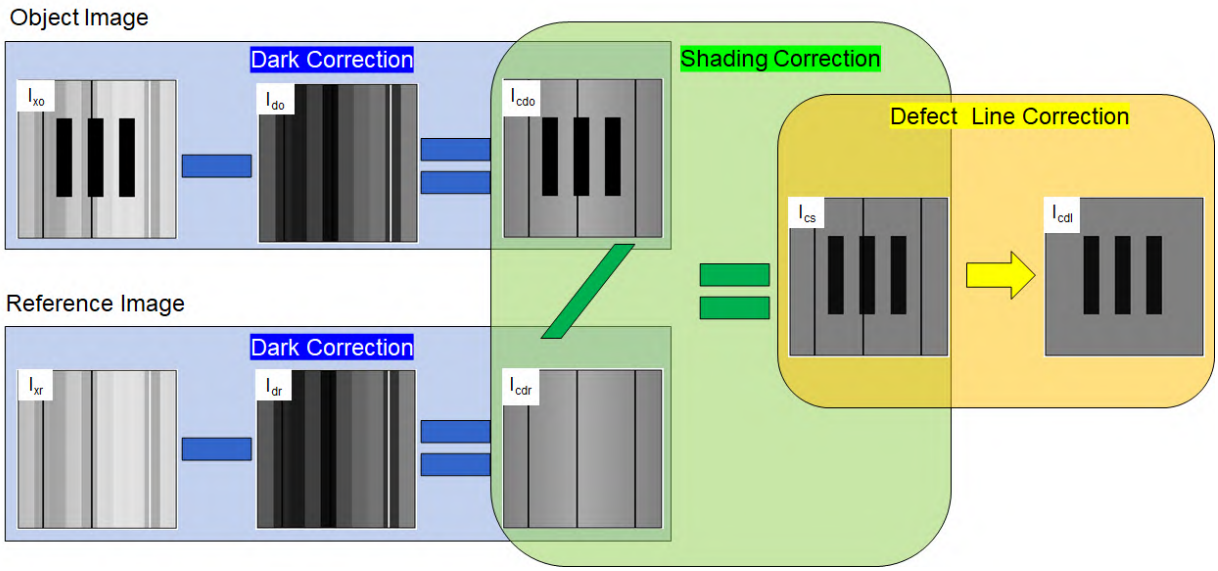


Figure 1-1: Overview of image correction

1-1. Preparation of reference images

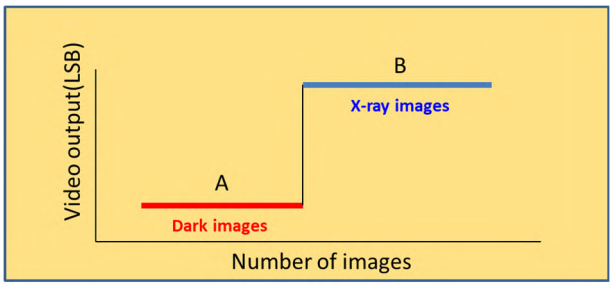


Figure 1-2: Reference image acquisition sequence

As shown in Figure 1-2, images are made continuously from dark (with no object) to x-ray emission.

1-1-1. Preparation of dark images

Create an image Idr (dark image for reference) that averages the image of dark part A (red line region in Figure 1-2). If the frame rate is changed during shooting, then it will be necessary to acquire a dark image for each frame rate.

1-1-2. Creation of averaged x-ray images

Create an image Ixr (x-ray image for reference) that averages x-ray emission area B (blue line region in Figure 1-2). To do accurate correction, the output value of this x-ray image must be close to the output value of the object x-ray image.

1-1-3. Creation of reference image

Subtract Idr from Ixr to create Icdr (dark corrected image for reference).

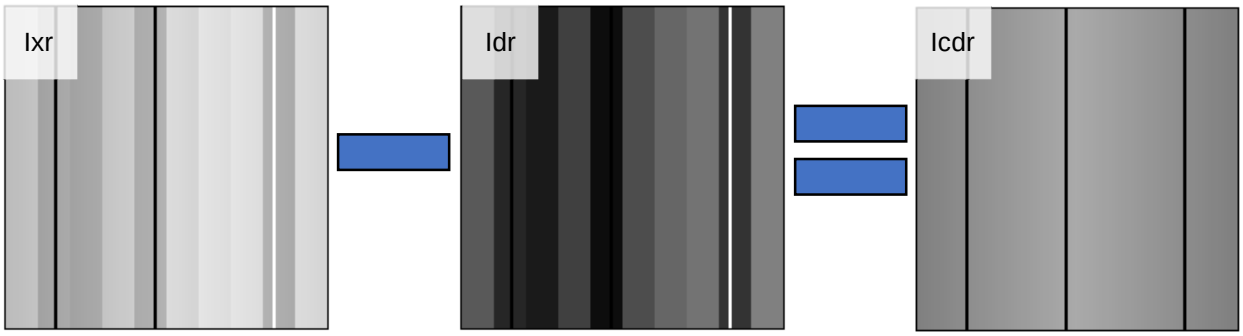


Figure 1-3: Create a reference image for shading correction

1-2. Dark Correction

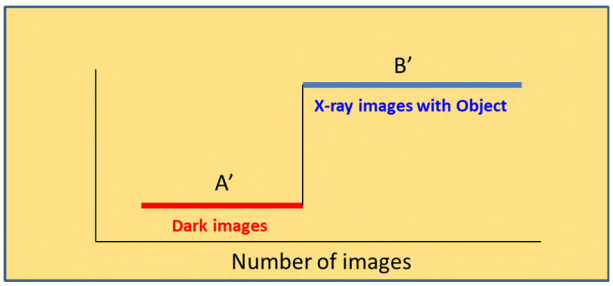


Figure 1-4: Object image acquisition sequence

As shown in Figure 1-4, images are made continuously from dark (with an object) to x-ray emission.

A dark image for dark correction must be acquired immediately before the x-ray imaging.

1-2-1. Preparing a dark image for reference

Create an image Ido (dark image with object) that averages the image of Dark part A' (red line region in Figure 1-4). If the frame rate is changed during imaging, then it will be necessary to acquire a dark image for each frame rate.

1-2-2. Object x-ray image acquisition

Let Ixo (image x-ray with object) be the X-ray image of the object in the X-ray irradiation area B' (blue line region in Figure 1-4).

1-2-3. Execution of dark correction

Subtract Ido from each Ixo to create Icdo (dark corrected image with object).

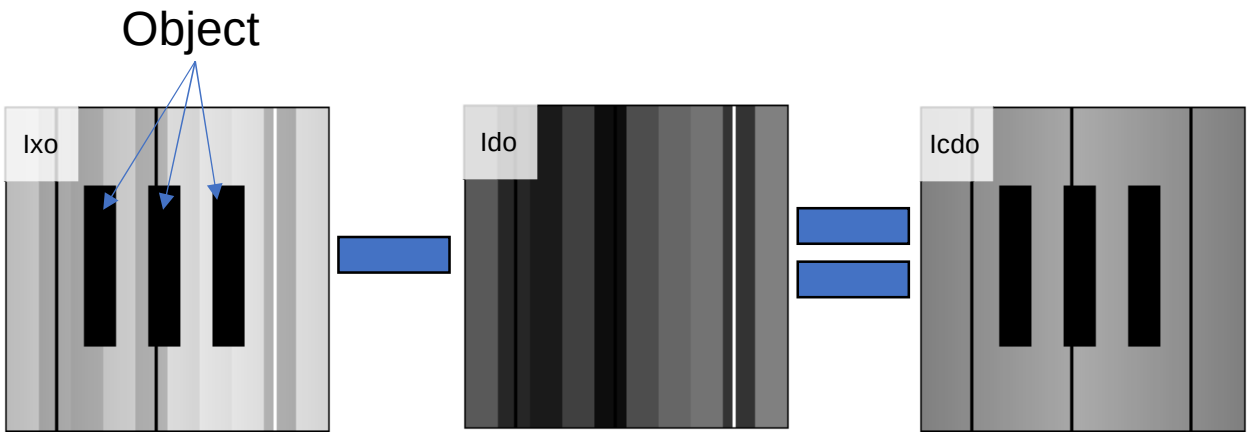


Figure 1-5: Creating a dark-corrected object image

1-3. Shading correction

Divide the dark corrected object image Icdo is divided by the dark corrected reference image Icdr to create Ics (shading corrected image).

$$I_{Cs}(x,y) = c \cdot \frac{I_{cdo}(x,y)}{I_{cdr}(x,y)} \qquad (1-1)$$

C: Average value of Icdr (x,y)

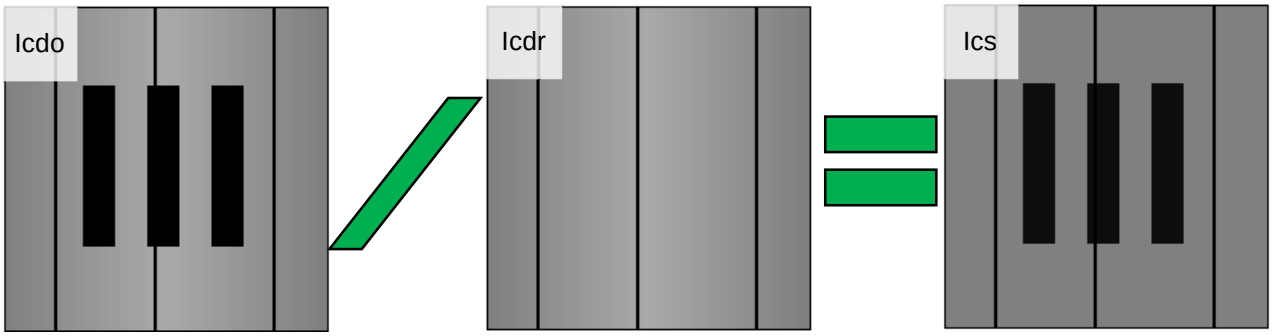


Figure 1-6: Execution of shading correction

1-4. Defect Line Correction

Extract the defect lines from the shading corrected image Ics. Please refer to individual datasheets for definitions of defective lines as it varies depending on the sensor. With the simplest defect line correction, the average output value of neighboring pixels are used to interpolate defect lines.

$$V(p,y) = \frac{V(p+1,y) + V(p-1,y)}{2} \qquad (1-2)$$

V(p,y): Output value of defective lines

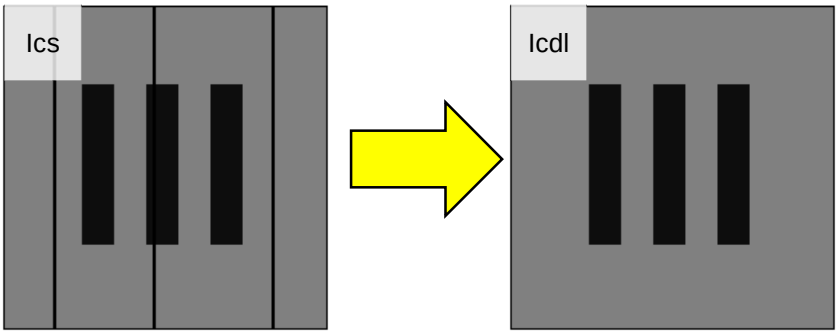


Figure 1-7: Execution of defective line correction

(Icdl: Defect Line Corrected Image)

1-5. Supplement: Number of images averaged

Use at least 50 images to do the averaging in “1-1-1. Preparation of dark images”, “1-1-2. Creation of averaged X-ray images”, ”1-2-1. Preparaing a dark image for reference”. Especially with shading correction, the more images that are used for averaging, the less impact there is from noise. Round the output of the final averaged image to whole numbers.

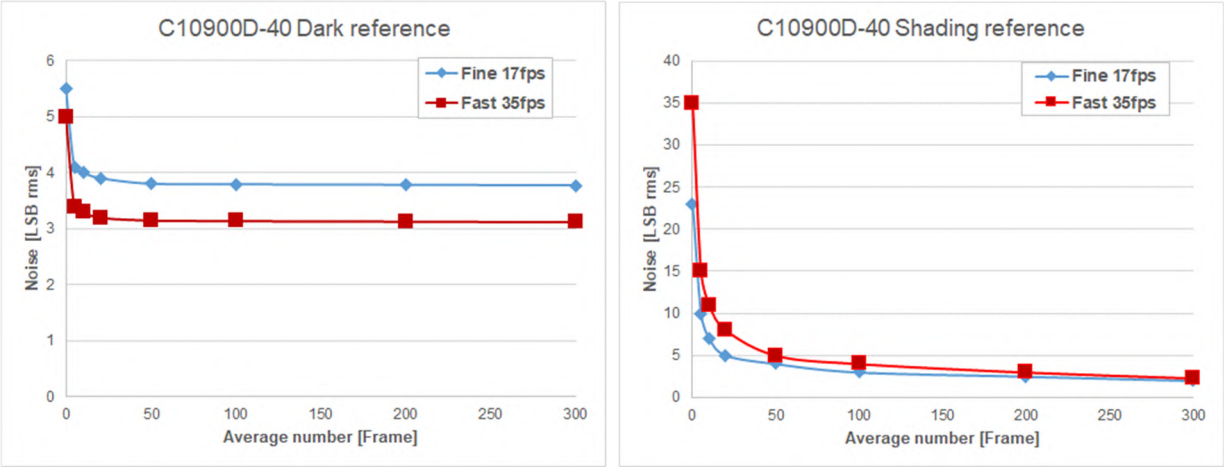


Figure 1-8: Relationship between noise and number of images averaged

2. Precautions when integrating into equipment

This chapter introduces precautions to when integrating sensors into equipment.

2-1. Hardware Precautions

With regard to hardware design, pay attention to the following parameters and take necessary measures on the equipment.

2-1-1. Integration

Beware of the following points when integrating the sensor into equipment.

- **When mounting the sensor to the chassis, use all mounting holes on the sensor to fasten it.**
- **Connect the fastening hole of the sensor to the ground of the device.**
- **Some sensors are heavy, so design the most suitable fastening method when fastening them.**
- **Some sensors have standard X-ray emission angles with respect to the photosensitive area. If this applies to the sensor you are using, then follow the guidelines. Refer to the individual datasheets for details.**
- **The sensor has a guaranteed operating temperature. Do design so that the ambient temperature during sensor operation does not exceed the guaranteed operating temperature range. Also, prevent condensation on the sensor, as it may affect the characteristics and reliability. Refer to the individual datasheets for sensor temperature specifications.**
- **Images may be noisy due to noise conducted/radiated from equipment. Take measures such as grounding, shield processing of cables, and screening noise sources such as motors, then increasing the distance from the sensor.**
- **Turn off the power supply to the sensor when connecting cables and equipment to the sensor.**
- **Do not apply strong stress to the cables connected to the sensor.**
- **Avoid bending the cable near the sensor connector. Take measures such as fixing cables to reduce stress.**

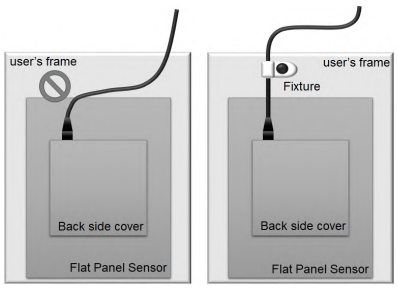


Figure 2-1: Cable fastening example

2-1-2. EMC

Bare-board type sensors are not enclosed in a housing, so the sensor must be shielded to comply with the EMC directives required for equipment. It is effective to make the sensor shield cover the entire sensor including the effective photosensitive part. Typically metal is used for the housing, and carbon fiber reinforced plastic (CFRP) is used for the X-ray emission window to obtain high X-ray transmittance.

Also, cables connected to sensors must be shielded, regardless of whether or not there is a housing. It is effective to use shielded cables or ferrite cores for cable shielding.

Also, external noise may cause noise in the image. It is also important to reduce the impact of external noise by checking if there are any noise sources inside the equipment, and whether there are any ground loops caused by connections between machinery or the way the sensor is grounded. If there are large ground loops or multiple ground loops, the loops may act as a single coil, generating an induced current and causing ground instability.

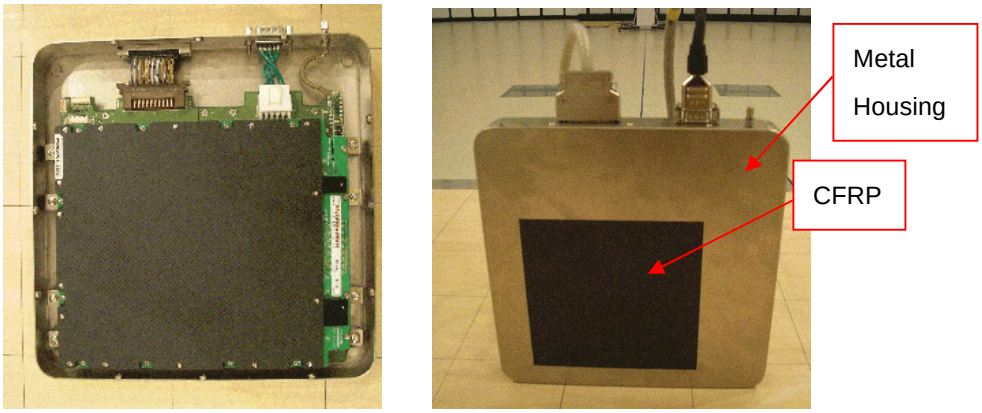


Figure 2-2: Example of sensor shielding (left: housing interior / right: housing exterior)

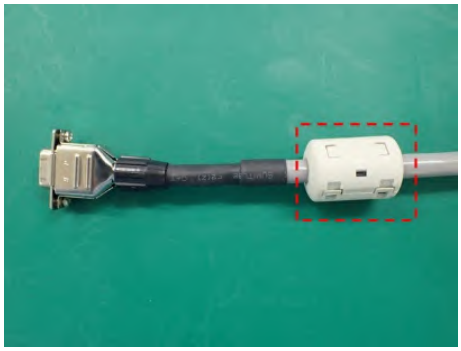


Figure 2-3: Example of shielded cable (red frame: ferrite core)

2-1-3. Timing of power supply

Video output may change (drift) immediately after the power supply is turned on, until thermal equilibrium is reached. Also, the dark image output may change depending on the temperature of the sensor. If the imaging conditions (time after turning on the power supply, sensor temperature) differ between the image subject to correction and the image taken, then it may not be possible to obtain the expected correction effect. Therefore, when providing a power supply to the sensor, it is effective to turn off the power supply (auto power off) when not imaging, or to keep the time from turning on the power to the start of imaging the same at all times.

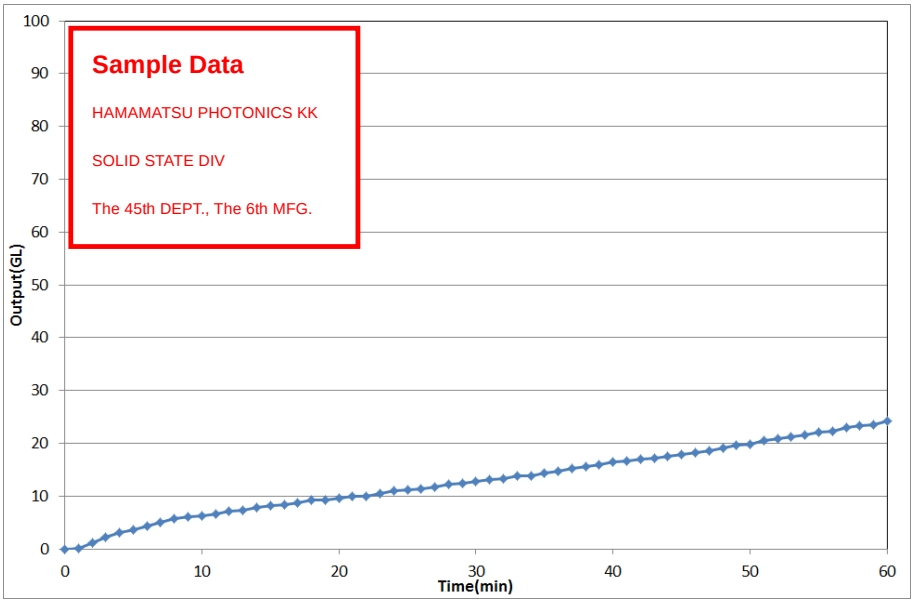


Figure 2-4: Drift example of dark offset output from turning on power supply

2-1-4.Frame Rate

Output of dark images and X-ray emission images from the sensor depending on the frame rate. When acquiring images continuously, it may be impossible to obtain the expected correction effect if the frame rate is different from that of the correction image. For this reason, use a fixed frame rate when acquiring images continuously.

2-2. Software Precautions

With regard to software design, pay attention to the following parameters and take necessary measures.

2-2-1. Order of Image Processing

Image correction is necessary to obtain a higher quality image from the raw image of the sensor. For details, see "1. Image Correction". In some cases, it may also do filter processing such as noise removal. The image quality obtained by these image processing changes depending on the order of processing. Therefore, we recommend the following image processing procedure.

(1) Dark/Shading Correction

(2) Defect Line Correction

(3) Filter Processing (Noise Removal)

For applications that do image reconstruction such as X-ray CT scanners, it is possible to obtain high-quality images by doing reconstruction using images subjected to the above image processing.

2-2-2. Bit numbers of application

For GigE interface type sensors, Hamamatsu's DCAM and other drivers support both 32-bit OS and 64-bit OS. Please check these specifications before creating applications for equipment. Also, when creating an application on a 64-bit OS, make sure to create a 64-bit application. If you create a 32-bit application on a 64-bit OS, you may not be able to maximize your computer's performance.

2-3. Other Precautions

2-3-1. LTPS(Low Temperature Poly Silicon)

Hamamatsu's lineup of Flat Panel Sensors includes not only CMOS type sensors but also sensors that use LTPS technology. By adopting LTPS technology, Hamamatsu has realized an image sensor with a large photosensitive area, which was difficult to fabricate with CMOS types. LTPS has higher carrier mobility than a-Si and can be used to create TFTs with high-speed response. On the other hand, LTPS type has unique operations and characteristics not found in the CMOS type. Beware of the following characteristics when using LTPS type sensors.

■ **Unevenness in sensitivity/dark**

Both the CMOS type and LTPS type use Si as the base material, but their image sensor manufacturing methods and structures are different. Therefore, raw images from the LTPS type have fixed pattern sensitivity unevenness and dark image unevenness. However, these fixed patterns can be improved with dark correction and shading correction. For information on correcting images, see "1. Image Correction".

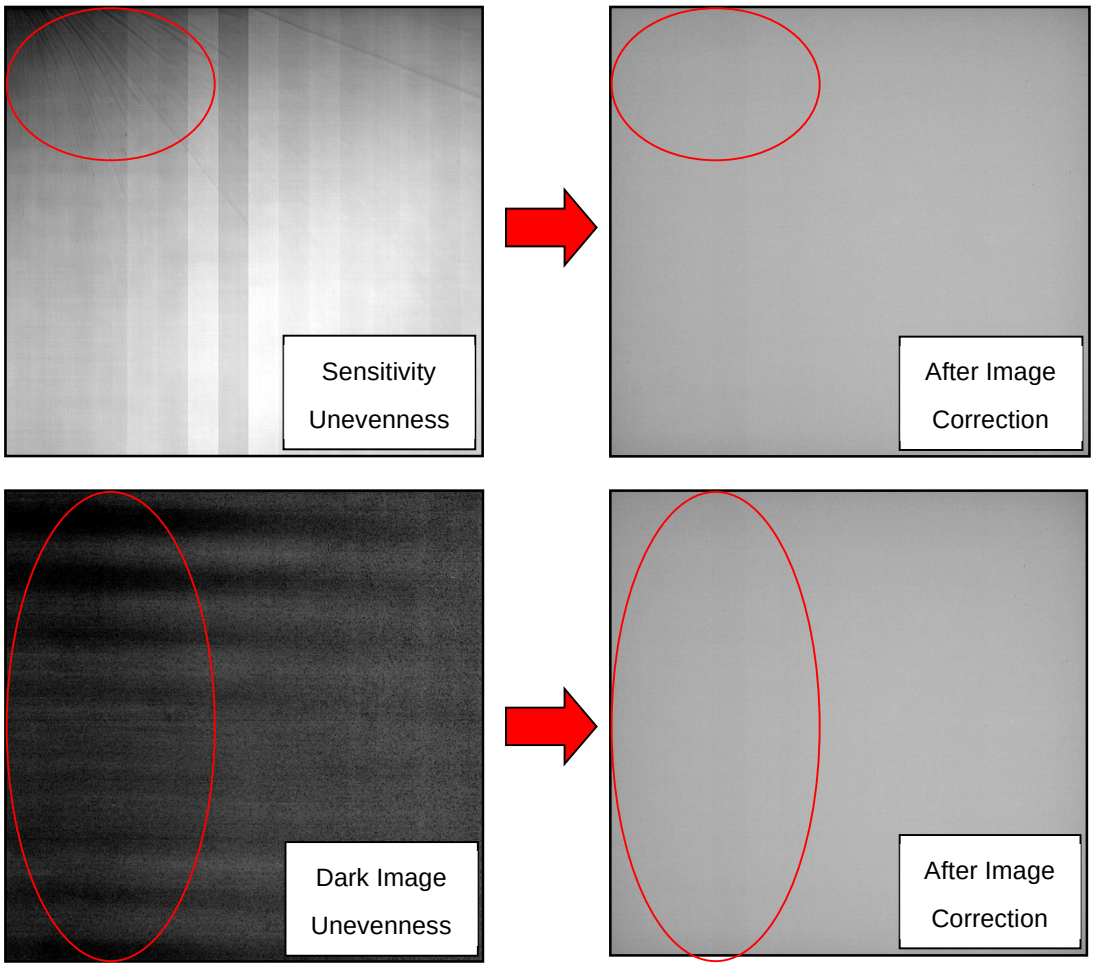


Figure 2-5: Examples of sensitivity unevenness and dark image unevenness

■ Blinker Pixels

The LTPS flat panel sensor involves some “Blinker pixels” which are defined as the pixels whose output fluctuation is large compared to the normal noise level though most of pixels are normal. The total number of Blinker pixels is very small compared to the all pixels of the LTPS panel. Depending on how you set the threshold level of Blinker pixel, the number of ratio for the blinker pixels was around 0.01%. It is recommended that the Blinker pixels are calibrated as the general defect pixels.

• Root cause of Blinker

LTPS is produced by laser annealing a-Si. There is a variation in the size of Poly-Si produced by laser annealing. This variation makes interface state, some carriers are captured at that state. It cause Blinker.

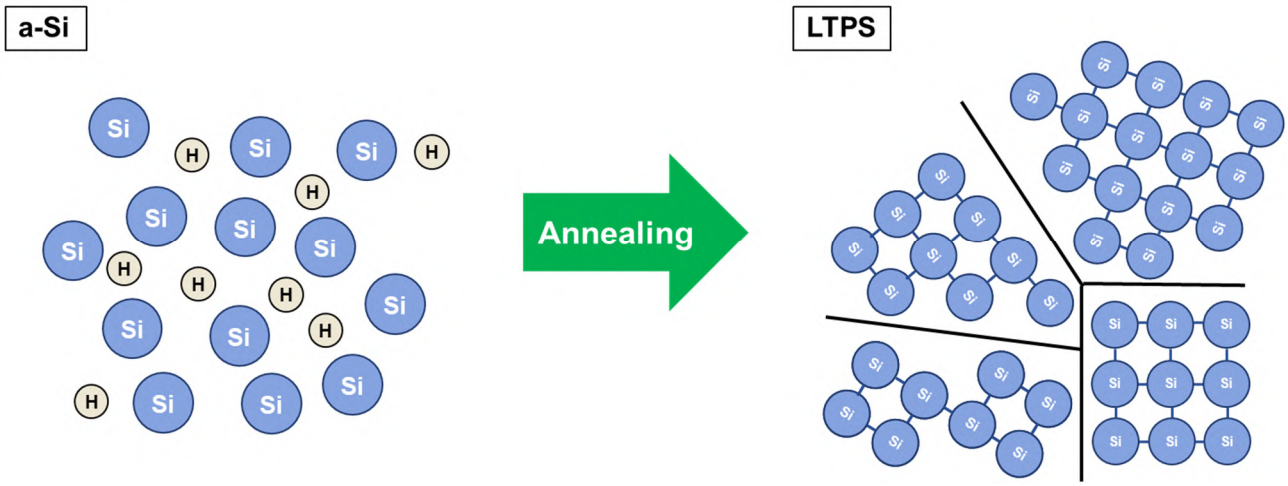


Figure 2-6: LTPS composition

• **Blinker pixel types**

There are two types of Blinker pixels: the type that occurs suddenly (Type A) and the type that occurs continuously for a certain period (Type B).

<Type A>

The blinker is occurred suddenly, and its output value return to normal output relatively quickly.

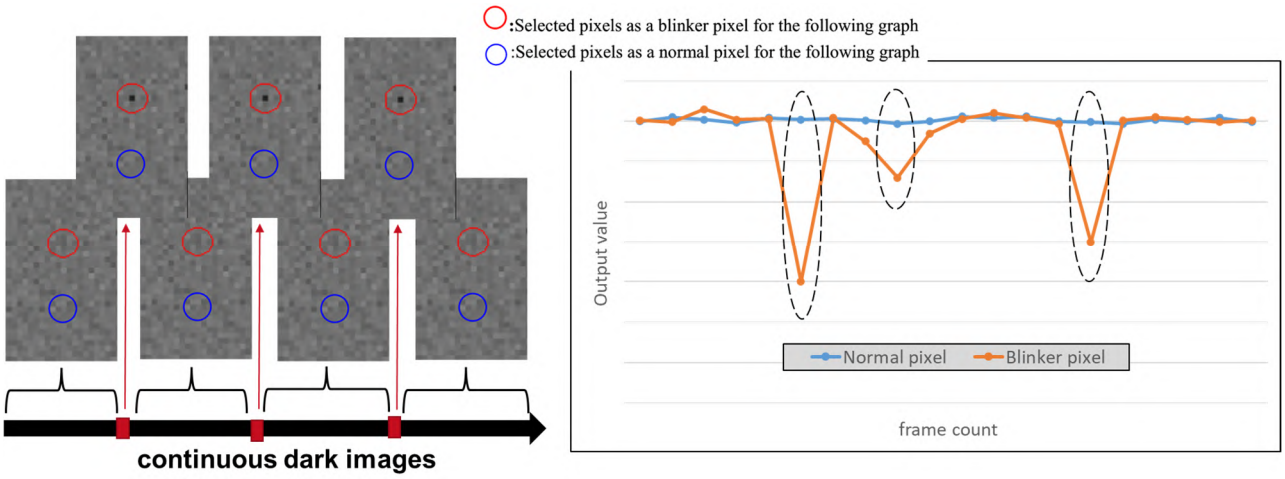


Figure 2-7: Blinker type A

<TypeB>

The blinker is occurred in frames for a certain period, after that its output value return to normal output.

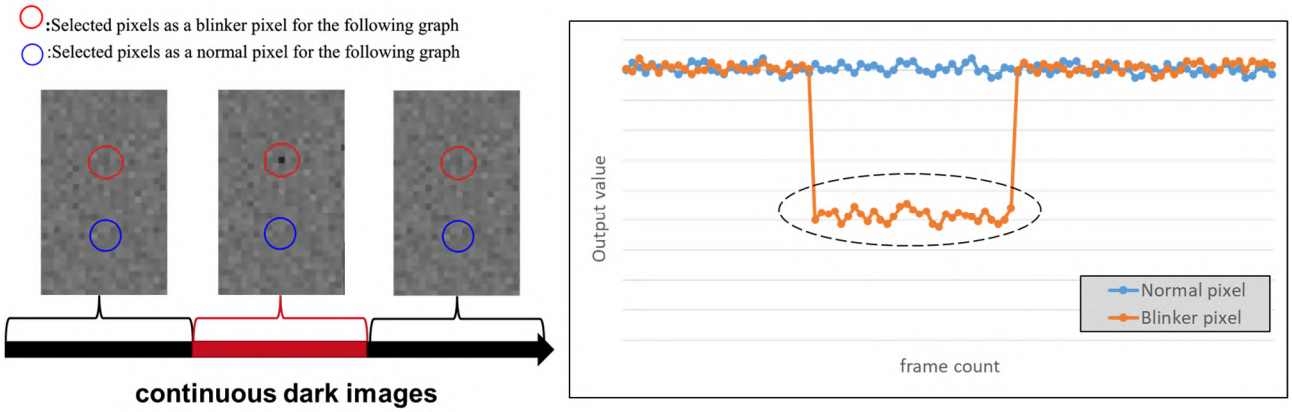


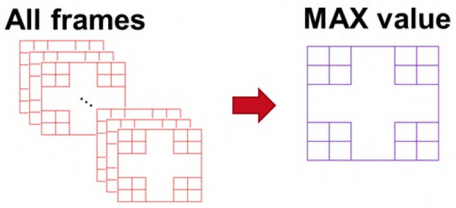
Figure 2-8: Blinker type B

• Method of detecting Blinker pixels

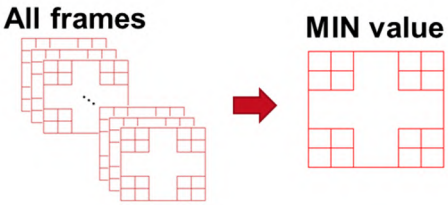
Basically, the Blinker pixels can be identified by acquiring the continuous dark images. We recommend to acquire several hundreds or thousand of continuous dark images because some of the blinker pixels show low frequency fluctuation. The number of continuous dark image depend on your required image quality level.

<Type A>

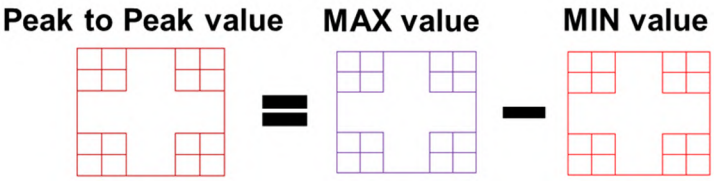
1. Calculate Maximum value of all frames for each pixel.



2. Calculate Minimum value of all frames for each pixel.



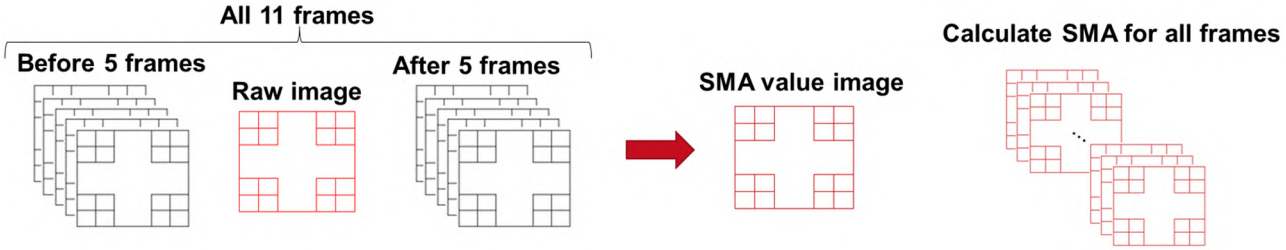
3. Calculate Peak to Peak value (Max value – Min value) for each pixel.



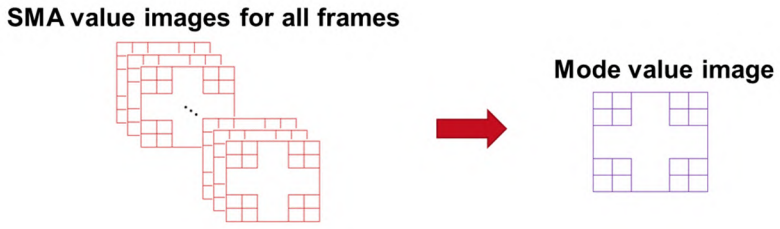
4. If “Peak to Peak value” is higher than some value (Threshold), that pixel is judged as the Blinker pixel. Threshold level depends on your required image quality level.

<Type B>

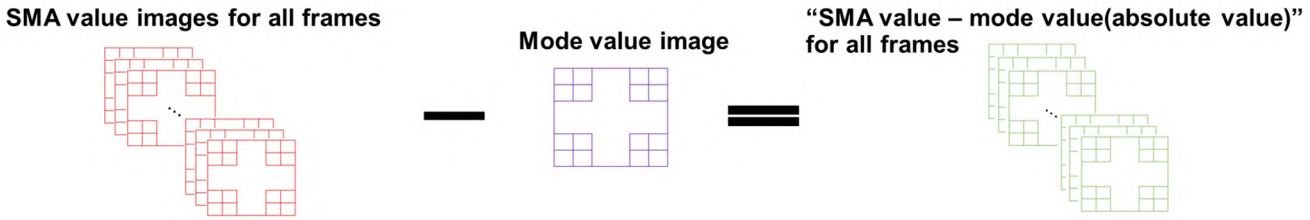
1. Calculate SMA (Simple Moving Average) value of 5 frames before and after for each pixels.



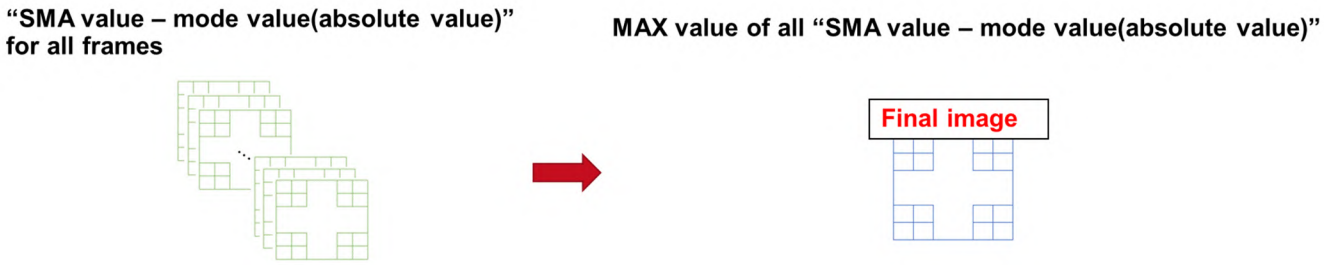
2. Calculate mode value of all SMA frames for each pixels.



3. Calculate “SMA value – mode value(absolute value)” for each pixels for all frames.



4. Calculate MAX value of all “SMA value – mode value(absolute value)” for each pixels.



5. If “Final image value” is larger than some value (Threshold), that pixel is judged as the Blinker pixel.
Threshold level depends on your required image quality level.

- **Support for Blinker pixels**

If you have any questions or concerns regarding Blinker pixels, please contact us. We will provide you with the utmost support.

If you request to us, we can provide to you “Blinker Map” detected by “I. Method” or “II. Method” in our production line. In that case, you don’t need to detect Blinker pixels, just correct them in “Blinker Map”. Currently, we are developing Blinker detection and correction software that do not need to prepare Blinker Map in advance from many images obtained in advance. We will contact you as soon as there is progress.

2-3-2. Image Reconstruction

With applications that reconstruct a single image (CT image or summing image) from multiple captured images, such as in X-ray CT scanner imaging or panoramic imaging, the image quality of reconstructed images can vary greatly depending on the quality of raw images obtained during imaging. The panoramic image concept is shown in Figure 2-9. In order to improve the image quality of such reconstructed images, please refer to the following measure examples. However, it depends on the emission conditions of each piece of equipment and the design of the equipment, so consider the best measures for the equipment in question.

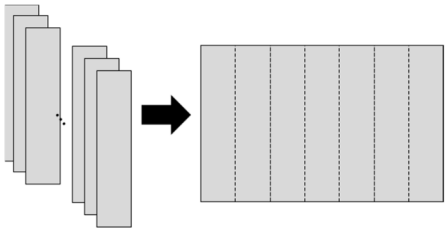


Figure 2-9: Schematic of a panoramic image

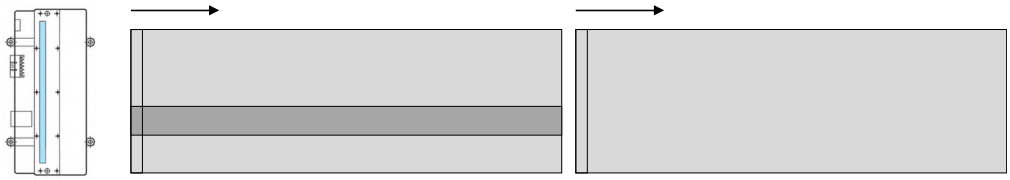


Figure 2-10: Differences in image quality before and after taking measures to improve image quality

(left: before measures / right: after measures)

■ **Countermeasure Example**

(1) Increase the X-ray exposure dose.

Doing this increases the output of the sensor and suppresses the impact of noise in the image. However, beware that radiation exposure of the object will also increase.

(2) Select an X-ray source with a stable X-ray exposure dose.

Doing this makes it possible to suppress output fluctuations caused by fluctuations in the radiation source.

(3) Use a power supply with small ripple noise.

This makes it possible to suppress noise (scroll noise, etc.) originating from the power supply.

(4) Use a constant frame rate while imaging.

Dark offset output varies with frame rate. For this reason, if you change the frame rate dynamically, accuracy of dark correction will decrease. If you dynamically change the frame rate during imaging, perform dark correction for each frame rate.

(5) Reacquire the reference image for correction periodically.

Sensitivity of the sensor degrades due to exposure to x-rays, so periodically reacquire reference images for shading correction.

(6) Do image processing using floating point numbers instead of integers.

Decimal information is very important for low output images. Therefore, high-precision image processing can be done by calculating with floating point numbers.

(7) Do image reconstruction using only the areas exposed to x-rays.

If the collimator is used to partially screen the effective photosensitive part, image reconstruction should be done using only the area exposed to x-rays (Figure 2-11). As a reference image for shading correction, we recommend using an image obtained by exposing x-rays to the entire effective photosensitive part without using a collimator.

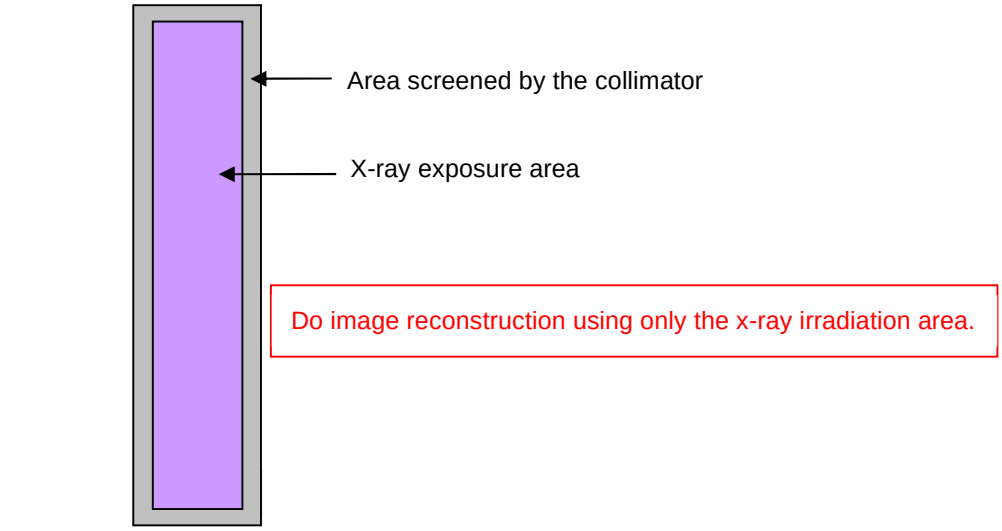


Figure 2-11: Collimation example of C10500D and C10502D series

(8) Do dark correction by estimating the dark offset output during x-ray exposure.

For dark correction, there is also the method of calculating the dark offset output during exposure from the dark offset output before and after x-ray exposure, and using them to do dark correction. With this method, dark correction is done by linear approximation of the dark offset output during X-ray exposure from the dark offset output before and after exposure.

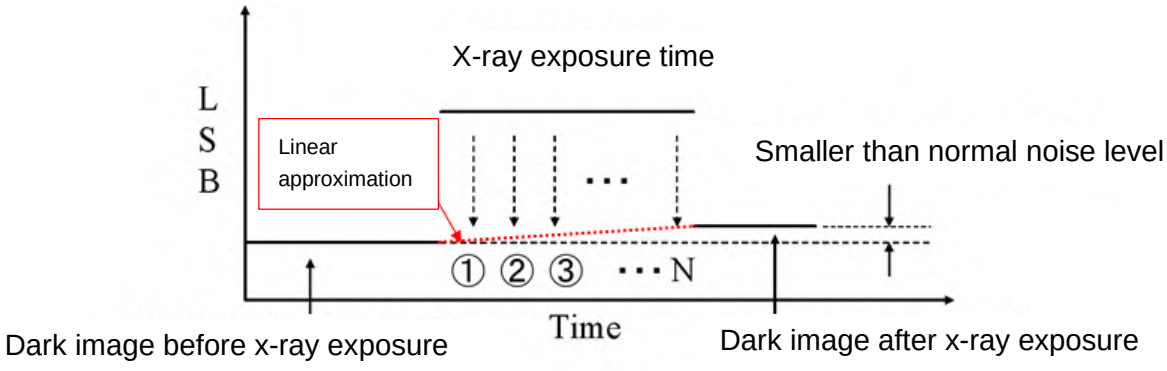


Figure 2-12: Estimation of dark offset output during x-ray exposure

(9) Decide when to start imaging with consideration for drift.

Drift is likely to affect applications with small signal level, such as when the exposure dose is low or when imaging at high speed, so take measures to reduce the impact of drift by referring to "2-1-3. Timing of power supply".

2-3-3. When an error occurs

When an error occurs in a device equipped with this sensor, the raw image output from the sensor is extremely important for determining whether the sensor is the cause. The state of the sensor cannot be confirmed with reconstructed images such as CT images. If the raw images are available, it may be possible to check the state of the sensor. Therefore, when creating applications, we recommend implementing a function that saves raw images and the image used for each correction within a certain period of time or when an error occurs.

Revision history

Revision date	Revision	Revision details
October 1, 2022	E01	First edition
April 1, 2024	E02	Added detailed description of Blinker pixel

For questions or consultations about our products, please use the inquiry form or call the nearest sales office.

Inquiry: https://www.hamamatsu.com/all/en/support/inquiry.html

HAMAMATSU PHOTONICS K.K.

Solid State Division 1126-1, Ichino-cho, Chuo-ku, Hamamatsu City, Shizuoka Pref., 435-8558, Japan