Vascular

Enhanced Functionality of High-Speed Image Processing Engine – SUREengine PRO –

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1. Introduction

In recent years, digital cardiovascular angiography systems have been mainly adopted for PCI and other interventional procedures. Shimadzu develops its systems with the aim of supporting safer treatments and quicker treatments. Distortion-free direct-conversion flat panel detectors were incorporated from 2003 to achieve high image quality that supports safer treatments. The SUREengine (Shimadzu Ultimate Realtime Enhancement) realtime, high-speed image processing engine was introduced from 2008 into new systems where high-speed operation is achieved. SUREengine increases the sharpness, contrast, and graininess of fluoroscopy and radiography dynamic images and simultaneously increases operation speed to support quicker treatments.

Extremely thin stents have been adopted for clinical applications in recent years. As such fine stents are difficult to see, interventional procedures using them are extremely complex and take a long time. Consequently, there is a demand for new digital image processing technologies to clearly view fine stents at a low exposure dose.

Against this background, two functions were added to SUREengine: automatic optimization of the image processing parameters according to the patient's body shape, the imaged area, and the C-arm geometrical angle (clinical angle) information for radiography and fluoroscopy; and image enhancement by pattern recognition (noise elimination and contrast enhancement). We named these two functions PRO (Pattern-Recognition-Optimizer). PRO improves the visibility of fine stents. This paper describes the operating principle of SUREengine PRO and provides some application examples.

2. Properties Determining Fluoroscopic and Radiographic Image Quality

Table 1 shows the properties that determine the quality of X-ray images.

Property affecting image quality		Item	Target	Sample images: Good		Sample images: Bad
Sharpness (spatial resolution)		Wire visibility, continuity of wires, etc.	Wire clearly visible. Continuous with constant thickness		⟺	
		Stent visibility	Stent structure clearly visible		⟺	
Graininess (noise intensity)		Graininess of overall image	Good graininess. High-density image clearly showing low-contrast objects		⟺	
Visibility (contrast)		Image tone	Uniform image with no conspicuous dark areas due to poor X-ray transmission		⟺	
		Blood vessel visibility	Borders of blood vessels clearly visible		⟺	
Dynamic image persistence (time response)		Persistence	No persistence (after image) due to motion		⟺	

Table 1 Properties Determining X-Ray Image Quality

Four properties affect the image quality: sharpness (spatial resolution), graininess (noise intensity), visibility (contrast), and dynamic image persistence (time response). They are interrelated. Sharpness (spatial resolution) and graininess (noise intensity) are inversely related: increasing the sharpness (spatial resolution) decreases the graininess (noise intensity). Applying time-recursion (integrating filter) to dynamic images improves the graininess (noise intensity) and visibility (contrast) of areas with little movement but results in persistence (time response) that detracts from image quality in areas with movement. Consequently, optimizing these four properties can produce good fluoroscopic and radiographic images.

3. Support for Safe Interventional Procedures

Supporting safer treatments and quicker treatments requires the establishment of both lower exposure dose and higher image quality, which are mutually contradictory. In this context, "higher image quality" means optimizing all four properties above. To achieve this and always deliver the optimal images requires changing the image quality of the system according to the examined area (head, heart, abdomen, lower extremities), type of procedure (PCI, CAG), and type of imaging (fluoroscopy, radiography, DSA, RSM-DSA, etc.).

The internal parameters for digital image processing are changed and individually optimized according to the examined area, type of procedure, and type of imaging. The parameters are automatically optimized in real time according to the patient's body shape, the C-arm geometrical angle (clinical angle) and X-ray conditions used for examination.

Fig. 1 shows the flow chart for digital image processing and an outline of the newly developed function to automatically optimize the parameters in real time.

The automatic parameter setting function adjusts the X-ray conditions, C-arm angle, SID conditions, examined area, type of examination, and patient information. Noise suppression, contrast enhancement, dynamic range compression, and offset and gain processing automatically change the parameters to perform optimal image processing.

The parts in the thick boxes are the newly developed automatic functions.

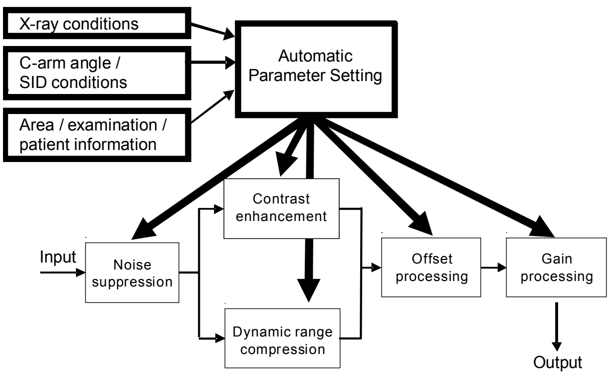


Fig. 1 Flow Chart for Digital Image Processing

4. Application of Pattern Recognition Technology

To optimize the four properties – sharpness (spatial resolution), graininess (noise intensity), visibility (contrast), and dynamic image persistence (time response) – and achieve high image quality requires improvements to the noise characteristics, which are common to all four properties. We developed a new noise elimination filter using pattern recognition based on a new filter algorithm that enhances the graininess (noise intensity) without reducing the sharpness (spatial resolution).

The operating principle is shown in Fig. 2. Initially, the features are extracted from the input image and the structural patterns are analyzed. Continuous structures such as catheters, wires, and stents are extracted as observation targets. Then, an anatomical database, which is based on the anatomical information of human body, is used to separate the background comprising human tissues from other background, as in Fig. 3. The structural pattern of the background of the overall image is analyzed to extract the non-continuous, non-structural objects from the image and eliminate them as noise. The initially separated catheters, wires, and stents are enhanced and finally recombined with the noise-eliminated background and output as a synthesized image. Noise reduction technology using pattern recognition performs this series of operations in real time.

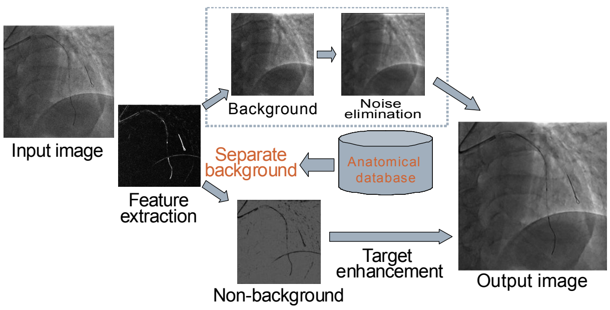


Fig. 2 Overview of Noise Elimination by Pattern Recognition

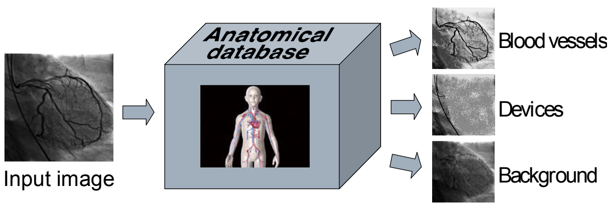


Fig. 3 Anatomical Database Processing

3.1 Noise Elimination

This section describes noise elimination using pattern recognition. Fig.4 shows an image before (left) and after (right) noise elimination by pattern recognition. The ratios of signal to noise for the area indicated by a red line are compared. Due to the reduction in noise, the ratio of signal to noise is higher in the image after noise reduction by pattern recognition. That is, suppressing noise has an effect equivalent to increasing the signal, such that more image information can be acquired at the same exposure dose.

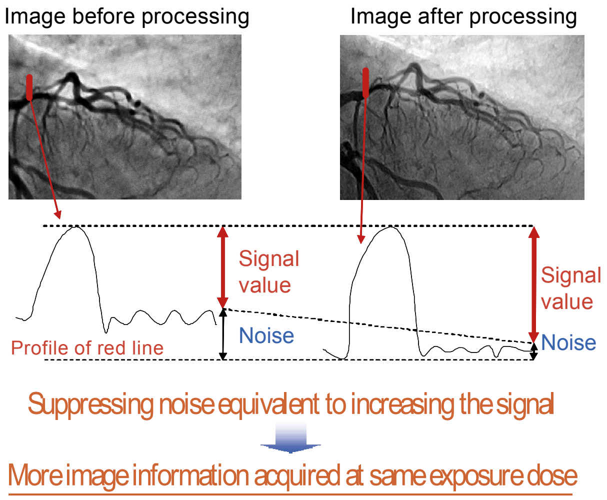


Fig. 4 Effect of Noise Elimination by Pattern Recognition

3.2 Contrast Enhancement

In addition to noise elimination, pattern recognition can be used to enhance the contrast of specific objects. The image processing system automatically evaluates what identical pixel values occurring in an image signify (contrast medium, tissue, or noise?). Contrast enhancement can be performed on specific targets (e.g., blood vessels full of contrast medium) to enhance them in the image. **Fig. 5** shows the operating principle of contrast enhancement.

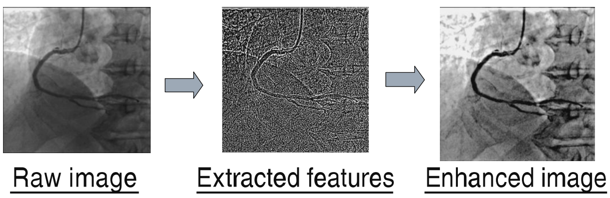


Fig. 5 Contrast Enhancement by Pattern Recognition

3.3 Eliminating Motion Blur

Image processing (noise elimination and contrast enhancement) by pattern recognition can eliminate motion blur from images. Conventionally, an integrating filter was applied to improve graininess in low-exposure dynamic images. This involves integrating and averaging frame units for several frames before the displayed frame on the time axis to reduce noise and improve graininess (noise intensity). This method is particularly effective for objects that have little motion and achieves appropriate improvements in graininess (noise intensity). However, if movement occurs in each frame, little effect is achieved and image persistence remains in previous frames due to the integrating filter. Image processing by pattern recognition is performed on the target frame only and each frame remains independent. It eliminates the problems with blur and image persistence on previous frames associated with the integrating filter.

Fig. 6 shows a fluoroscopic image of a rotating object. Looking at the area around the number 2, it is apparent that image processing by pattern recognition results in no image persistence and achieves images free of motion blur.

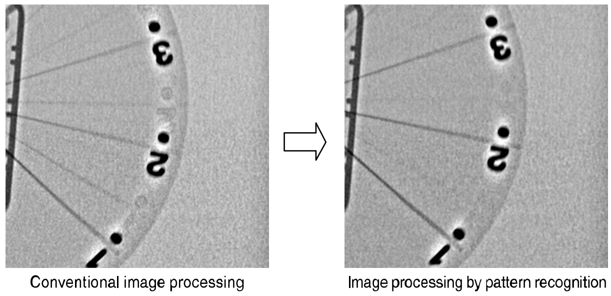
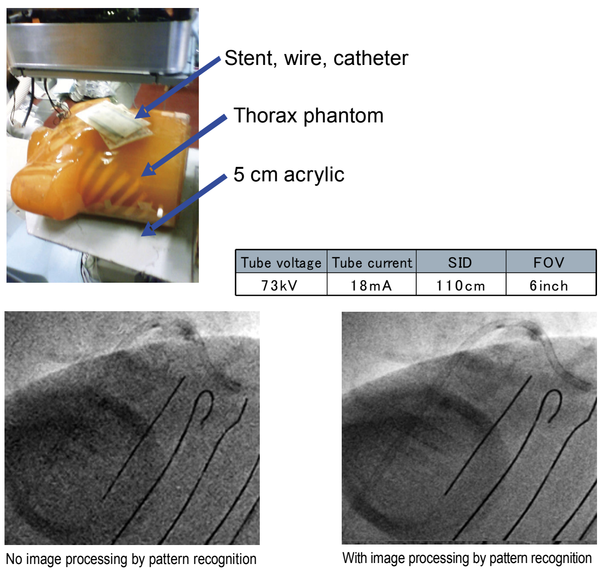


Fig. 6 Persistence due to Motion

3.4 Verification Testing with a Phantom

As shown in **Fig. 7**, a simulation phantom comprising 5 cm-thick acrylic, a thorax phantom, stents, wires, and catheters is used to verify the results of image processing by pattern recognition. Fluoroscopic images using the previous image processing and new image processing methods taken at the same exposure dose were compared. **Fig. 7** shows enlargements of the wire portions of the fluoroscopic images. Compared to the conventional image (left), the image with the new image processing (right) offers superior visibility with no coarseness due to noise and with the wire contours clearly visible.

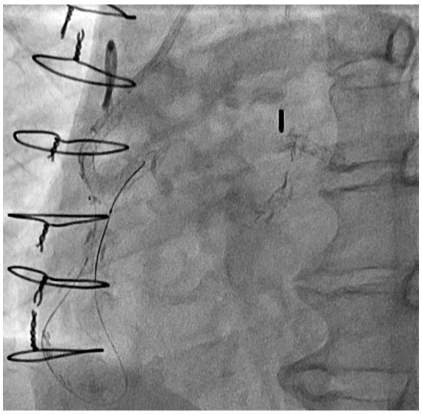


Tube voltage	Tube current	SID	FOV
73kV	18mA	110cm	6inch

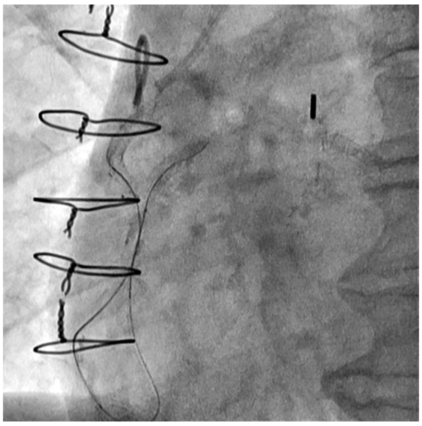
Fig. 7 Verification Testing with a Phantom

3.5 Clinical Verification

This section describes the use of clinical images (Fig. 8) to verify image processing technology by pattern recognition. Enhancing the visibility of devices such as stents and wires and reducing noise eliminates any perceived difference in image quality between the fluoroscopic and radiographic images taken with an almost five times difference in exposure dose. This result suggests that fluoroscopic records may be used more frequently in the future as a replacement for radiography.



Radiography: 68 kV, 418 mA, 4.5 inch



Fluoroscopy: 71 kV, 17 mA, 4.5 inch

Fig. 8 Fluoroscopy and Radiography Using Image Processing Technology by Pattern Recognition

* Images supplied by Kokura Memorial Hospital

4. Incorporation into Leading-Edge Digital Angiography Systems

The SUREengine PRO realtime, high-speed image processing engine is available as an option for the Shimadzu BRANSIST safire digital angiography system. This system has enhanced operability and applications to provide more powerful support for PCI and IVR. It is introduced below.

4.1 CT-Like Imaging Axial 17-Inch Field of View

CT-like imaging with the BRANSIST safire digital angiography system with a 17-inch FPD (Fig. 9) was conventionally performed using a 17 × 12-inch field of view. However, this new system increases processing accuracy and speed and offers a 17-inch field of view in the body-axis direction (Fig. 10 and Fig. 11).

The CT-like imaging image quality has also been enhanced for systems with a 9-inch FPD to improve the visibility of low contrast images (Fig. 12).

Fig.9 BRANSIST safire VC17

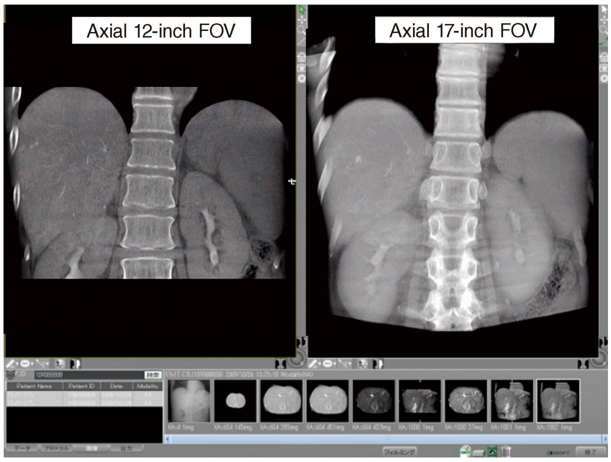


Fig. 10 Comparison of 12-Inch and 17-Inch Axial Field of View

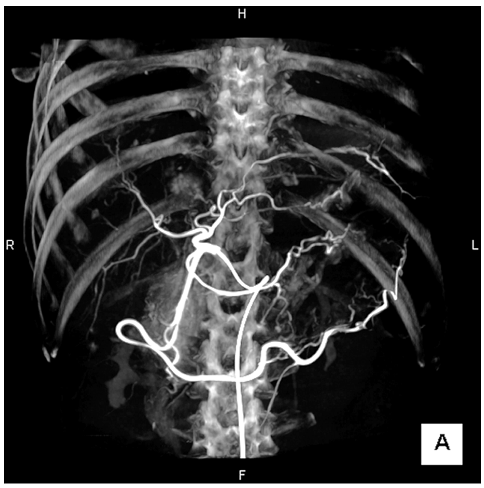


Fig. 11 Axial 17-Inch FOV

* Image supplied by University Of Occupational And Environmental Health

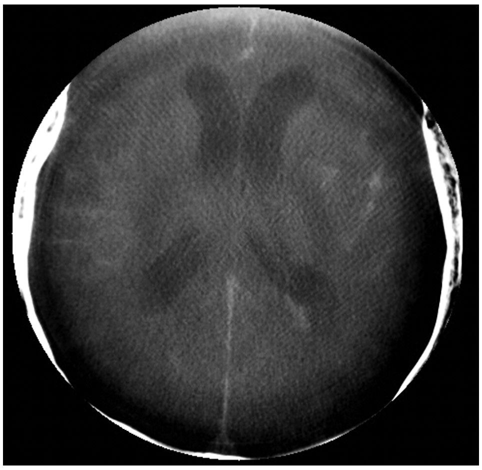


Fig. 12 CT-Like Image of Head

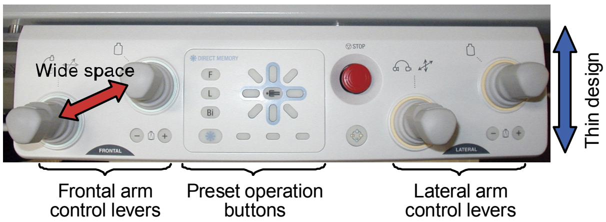
* Image supplied by Ako City Hospital

4.2 New Bedside Console (Cyber Console)

The BRANSIST safire originally incorporated the CyberGrip to control all major C-arm operations without the operator having to release it. However, with the more complex C-arm operations of the Bi-plane system, some operators report that the CyberGrip has become too complicated to use. Therefore, we developed a new bedside console, Cyber Console, for intuitive operation of Bi-plane systems.

The features of the Cyber Console (Fig. 13) are described below for a Bi-plane system. Fig.14 shows the panel layout of the Cyber Console. The frontal arm control levers are positioned at the left, the preset operation buttons (Direct Memory) in the center, and the lateral arm control levers at the right. Making the frontal and lateral levers independent allows direct operation of the respective arms without switching over. By being located at both edges of the panel, the frontal and lateral control levers can be identified without looking. To further improve ease of operation, the levers are separated as wide as possible in a diagonal configuration. The console was made as thin as possible to allow easy access for an operator to a patient over the console.

Fig.13 Cyber Console



- Identify frontal / lateral levers without looking
- Levers widely spaced in a diagonal configuration
- Thin design

Fig.14 Cyber Console Functions (Panel Layout)

I will now introduce the features of the levers (Fig. 15). There are two types of frontal and lateral control levers: one for C-arm rotation, sliding, and travel along the floor or ceiling; and the other to advance and retract the FPD. The two lever types are different in height and configured diagonally on the control panel to allow them to be identified without looking. As a safety precaution, check buttons are installed behind each lever. A check button has to be held down when moving the lever to control the C-arm operation. The check buttons on the levers controlling C-arm operations also switch the lever function. There are two check buttons at different heights on these levers. The function switches according to which button is selected. A ridge between the buttons prevents accidentally pressing the wrong button. The levers have an almost triangular cross-section, making them easy to hold with your index finger on a check button. They are designed to prevent slipping even when operated through a sterilization cover.

- Identify lever type by height and position
- Check button safety mechanism
- Function switching by check button
- Low-slip cross-section

Fig.15 Cyber Console Features (Joy Stick)

Fig. 16 shows the Direct Memory buttons for C-arm preset operation. The buttons are arranged around a symbol for the patient. The C-arm angle can be registered to match the actual positional relationship, to intuitively call up the required C-arm angle. Changing from the previous sheet keys to rubber buttons makes it easier to hold down a button when operating the system. The panel illuminates to improve visibility through a sterilization sheet.

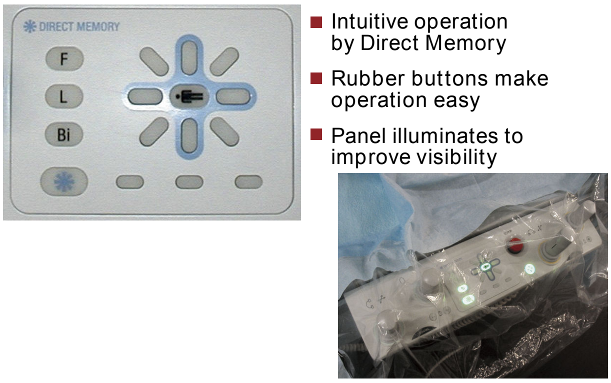


Fig.16 Cyber Console Features (Panel Switches)

The Cyber Console is mounted on a sliding rail to allow it to be moved to facilitate the patient getting on and off the table **(Fig. 17)**.

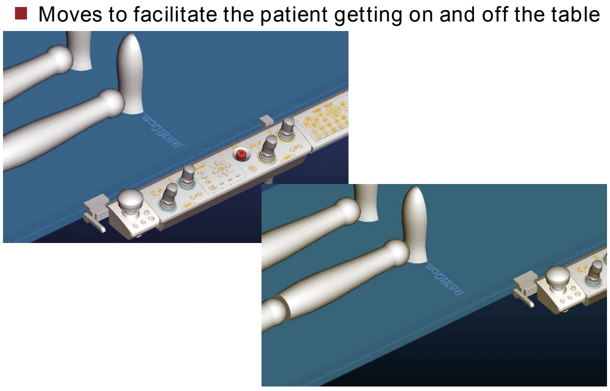


Fig. 17 Console Mounted on Sliding Rail

5. Conclusions

To meet the demands of users engaged in performing leading-edge interventional procedures in medical facilities, the SUREengine PRO realtime, high-speed image processing engine introduced above was designed to offer safe and accurate vascular interventional radiology. Therefore, we believe it will become widely adopted to deliver close to the optimal images. In the future, we will continue to strive to develop new applications to enhance image quality and to provide support for safer and quicker treatments.

Finally, I wish to express my sincere gratitude to staff at the University Of Occupational And Environmental Health, Kokura Memorial Hospital, Ako City Hospital for supplying images and for their advice and guidance; and to staff at the Iwate Prefectural Central Hospital for their valuable advice and guidance on evaluating the new console.