Harmonization of CT for Densitometry Analysis

Raúl San José Estépar, PhD
Applied Chest Imaging Laboratory
Brigham and Women’s Hospital
Harvard Medical School
Densitometry Identifies CODP in LCS

Sources of CT Signal Bias

- Systematic bias due to mis-calibration among devices
  - Phantoms can address this problem

- Noise-induced bias
  - The intimate relation between noise and bias is not currently addressed.
  - They have to be jointly corrected to have a proper densitometry assessment.
Sources of Noise in CT Acquisitions

- **Intrinsic**
  - Dose
  - Reconstructions
- **Physiological Factors**
  - Volume Change
  - Weight Change
- **Extrinsic**
  - Implants

Noise is spatially variant up to levels of ± 70 HU that can yield a bias of 30 HU
The Noise is Spatially Variant
How Does Bias Affect the Signal?

- Variance of noise is non-stationary
- Variance of noise affects the average attenuation levels
- Average attenuation levels are biased due to non-homogeneous nature of noise
Observations:

1. Histograms are right skewed and show different mean and variances
2. Current calibrations are not effective with spatially-variant noise
Lower attenuations are the most biased ➔ Emphysema can be misclassified
Location matters ➔ Lower regions of the lung are more biased
Observations:

1. CT numbers behave equally for water and air
2. Strong deviations for other CT numbers
Noise Stabilization:
- Transform input signal in such a way that the output follows known statistical properties
  - Gaussian
  - Stationary

Goal:
- Enabling statistical comparison between different regions for different acquisition protocols (including kernels, doses and reconstruction algorithms)
Stabilization of Noise for Harmonization

Attenuation levels as a stochastic process

Vegas-Sánchez-Ferrero G, Medical Image Analysis 2017
Mixture of Gammas:

- Fits the statistical behavior of noise with different kernels, doses and reconstruction methods.
- Leads for the estimation of local statistics.
- Allows us to distinguish different tissue responses
Main Advantage:

- Enables the estimation of the signal considering the likelihood of each density component associate to a tissue type.
Methodology

1. Bias correction
1. Bias correction
2. Noise Stabilization

- Transformation of the CT signal that employs
  - Estimated signal
  - Estimated noise variance
Observations:
The influence of noise is dramatically reduced throughout the image (contrast in soft tissues increases).
Difference between Local Histograms

Histogram

-1000  -500   0    500
HUs

x 10^{-3}

LD
HD1
HD2

30 HU

x 10^{-3}

LD
HD1
HD2
High Dose Acquisition with Kernel (Sharp and Smooth) vs. Low Dose Reconstruction

Ratio of statistically equal histograms (p-value < 0.0001)
Iterative Low Dose vs. High Dose FBP

LD Iterative Reconstruction vs. HD Filtered Back Projection

<table>
<thead>
<tr>
<th></th>
<th>LD I44f vs. HD B31f</th>
<th>LD I44f vs. HD B45f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>52.12%</td>
<td>80.61%</td>
</tr>
<tr>
<td>Stabilized</td>
<td>80.61%</td>
<td>96.97%</td>
</tr>
</tbody>
</table>

Ratio of statistically equal histograms (p-value < 0.0001)
Noise Stabilization and Resolution

Original

Stabilized
Noise Stabilization and Resolution

The MTFs are unaltered after noise stabilization

Table 5: Distance of the 10%-90% of the edge response in pixel units for stabilized images with $C = 0$. The differences between both measures is always below 0.5 pixels.
Conclusions

- Noise also depends on the scanned subject
  - Current calibrations should consider this

- Variance of noise is spatially variant
  - Local Effects

- Variance of Noise introduces a Bias in low CT numbers

- Systematic Bias between devices is non-linear