Optimize computed tomography imaging quality with surface response model

Purpose of study: Computed tomography (CT) is one of the most widely-used non-invasive imaging techniques in the medical field. It has been applied to various clinical applications, such as tumor diagnosis, lung fibrosis, bone fractures and etc. Its basic imaging principle is to use a rotating x-ray tube and a row of detectors to measure X-ray attenuations taken from different angles across different tissues, and then reconstruct the tomographic image with the measurements. However, the CT imaging quality is highly dependent on multiple factors related to device system to screened tissues, including voltage, slice thickness, scan time and etc. This continuous parameter space is too large for exhaustive search to find the optimal parameters. We need systematic optimization of CT parameters, and response surface methodology (RSM) is a good candidate to adjust the parameters quantitatively to improve imaging quality. In this study, we would use the central composite design (CCD) to screen the optimal values of the following factors which could produce the best model performance: 1) Voltage, 2) Slice thickness, 3) Voxel volume, 4) Scan time, 5) Field of view (FOV).

Methods: The pipeline includes the following components: 1) experiment design to define parameter search space; 2) quadratic fitting model; 3) evaluation datasets and devices, 4) quality evaluation.

1. Experiment dataset. In this study, we plan to employ CCD design to approximate the fitting model. CCD estimates both center points, factorial points, and axial points of a multiple-dimensional cube, which provides a clear estimation of both first-order main effects and second-order interaction and quadratic effects. Levels of the 6 factors are coded as low(-1), medium(0), and high(1), whose ranges are as shown in the following table. To achieve a uniform precision and rotatable CCD design, we The total experiments has 91 runs, with 64 factorial points, 12 axial points, and 15 center points.

Factor	Voltage	Slice thickness	Voxel volume	Scan time	FOV
low	80	0.75	0.5	48	400
medium	100	2	1.5	72	500
high	120	1.5	3	96	600

2. Quadratic model. The quadratic model to estimate the effect of each parameter could be formalized as the following equation: $y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_i x_i^2 + \sum_{j=1}^{k} \sum_{i=1}^{j-1} \beta_{ij} x_i x_j$, where y is the measured response representing the imaging quality, x represents each parameter, and β represents the effect size of each factor.

3. Datasets and devices. In this study, we would explore the parameters by running CT scans of QA phantom samples on GE BrightSpeed RT16 CT scanner. The CT scanner contains the 24-bit digital data acquisition system with 0.65mm isotropic spatial image resolution. The scanner produces a set of 2-dimensional CT images after adjusting each combination of parameters. After the optimal scanning parameters are screened, they would be utilized for the imaging of real patient data, visually estimating its performance.

4. Quality evaluation metrics. CT image quality is mainly characterized by 3 metrics, including signal-to-noise ratio (SNR), high contrast spatial resolution (HCSR), and low contrast object detectability (LCD). These 3 metrics are computed to evaluate the performance after running each factor combination. Among them, HCSR and LCD are applied to QA phantoms.