Introduction of a Pixel-Specific Model Observer to Accommodate Spatially Complex Clinical Devices as Test Objects

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PURPOSE

Existing spatial domain implementations of Hotelling observers used to assess imaging system performance provide a single SNR estimate of a symmetric test object. The purpose of this work was to develop a multivariate statistical observer model which can be readily applied to spatially complex clinical devices as test objects.

METHODS

Three multivariate statistical methods used to estimate symmetric test object SNR are summarized in Table 1 (Ref. 1). Of these, the pixel-specific observer (PSO) estimates the multivariate snr^2 of each pixel, the sum of which is object SNR^2 (Ref. 2). For the PSO model, the total covariance (ω^2) is the sum of the individual pixel variance and covariance of that pixel with other pixels within a local neighborhood or 'patch' (Fig. 1).

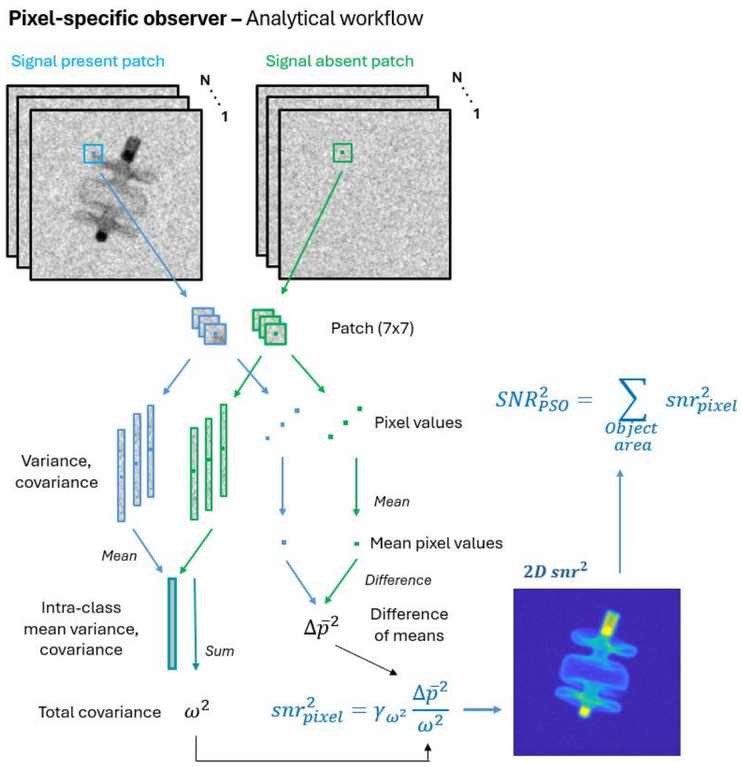
For each method, the multiplicative effect of finite sampling bias was corrected using established theory. Unprocessed sample images (n=1200) of 0.5 to 4 mm iodine disks were acquired using an X-ray angiography system and submitted to the three variants of multivariate statistical methods. The PSO method was additionally applied to images of clinical devices acquired using 0.4 and 0.9 mm focal spots to produce detailed ***2D snr*** maps.

TABLE 1: Summary of multivariate statistical model observers.

Observer Model	Multivariate data type	Theory – Pixel-specific snr^2	Theory - Test object SNR^2	* Minimum sample size
Hotelling (HO)	Pixel value		$SNR^2_{HO} = \gamma_{Hot}\, \Delta\bar{p}^t\, S^{-1} \Delta p$	~1000
Channelized Hotelling (CHO)	Channel response		$SNR^2_{CHO} = \gamma_{Hot}\, \Delta\bar{c}^t S_c^{-1}\, \Delta\bar{c}$	~100
Pixel-specific (PSO)	Pixel value	$snr^2_{pixel} = \gamma_{\omega^2} \frac{\Delta\bar{p}^2}{\omega^2}$	$SNR^2_{PSO} = \sum_{Object\ area} snr^2_{pixel}$	~100

* - To invert intra-class scatter matrix (S) and/or ensure appropriate precision
$\Delta\bar{p}$ - Difference between mean of signal present and absent vectors
S - Intra-class scatter matrix (covariance) calculated from pixel data
γ_{Hot} - Finite sampling bias correction factor for HO, CHO
$\Delta\bar{c}$ - Difference between mean signal present and absent channel response vectors
S_c - Intra-class scatter matrix (covariance) calculated from channel responses
$\Delta\bar{p}$ - Single pixel difference between signal absent and present
ω^2 - Sum of single pixel variance and covariance with pixels within ± 4 pixels range
γ_{ω^2} - Finite sampling bias correction factor for PSO

FIGURE 1. Analytical workflow of the pixel-specific observer model.



RESULTS

As shown in Fig. 3, Iodine disk SNR by the 3 methods was linear versus object size. That SNR estimated by the 3 methods agreed to within ±15% supports their collective accuracy.

Pixel-specific **2D snr** maps of the clinical devices acquired using 0.4 and 0.9 mm focal spots are shown in Fig. 4. In Fig. 4, right, the difference between the snr maps of the 2 focal spots highlights the spatial sensitivity of the PSO method snr estimates. Not shown is that the SNR^2 of the clinical test objects can be readily estimated as the sum of the snr^2 of pixels within the test object.

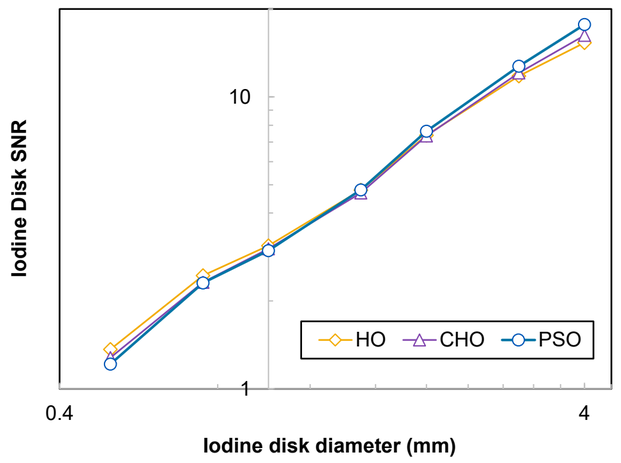
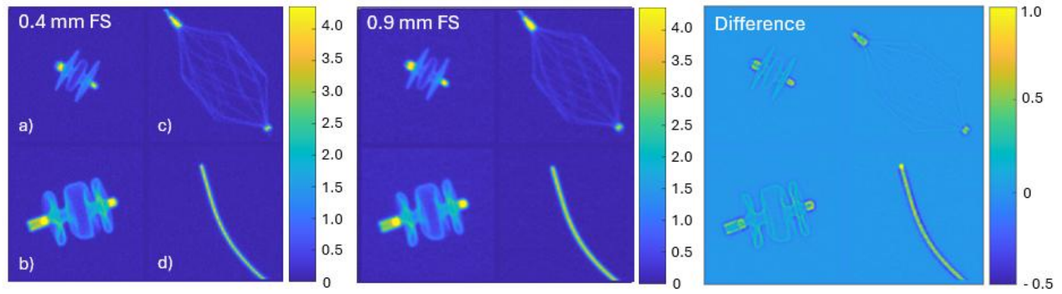


FIGURE 2: Iodine disk SNR verus disk diameter.

FIGURE 3. Pixel-specific *2D snr* maps of clinical devices for the 0.4 mm and 0.9 mm focal spots. Right – Difference between *snr* estimates from 2 focal spots.



INNOVATION / IMPACT

While the pixel-specific method can also estimate object SNR, the novelty of this approach is that the contribution of any portion of a spatially complex test object (down to a single pixel) can be directly estimated. For example, the SNR of the relatively radiolucent body of a pediatric closure device can be estimated independent of the relatively radio-dense hubs of the device. Work has been initiated to correlate the visual impression of 2D snr maps with human perception. Early results indicate that the human visual system can detect localized collections of pixels for which pixel-specific snr is greater than ~0.5. Also, while the PSO methods reported herein require hundreds of images to produce precise object SNR estimates, future work will describe an approach using as few as ~10 images.

REFERENCES

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