Grid-like contrast enhancement for bedside chest radiographs acquired without anti-scatter grid

Philips SkyFlow

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Bedside chest radiography is the examination of choice for patients who cannot undergo routine upright chest radiography because of their age or general health status [1-3]. It is an important and well-established diagnostic tool for the examination of patients with cardiopulmonary symptoms and patients who are critically ill. It is also an indispensable tool to verify correct positioning of catheters, tubes and lines, and to avoid complications due to misplacements.

Bedside chest radiographs can be acquired with or without an anti-scatter grid. Using a grid may improve image contrast, although it is frequently avoided in clinical practice, due to dose considerations, beam alignment difficulties, and a more complicated workflow[2]. Also, structures appearing from the (usually stationary) grid may interfere with diagnostic details[4]. Unfortunately, the image quality of non-grid chest images is frequently compromised by a large amount of scattered radiation, causing a significant loss of image contrast. The images may appear flat, and even with manually adapted viewing settings for digital chest radiographs, image representation may be poor.

With SkyFlow technology, Philips offers a novel, patient-adaptive, digital image processing that provides grid-like image contrast enhancement for bedside chest radiographs acquired without an anti-scatter grid. Based on a physical model and Monte-Carlo simulations, SkyFlow compensates for the effect of scattered radiation by an estimation of the scatter signal and subsequent partial subtraction. The technology provides contrast enhancement that automatically adapts to the patient, resulting in an image impression almost indiscernible from an image acquired with a grid.

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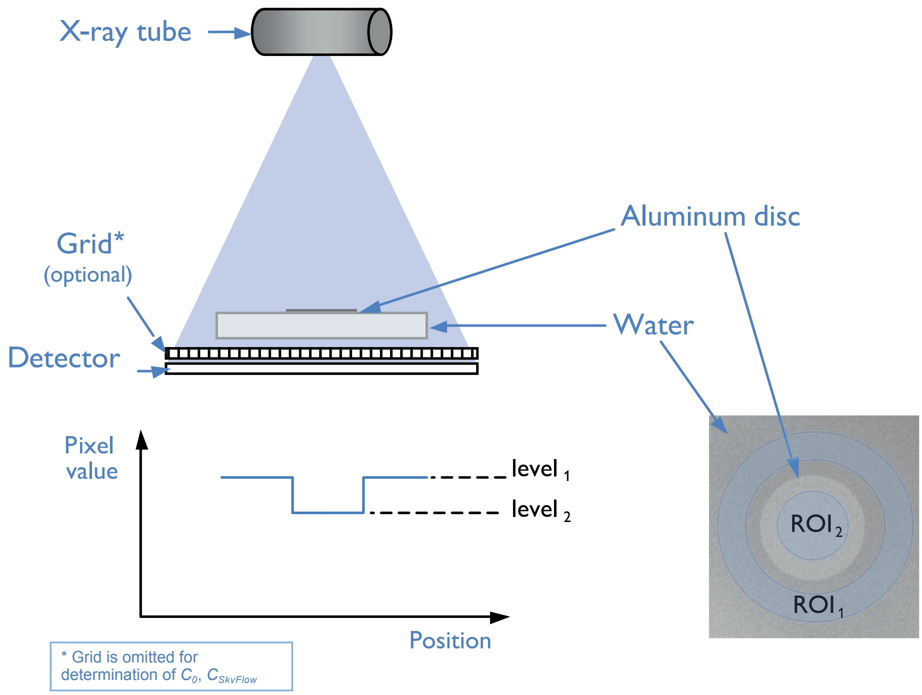
Determination of the contrast improvement factor



$$C = \frac{\text{level}_1 - \text{level}_2}{\text{level}_1} \qquad CIF_{Grid} = \frac{C_{Grid}}{C_0} \qquad CIF_{SkyFlow} = \frac{C_{SkyFlow}}{C_0}$$

Figure 1: For the determination of the contrast improvement factor (CIF), an image is acquired which contains a contrast step generated by a thin aluminum disc on top of water. Two regions of interest (ROI_1 and ROI_2) are defined in the image, one outside and one within the attenuated area of the aluminum disc. In the definition of contrast (C), level_1 and level_2 are the mean pixel values of the regions of interest ROI_1 and ROI_2. The contrast improvement factor is defined as the ratio of the improved contrast (C_{Grid}: contrast achieved with hardware grid; $C_{SkyFlow}$: contrast achieved with SkyFlow) and the reference contrast (C_0: contrast achieved without grid or SkyFlow). The CIF determined in this way may be measured for arbitrary scatter conditions as generated by different water heights. The contrast improvement ratio K according to IEC [7] corresponds to a CIF determined under standard scatter conditions.

Scattered radiation and anti-scatter grids

When X-rays penetrate a patient, scattered radiation is generated. The scattered image signal recorded by the X-ray detector is a slowly varying background signal accompanied by noise, superimposed on top of the primary image signal. While the primary signal reflects the physical attenuation properties of the body and provides the diagnostically important contrast information, the scatter signal is an interfering signal, reducing primary contrast and causing the image to appear flat.

Anti-scatter grids, positioned between the patient and the digital X-ray detector, are a conventional tool used to reduce scatter. Their main property is to attenuate scattered X-rays, while primary X-rays pass preferentially. This results in a contrast improvement which may be characterized by the 'contrast improvement factor' (Figure 1).

Workflow challenges when using anti-scatter grids

To avoid image artifacts and to minimize the absorption of primary radiation, grids must be properly positioned and aligned with respect to the X-ray beam. For free exposures such as bedside chest radiographs, this is a time-consuming and error-prone procedure, as there is no fixed geometry [5]. Therefore, the benefits of grid use are difficult to achieve in this situation. In addition, the extra weight and bulk of an attached grid hampers workflow in a clinical environment, such as an intensive care unit.

SkyFlow: Scatter estimation and grid-like correction

SkyFlow is based on Monte Carlo simulations of the passage of X-rays through water, and a calibrated correction step, which is tailored to mimic the properties of an anti-scatter grid.

Step 1 – Scatter estimation

The amount of scattered radiation generated in an object depends upon its thickness and composition. The total scatter signal present in an image of the object can be thought of as a superposition of scatter contributions generated by thin pencil-like X-ray beams passing through the object. These contributions are called scatter kernels. In order to estimate the scatter for a given image, SkyFlow selects the appropriate kernel for each pencil beam from a database, which is pre-calculated in a Monte-Carlo simulation. The selection is based on the local image signal and its spatial gradient.

The superposition of all scatter kernels in the image area then yields a precise estimate of the total scatter image [6]. Since the scatter image is a smoothly varying image signal dominated by low frequency components, the scatter estimation is based on a low-resolution version of the original image, leading to very short computation times. In a final step, the scatter image resulting from the estimation step is then scaled up to full resolution.

Many hours of simulation computing were required to establish the database of scatter kernels for SkyFlow, making it self-adapting to patients with different constitutions. Since this computational expense has been spent in advance, the overall time-to-display for images is preserved in practical work. In this way, SkyFlow benefits from the precision and accuracy of the Monte Carlo technique and delivers a computationally efficient correction tailored to each patient.

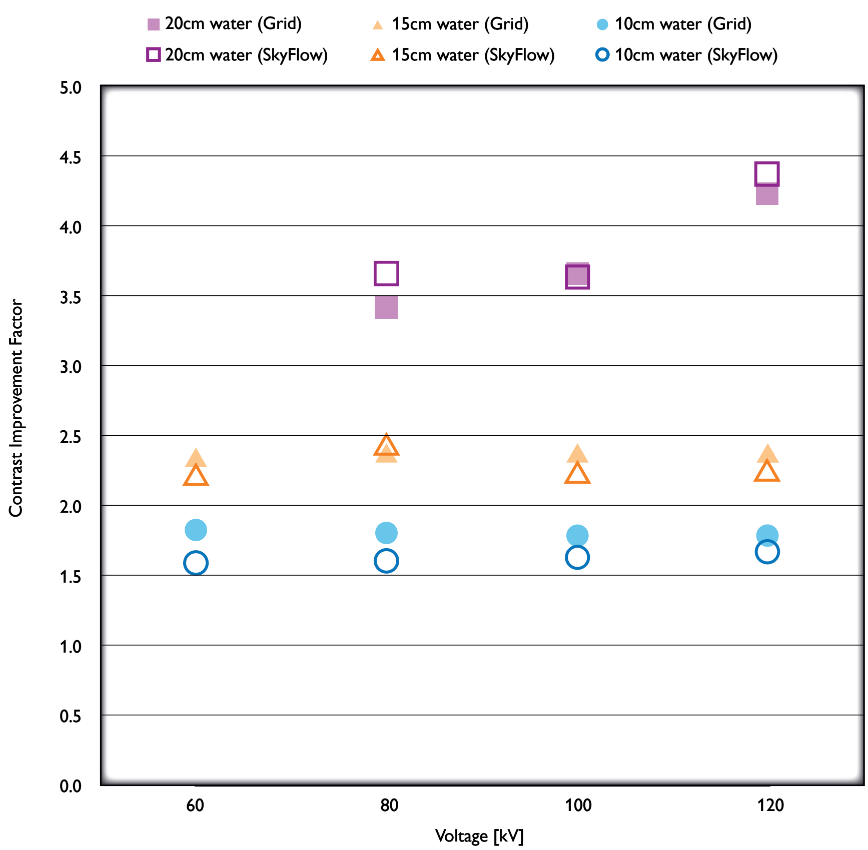


Figure 2: Experimental verification of the calibration of the SkyFlow processing. Contrast improvement factors were determined for different water heights and tube voltages. Filled symbols: Contrast improvement factors measured with the grid. Empty symbols: Contrast improvement factors obtained with SkyFlow.

Step 2 – Grid-like scatter correction

The resulting scatter corrected image, with enhanced contrast, is obtained by subtracting a grid-adapted scatter image from the original detector image.

A calibration is then needed to tune the contrast enhancement achieved with SkyFlow to the level achieved with a real grid. The calibration procedure serves to calculate a scatter image adapted to the grid properties, meaning that this image only contains the amount of scatter that is physically removed by a grid. It is important to note that a grid does not remove the entirety of scattered radiation, but only a part of it. This means that a grid restores primary contrast only to a certain extent. Typical quantities related to the grid's ability to restore contrast are its contrast improvement ratio K and selectivity Σ. Both quantities are defined in the IEC standard 60627 [7].

The algorithm used for SkyFlow is parameterized using a single parameter, which is closely related to the grid selectivity Σ. In principle, this steering parameter may be selected to match the contrast enhancement properties of any given hardware grid in different scatter conditions. The appropriate parameter value is determined by a physical calibration measurement.

The calibration for SkyFlow is carried out with a typical anti-scatter grid for bedside chest examinations (ratio 1:8) and water as patient-equivalent material, generating scattered radiation. With the calibration data at hand, a grid-adapted scatter image is calculated which provides an estimate of the scatter signal physically removed by the grid. In the correction step, the adapted scatter image is subtracted from the original detector image to obtain the resulting scatter corrected image.

It has been verified experimentally that SkyFlow improves contrast like an anti-scatter grid by a measurement of contrast improvement factors. The verification experiments were carried out at different scatter conditions and for a wide range of tube voltages (Figure 2).

Just as an image acquired with a grid, the resulting SkyFlow image is then passed to the Philips UNIQUE algorithm for subsequent multiscalar image processing. An overview of the image processing flowchart for SkyFlow is given in Figure 3.

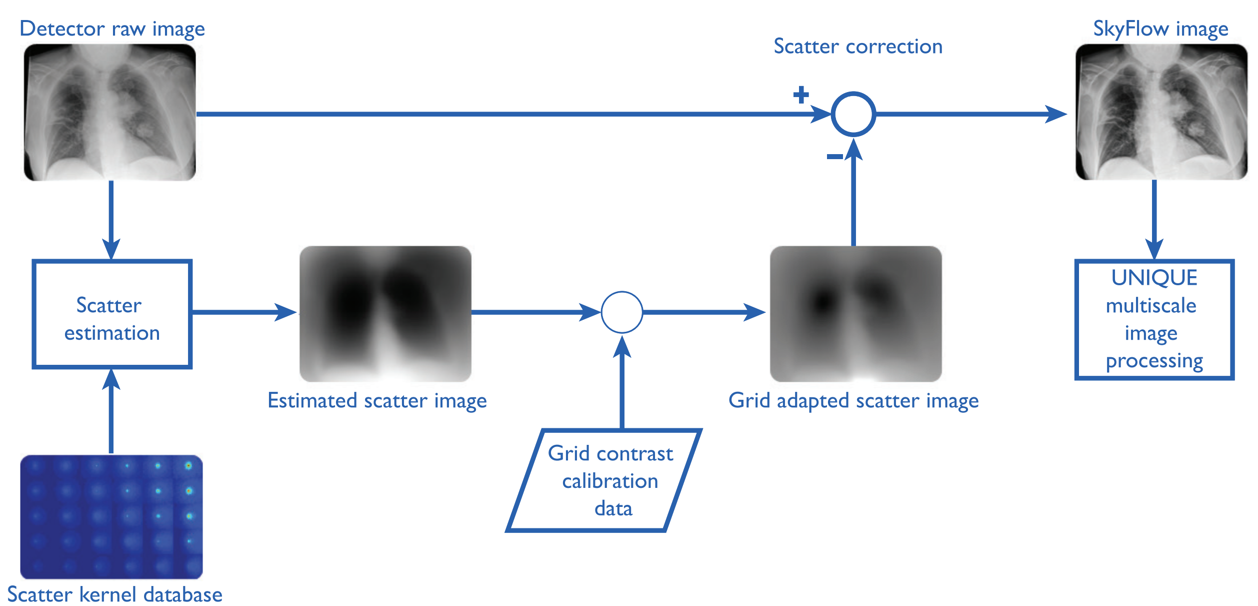


Figure 3: High-level flowchart of SkyFlow.

Phantom experiments

To demonstrate the similarity between the contrast enhancement of a grid and the SkyFlow processing, radiographs of a thorax phantom[1] were acquired both with and without a stationary grid. The use of additional chest plates with the phantom allows it to mimic patients of different sizes.

Three aluminum discs were positioned in the lung, the retrocardial, and the abdominal areas. The image contrast generated by the discs was measured in the grid image and in the non-grid image. The ratio of these contrasts (the contrast improvement factors achieved with the grid, CIF_{Grid} , see Figure 1) was determined for each anatomical area and phantom size.

Subsequently, the non-grid images were processed with SkyFlow[2]. The contrasts generated by the discs were measured before and after processing. The CIFs achieved by SkyFlow were calculated and compared to the CIFs achieved by the grid (Figure 4).

The agreement between the CIFs obtained with SkyFlow and with the grid is strong (maximum deviation: -7.2%), both for the different anatomical positions and for the different phantom sizes. This demonstrates that SkyFlow is able to restore the image contrast of a non-grid image to the level of a grid image.

[1] Multipurpose Chest Phantom "Lungman", Kyoto Kagagu, Kyoto, Japan

[2] Since the phantom is made of polyurethane, a steering parameter calibrated to this material is used in this particular case.

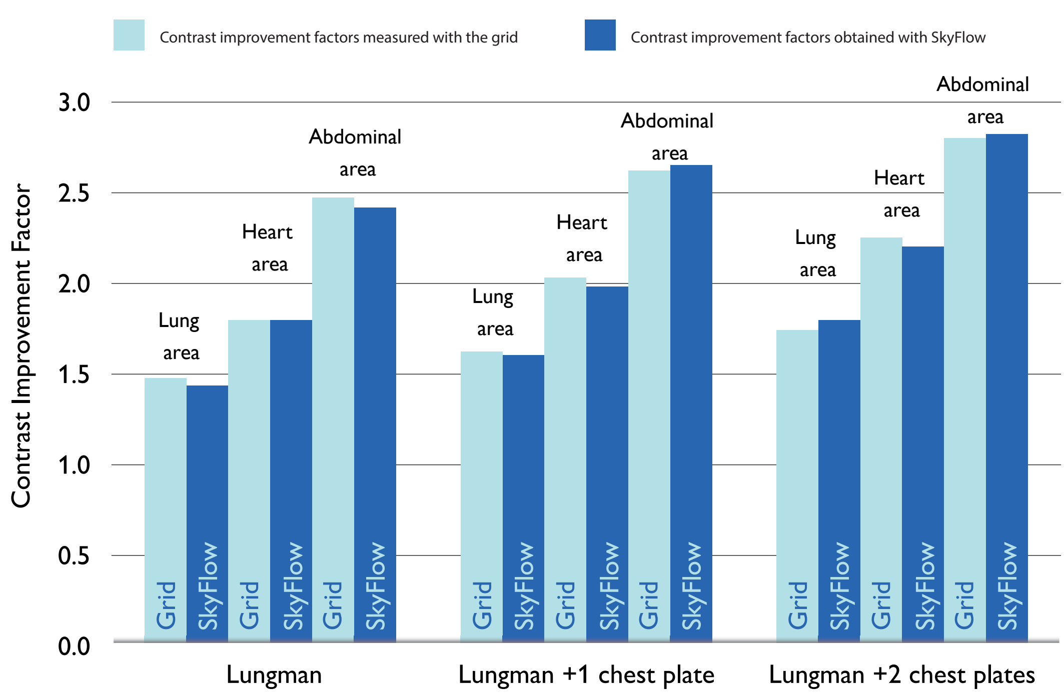
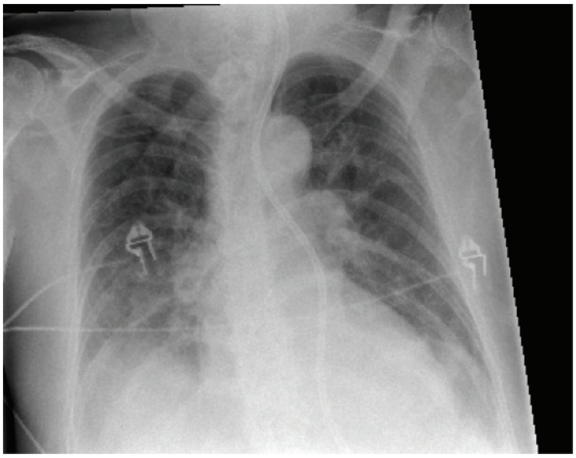
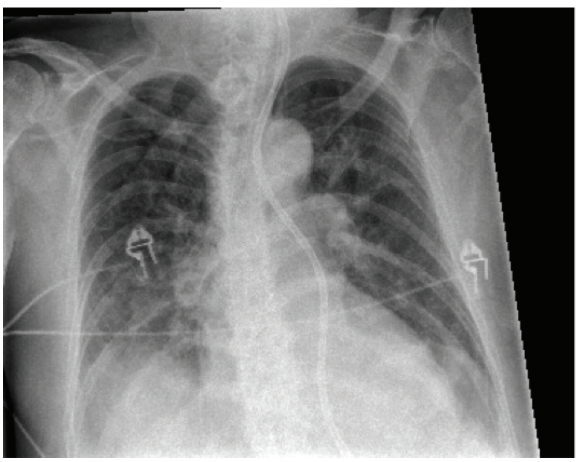


Figure 4: Contrast improvement factors determined on a thorax phantom at 90 kV tube voltage.

Figure 5: Example of bedside chest examinations.



Reference image acquired without grid.



Same exposure, but processed with SkyFlow.

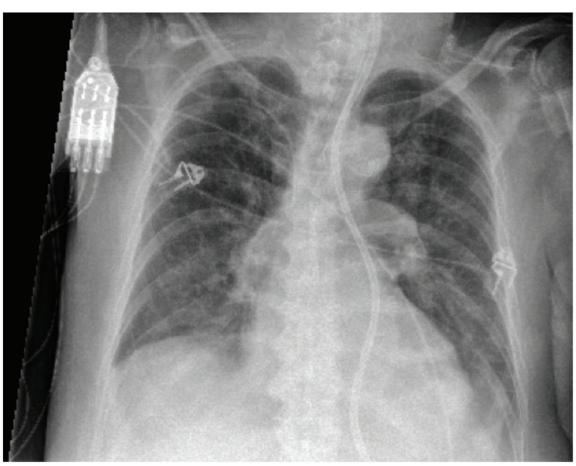


Image of same patient acquired on a different day. A grid was used, and X-ray dose was increased by a factor of 1.6.

Clinical experience

In an observer study significant improvements of the visibility of five image quality features were observed using SkyFlow compared to conventional image processing. The SkyFlow technology yields significantly higher image quality for grid-less bedside chest radiographs[8]. As an example, Figure 5 provides a comparison of clinical images acquired in this study. A conventionally processed non-grid image is shown together with the same exposure processed with SkyFlow, demonstrating the contrast gain. For comparison, a grid image of the same patient (acquired at 1.6fold increased X-ray dose on a different day) is also shown. With regard to an appropriate required diagnostic image quality the SkyFlow image is comparable to the grid image and SkyFlow does not generate a disturbing artificial noise impression. SkyFlow offers a true alternative to traditional use of anti-scatter grids for improved quality.

Conclusion

With SkyFlow, Philips offers a novel technology allowing clinicians to combine the ease of the grid-less acquisition workflow with the contrast quality of a grid image for bedside chest radiography. SkyFlow is based on a detailed model calculation of the scatter signal and a calibrated correction. Without any user interaction or implications on workflow, SkyFlow enhances image contrast as a grid would. For a given chest image, contrast enhancement is stronger in areas with a high scatter fraction (e.g. mediastinum and abdomen) and weaker in low-scatter areas (e.g. lung). For images of different patients, contrast enhancement is stronger for obese patients than for slim patients. In conclusion, SkyFlow supports an efficient workflow by providing a consistent grid-like image impression for a wide range of patient types, which is available instantly.

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Glossary

CIF	Contrast Improvement Factor
K	Contrast Improvement Factor under standard conditions IEC 60627[7]
Σ	Grid selectivity according to IEC 60627[7]

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