

Purpose: Cascaded systems analysis (CSA) offers a quantitative basis to optimize design and operation of novel imaging systems. Considering a CBCT scanner under development for musculoskeletal imaging, we employed CSA for design and technique optimization in relation to specific imaging tasks.

Methods and Materials: A comprehensive system model combined spatial-frequency-dependent noise transfer characteristics, “system” parameters such as focal spot size and x-ray scatter, and “generalized” parameters of anatomical clutter – each in relation to task-based detectability. System performance was computed as a function of system geometry (magnification, detector pixel size, focal spot size, etc.), anatomical site (upper and lower extremities), imaging technique (kVp and dose), and reconstruction technique (voxel size and reconstruction filter). The vast parameter space was investigated in multivariate analysis for tasks ranging from low-contrast, low-frequency, soft-tissue discrimination to higher-contrast, high-frequency detectability. Theoretical predictions were validated versus measurements on an imaging bench, and qualitative verification was obtained in cadaver images.

Results: The analysis identified distinct optima and key tradeoffs among factors of contrast, noise, resolution, and dose. System geometry was a critical parameter in terms of focal spot blur, dose, and scatter, and a multivariate optimum was identified at magnification ~ 1.3 . Other optima included: kVp (90 kVp + 0.3 mm Cu); pixel size (0.15-0.19 mm); binning (2x2 binning for soft-tissue discrimination); and filter (Hann versus ramp for soft-tissue and bone tasks). Results were qualitatively confirmed in cadaver images and guided the selection of components and physical design of the extremity scanner.

Conclusions: A CSA model providing a comprehensive treatment of quantum noise with “system” and “generalized” parameters provided a powerful basis for design and optimization. The work identified distinct optima in system geometry and operation without costly experimental trial and error and guided the development of a prototype CBCT scanner for musculoskeletal imaging now in translation.

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