Appendix A Details of CT-Radiomics features

CT-Radiomics features

The total of 1029 imaging features were computed. These could be divided into three groups: 1) first-order features (19 features), 2) shape features (15 features), 3) texture features (59 features). Furthermore, texture features could be divided into three subgroups: Gray Level Co-occurrence Matrix (GLCM), Gray Level Run Length Matrix (GLRLM) and Gray Level Size Zone Matrix (GLSZM). Each feature in the groups of first-order features, shape features, GLCM, GLRLM and GLSZM is listed in **Table A1**.

Table A1 The listing of radiomics features

Group/Subgroup	**Radiomics features**
First-order features (19)	Energy, Total Energy, Entropy, Minimum, Maximum, 10Percentile, 90Percentile, Mean, Median, Interquartile Range, Range, Mean Absolute Deviation (MAD), Robust Mean Absolute Deviation (rMAD), Root Mean Squared (RMS), Standard Deviation, Skewness, Kurtosis, Variance, Uniformity
shape features(15)	Volume, Surface Area, Surface Area to Volume Ratio, Sphericity, Compactness1, Compactness2, Spherical Disproportion, Maximum 3D Diameter, Maximum 2D Diameter Column, Maximum 2D Diameter Row, Major Axis, Minor Axis, Least Axis, Elongation, Flatness
GLCM(27)	Auto-correlation, Average Intensity, Cluster Prominence, Cluster Shade, Cluster Tendency, Contrast, Correlation, Difference Average, Difference Entropy, Difference Variance, Energy, Entropy, Informal Measure of Correlation1 (IMC1), Informal Measure of Correlation2 (IMC2), Inverse Difference Moment (IDM), Inverse Difference Moment Normalized(IDMN), Inverse Difference(ID), Inverse Difference Normalized (IDN), Inverse Variance, Maximum Probability, Sum Average, Sum Entropy, Sum of Squares, Dissimilarity, Homogeneity1, Homogeneity2, Sum Variance
GLRLM(16)	Short Run Emphasis (SRE), Long Run Emphasis (LRE), Gray Level Non-Uniformity (GLN), Gray Level Non-Uniformity Normalized (GLNN), Run Length Non-Uniformity (RLN), Run Length Non-Uniformity Normalized (RLNN), Run Percentage (RP), Gray Level Variance (GLV), Run Variance (RV), Run Entropy (RE), Low Gray Level Run Emphasis (LGLRE), High Gray Level Run Emphasis (HGLRE), Short Run Low Gray Level Emphasis (SRLGLE), Short Run High Gray Level Emphasis (SRHGLE), Long Run Low Gray Level Emphasis (LRLGLE), Long Run High Gray Level Emphasis (LRHGLE)
GLSZM(16)	Small Area Emphasis (SAE), Large Area Emphasis (LAE), Gray Level Non-Uniformity (GLN), Gray Level Non-Normalized (GLNN), Size Zone Non-Uniformity (SZN), Size Zone Non-Uniformity Normalized (SZNN), Zone Percentage (ZP), Gray Level Variance (GLV), Zone Variance (ZV), Zone Entropy (ZE), Low Gray Level Zone Emphasis (LGLZE), High Gray Level Zone Emphasis (HGLZE), Small Area Low Gray Level Emphasis (SALGLE), Small Area High Gray Level Emphasis (SAHGLE), Large Area Low Gray Level Emphasis (LALGLE), Large Area High Gray Level Emphasis(LAHGLE)

Shape features were calculated based on the original image, while first-order features and texture features were computed based on the original image and derived images obtained by applying several filters (including exponential filter, square filter, square root filter, logarithm filter and wavelet decomposition filters).[1] In addition, the wavelet decomposition includes the following three-dimensional wavelet transforms obtained by directional low-pass (L) and high-pass (H) filtering: wavelet-LHL, wavelet-LHH, wavelet-HLL, wavelet-LLH, wavelet-HLH, wavelet-HHH, wavelet-HHL and wavelet-LLL. The schematic of wavelet decomposition is depicted in **Figure A1**.[2]

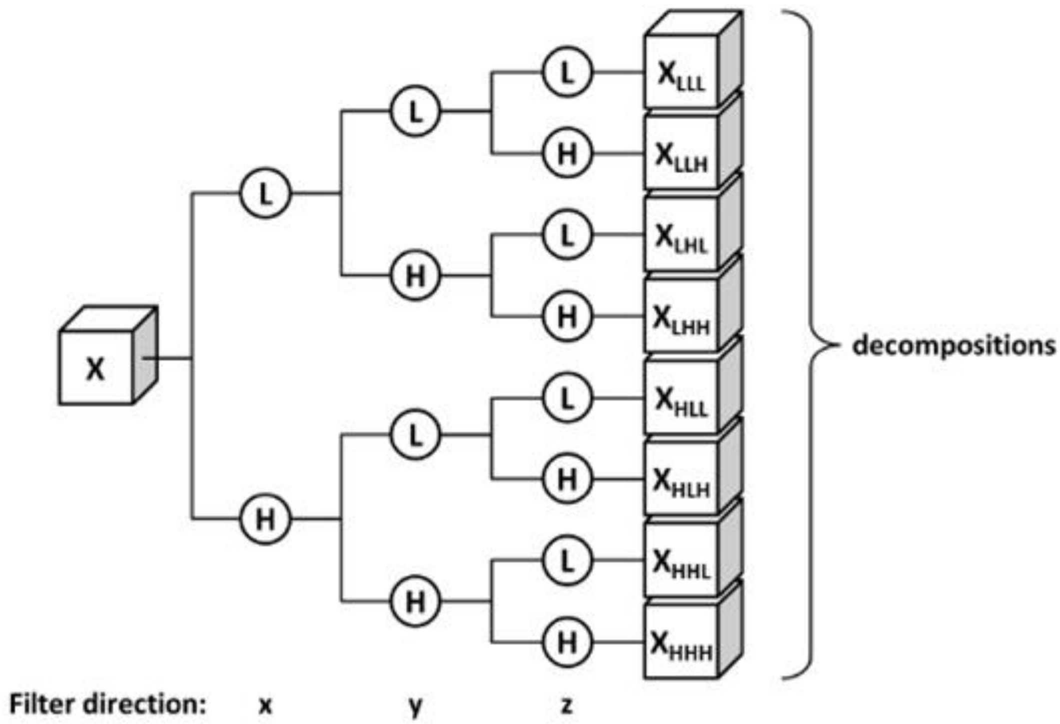

Figure A1 Schematic of three-dimensional wavelet transform applied to each image. The original X image was decomposed into 8 decompositions: X_{LHL}, X_{LHH}, X_{HLL}, X_{LLH}, X_{HLH}, X_{HHH}, X_{HHL} and X_{LLL}.

In conclusion, the feature distribution: the number of all features (1029) = shape features (15) + [first-order features (19) + GLCM (27) + GLRLM (16) + GLSZM (16)] × the numbers of original and derived images (13).

Filters

Exponential Filter

$$f(x) = e^{cx}, c = \frac{\log(\max(|x|))}{\max(|x|)}$$

Square Filter

$$f(x) = (cx)^2, c = \frac{1}{\sqrt{\max(|x|)}}$$

Square root Filter

$$f(x)=,\begin{cases}\sqrt{cx} & for \quad x\geq 0\\ -\sqrt{-cx} & for \quad x<0\end{cases}, c=\max(|x|)$$

Logarithm Filter

$$f(x)=,\begin{cases}c\log(x+1) & for \quad x\geq 0\\ -c\log(-x+1) & for \quad x<0\end{cases}, c=\frac{\max(|x|)}{\log(\max(|x|)+1)}$$

where x and $f(x)$ are the original and filtered image for all the above filters, respectively.

First order features

Notations

X is an image of N voxels included in the VOI

Pi is the first order histogram with N_l discrete intensity levels, in which N_l is the number of non-zero bins, pi is the normalized first order histogram and equal to $\frac{P_i}{\Sigma P_i}$ (This definition is the same for the following sections)

Energy

$$energy=\sum_{i=1}^{N}(X(i)+c)^2$$

Here, c is an optional value, which shifts the intensities to prevent negative values in X . This ensures that voxels with the lowest gray values contribute the least to Energy, instead of voxels with gray level intensity closest to zero.

Total Energy

$$total\ energy=V_{voxel}\sum_{i=1}^{N}(X(i)+c)^2$$

Entropy

$$entropy=-\sum_{i=1}^{N_l}p(i)\log_2(p(i)+\varepsilon)$$

Here, ε is an arbitrarily small positive number ($\approx 2.2\times 10^{-16}$)

Minimum

$$\text{minimum}=\min(X)$$

Maximum

$$\text{maximum}=\max(X)$$

10Percentile

$$\text{The } 10^{\text{th}} \text{ percentile of } X$$

90Percentile

$$\text{The } 90^{\text{th}} \text{ percentile of } X$$

Mean

$$mean=\frac{1}{N}\sum_{i=1}^{N}X(i)$$

Median

The median gray level intensity within the VOI

Interquartile Range

$$\text{interquartile range} = P_{75} - P_{25}$$

Range

$$\text{range} = \max(X) - \min(X)$$

Mean Absolute Deviation (MAD)

$$MAD = \frac{1}{N}\sum_{i=1}^{N}\left|X(i) - \overline{X}\right|$$

Robust Mean Absolute Deviation (rMAD)

$$\text{r}MAD = \frac{1}{N_{10-90}}\sum_{i=1}^{N_{10-90}}\left|X_{10-90}(i) - \overline{X}_{10-90}\right|$$

Root Mean Squared (RMS)

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(X(i) + \text{c}\right)^2}$$

Standard Deviation

$$\text{standard deviation} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(X(i) - \overline{X}\right)^2}$$

Skewness

$$\text{skewness} = \frac{\mu_3}{\sigma^3} = \frac{\frac{1}{N}\sum_{i=1}^{N}(X(i) - \overline{X})^3}{\left(\sqrt{\frac{1}{N}\sum_{i=1}^{N}(X(i) - \overline{X})^2}\right)^3}$$

Kurtosis

$$\text{kurtosis} = \frac{\mu_4}{\sigma^4} = \frac{\frac{1}{N}\sum_{i=1}^{N}(X(i) - \overline{X})^4}{\left(\sqrt{\frac{1}{N}\sum_{i=1}^{N}(X(i) - \overline{X})^2}\right)^4}$$

Variance

$$\text{variance} = \frac{1}{N}\sum_{i=1}^{N}\left(X(i) - \overline{X}\right)^2$$

Uniformity

$$\text{uniformity} = \sum_{i=1}^{N_l} p(i)^2$$

Shape features

Volume

$$V = \sum_{i=1}^{N} V_i$$

Surface Area

$$A = \sum_{i=1}^{N} \frac{1}{2} |a_i b_i \times a_i c_i|$$

$a_i b_i$ and $a_i c_i$ are the edges of the i^{th} triangle formed by points a_i, b_i and c_i

Surface Area to Volume Ratio

$$\text{surface to volume ratio} = \frac{\mathrm{A}}{\mathrm{V}}$$

Sphericity

$$sphericity = \frac{\sqrt[3]{36\pi V^2}}{A}$$

Compactness1

$$compactness1 = \frac{V}{\sqrt{\pi A^3}}$$

Compactness2

$$compactness2 = 36\pi \frac{V^2}{A^3}$$

Spherical Disproportion

$$\text{spherical disproportion} = \frac{\mathrm{A}}{\sqrt[3]{36\pi V^2}}$$

Maximum 3D Diameter

The maximum three-dimensional diameter is measured as the largest pairwise Euclidean distance between voxels on the surface of the tumor volume.

Maximum 2D Diameter Column

The maximum 2D diameter (Column) is defined as the largest pairwise Euclidean distance between surface voxels in the coronal plane.

Maximum 2D Diameter Row

The maximum 2D diameter (Row) is defined as the largest pairwise Euclidean distance between surface voxels in the sagittal plane.

Major Axis

$$\text{major axis} = 4\sqrt{\lambda_{\text{major}}}$$

Minor Axis

$$\text{minor axis} = 4\sqrt{\lambda_{\text{minor}}}$$

Least Axis

$$\text{least axis} = 4\sqrt{\lambda_{\text{least}}}$$

Elongation

$$\text{elongation} = \sqrt{\frac{\lambda_{\text{minor}}}{\lambda_{\text{major}}}}$$

Flatness

$$\text{flatness} = \sqrt{\frac{\lambda_{\text{least}}}{\lambda_{\text{major}}}}$$

Here, $\lambda_{\text{major}}, \lambda_{\text{minor}}$ *and* λ_{least} are the lengths of the largest, second largest and smallest principal component axes.

GLCM features

A Gray Level Co-occurrence Matrix (GLCM) of size $N \times N$ describes the second-order joint probability function of an image region constrained by the mask[1-3].

Notations

$P(i, j)$ is the co-occurrence matrix for δ (distance) and α (angle)

$p(i, j)$ is element i, j of the normalized symmetrical co-occurrence matrix and equal to $\frac{P_i}{\sum P_i}$

N_{g} is the number of discrete intensity levels in the image

$p_x(i) = \sum_{j=1}^{N_g} p(i, j)$ is the marginal row probability for the *i*th row

$p_y(j) = \sum_{i=1}^{N_g} p(i, j)$ is the marginal column probability for the *j*th column

$\mu_x = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} p(i, j)i$ is the mean gray level intensity of p_x

$\mu_{\text{y}} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} p(i, j)j$ is the mean gray level intensity of p_{y}

σ_{x} is the standard deviation of p_x

σ_{y} is the standard deviation of p_{y}

$$p_{x+y}(k) = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} p(i,j), \textit{ where } i + j = k$$

$$p_{x\text{-}y}(k) = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P(i,j), \textit{ where } |i - j| = k$$

$$HX = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p_x(i)\log_2(p_x(i)+\varepsilon)$$ is the entropy of p_x

$$HY = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p_y(i)\log_2(p_y(i)+\varepsilon)$$ is the entropy of p_y

$$HXY = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p\ (i,j)\log_2(p\ (i,j)+\varepsilon)$$ is the entropy of $p(i,j)$

$$HXY1 = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p(i,j)\log_2(p_x(i)p_y(i)+\varepsilon)$$

$$HXY2 = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p_x(i)p_y(i)\log_2(p_x(i)p_y(i)+\varepsilon)$$

Auto-correlation

$$\textit{auto-correlation} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p(i,j)ij$$

Average Intensity

$$\text{average intensity} = \mu_x = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p(i,j)i$$

Cluster Prominence

$$\text{cluster prominence} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} (i+j-\mu_x-\mu_y)^4\, p(i,j)$$

Cluster Shade

$$\text{cluster shade} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} (i+j-\mu_x-\mu_y)^3\, p(i,j)$$

Cluster Tendency

$$\text{cluster tendency} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} (i+j-\mu_x-\mu_y)^2\, p(i,j)$$

Contrast

$$\text{contrast} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} (i-j)^2\, p(i,j)$$

Correlation

$$\textit{correlation} = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p(i,j)ij - \mu_x\mu_y}{\sigma_x(i)\sigma_y(j)}$$

Difference Average

$$difference\ average = \sum_{k=0}^{N_g-1} k p_{x-y}(k)$$

Difference Entropy

$$difference\ entropy = \sum_{k=0}^{N_g-1} p_{x-y}(k) \log_2 (p_{x-y}(k) + \varepsilon)$$

Difference Variance

$$\text{difference varinance} = \sum_{k=0}^{N_g-1} (k - DA)^2 p_{x-y}(k)$$

Energy

$$energy = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} (p(i-j))^2$$

Entropy

$$entropy = -\sum_{i=1}^{N_g} \sum_{j=1}^{N_g} p(i,j) \log_2 (p(i,j) + \varepsilon)$$

Informal Measure of Correlation1 (IMC1)

$$IMC1 = \frac{HXY - HXY1}{\max\{HX, HY\}}$$

Informal Measure of Correlation2 (IMC2)

$$IMC2 = \sqrt{1 - \mathrm{e}^{-2(HXY2 - HXY)}}$$

Inverse Difference Moment (IDM)

$$\mathrm{I}DM = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \frac{p(i,j)}{1 + |i-j|^2}$$

Inverse Difference Moment Normalized(IDMN)

$$\mathrm{I}DMN = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \frac{p(i,j)}{1 + \left(\frac{|i-j|^2}{N_{\mathrm{g}}^2} \right)}$$

Inverse Difference(ID)

$$\mathrm{ID} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \frac{p(i,j)}{1 + |i-j|}$$

Inverse Difference Normalized (IDN)

$$\mathrm{IDN} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g}\frac{p(i,j)}{1+\left(\frac{|i-j|}{N_g}\right)}$$

Inverse Variance

$$\text{inverse variance} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g}\frac{p(i,j)}{|i-j|^2}, i \neq j$$

Maximum Probability

$$\text{maximum probability} = \max(p(i,j))$$

Sum Average

$$\mathit{sum\ average} = \sum_{k=2}^{2N_g} p_{x+y}(k)k$$

Sum Entropy

$$\mathit{sum\ entropy} = \sum_{k=2}^{2N_g} p_{x+y}(k)\log_2(p_{x+y}(k)+\varepsilon)$$

Sum of Squares

$$\mathit{sum\ squares} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g}(i-\mu_x)^2 p(i,j)$$

Dissimilarity

$$\mathit{dissimilarity} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g}|i-j|\,p(i,j)$$

Homogeneity1

$$\text{homogeneity } 1 = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g}\frac{p(i,j)}{1+|i-j|}$$

Homogeneity2

$$\text{homogeneity } 2 = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g}\frac{p(i,j)}{1+|i-j|^2}$$

Sum Variance

$$\text{sum variance} = \sum_{k=2}^{2N_g}(k-SA)^2\, p_{x+y}(k)$$

GLRLM features

A Gray Level Run Length Matrix (GLRLM) quantifies gray level runs, which are defined as the length in number of pixels, of consecutive pixels that have the same gray level value.[1–5]

Notations

$P(i,j\,|\,\theta)$ is the run length matrix for θ (direction)

$p(i, j \mid \theta)$ is the normalized run length matrix, defined as $p(i, j|\theta) = \frac{P(i,j|\theta)}{N_z}$

N_g is the number of discrete intensity levels in the image

N_r is the number of discrete run lengths in the image

N_p is the number of voxels in the image

$N_z(\theta)$ is the number of runs in the image along angle θ, $N_z(\theta) = \sum_{i=1}^{N_g}\sum_{j=1}^{N_r} P(i, j \mid \theta)$

Short Run Emphasis (SRE)

$$SRE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} \frac{P(i, j \mid \theta)}{j^2}}{N_z(\theta)}$$

Long Run Emphasis (LRE)

$$LRE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} P(i, j \mid \theta) j^2}{N_z(\theta)}$$

Gray Level Non-Uniformity (GLN)

$$GLN = \frac{\sum_{i=1}^{N_g}(\sum_{j=1}^{N_r} P(i, j \mid \theta))^2}{N_z(\theta)}$$

Gray Level Non-Uniformity Normalized (GLNN)

$$GLN = \frac{\sum_{i=1}^{N_g}(\sum_{j=1}^{N_r} P(i, j \mid \theta))^2}{N_z(\theta)^2}$$

Run Length Non-Uniformity (RLN)

$$RLN = \frac{\sum_{j=1}^{N_r}(\sum_{i=1}^{N_g} P(i, j \mid \theta))^2}{N_z(\theta)}$$

Run Length Non-Uniformity Normalized (RLNN)

$$RLNN = \frac{\sum_{j=1}^{N_r}(\sum_{i=1}^{N_g} P(i, j \mid \theta))^2}{N_z(\theta)^2}$$

Run Percentage (RP)

$$RP = \frac{N_z(\theta)}{N_p}$$

Gray Level Variance (GLV)

$$GLV = \sum_{i=1}^{N_g}\sum_{j=1}^{N_r} p(i,j|\theta)(i-\mu)^2, \mu = \sum_{i=1}^{N_g}\sum_{j=1}^{N_r} p(i,j|\theta)i$$

Run Variance (RV)

$$RV = \sum_{i=1}^{N_g}\sum_{j=1}^{N_r} p(i,j|\theta)(j-\mu)^2, \mu = \sum_{i=1}^{N_g}\sum_{j=1}^{N_r} p(i,j|\theta)j$$

Run Entropy (RE)

$$RE = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} p(i,j|\theta)\log_2(p(i,j|\theta)+\varepsilon)$$

Low Gray Level Run Emphasis (LGLRE)

$$LGLRE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r}\frac{P(i,j|\theta)}{i^2}}{N_z(\theta)}$$

High Gray Level Run Emphasis (HGLRE)

$$HGLRE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} P(i,j|\theta)i^2}{N_z(\theta)}$$

Short Run Low Gray Level Emphasis (SRLGLE)

$$SRLGLE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r}\frac{P(i,j|\theta)}{i^2 j^2}}{N_z(\theta)}$$

Short Run High Gray Level Emphasis (SRHGLE)

$$SRHGLE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r}\frac{P(i,j|\theta)i^2}{j^2}}{N_z(\theta)}$$

Long Run Low Gray Level Emphasis (LRLGLE)

$$LRLGLE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r}\frac{P(i,j|\theta)j^2}{i^2}}{N_z(\theta)}$$

Long Run High Gray Level Emphasis (LRHGLE)

$$LRHGLE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} P(i,j|\theta)i^2 j^2}{N_z(\theta)}$$

GLSZM features

A Gray Level Size Zone (GLSZM) quantifies gray level zones in an image. A gray level zone is defined as a the number of connected voxels that share the same gray level intensity [1,5].

Notations

$P(i, j)$ is the size zone matrix

$p(i, j)$ is the normalized size zone matrix, defined as $p(i,j) = \frac{P(i,j)}{N_z}$

N_g is the number of discrete intensity levels in the image

N_s is the number of discrete zone sizes in the image

N_p is the number of voxels in the image

N_z is the number of zones in the image, $N_z = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} P(i, j)$

Small Area Emphasis (SAE**)**

$$SAE = \frac{\sum_{i=1}^{N_g} \sum_{j=1}^{N_s} \frac{P(i, j)}{j^2}}{N_z}$$

Large Area Emphasis (LAE)

$$LAE = \frac{\sum_{i=1}^{N_g} \sum_{j=1}^{N_s} P(i, j)\, j^2}{N_z}$$

Gray Level Non-Uniformity (GLN)

$$GLN = \frac{\sum_{i=1}^{N_g} (\sum_{j=1}^{N_s} P(i, j))^2}{N_z}$$

Gray Level Non-Uniformity Normalized (GLNN)

$$GLN = \frac{\sum_{i=1}^{N_g} (\sum_{j=1}^{N_s} P(i, j))^2}{{N_z}^2}$$

Size Zone Non-Uniformity (SZN)

$$SZN = \frac{\sum_{j=1}^{N_s} (\sum_{i=1}^{N_g} P(i, j))^2}{N_z}$$

Size Zone Non-Uniformity Normalized (SZNN)

$$SZNN = \frac{\sum_{j=1}^{N_s} (\sum_{i=1}^{N_g} P(i, j))^2}{N_z^{\ 2}}$$

Zone Percentage (ZP)

$$ZP = \frac{N_z}{N_p}$$

Gray Level Variance (GLV)

$$GLV = \sum_{i=1}^{N_g} \sum_{j=1}^{N_s} p(i, j)(i - \mu)^2, \mu = \sum_{i=1}^{N_g} \sum_{j=1}^{N_s} p(i, j)i$$

Zone Variance (ZV)

$$ZV = \sum_{i=1}^{N_g} \sum_{j=1}^{N_s} p(i, j)(j - \mu)^2, \mu = \sum_{i=1}^{N_g} \sum_{j=1}^{N_s} p(i, j)\, j$$

Zone Entropy (ZE)

$$ZE = -\sum_{i=1}^{N_g} \sum_{j=1}^{N_s} p(i, j) \log_2 (p(i, j) + \varepsilon)$$

Low Gray Level Zone Emphasis (LGLZE)

$$LGLZE = \frac{\sum_{i=1}^{N_g} \sum_{j=1}^{N_s} \frac{P(i, j)}{i^2}}{N_z}$$

High Gray Level Zone Emphasis (HGLZE),

$$HGLZE = \frac{\sum_{i=1}^{N_g} \sum_{j=1}^{N_s} P(i, j) i^2}{N_z}$$

Small Area Low Gray Level Emphasis (SALGLE)

$$SALGLE = \frac{\sum_{i=1}^{N_g} \sum_{j=1}^{N_s} \frac{P(i, j)}{i^2 j^2}}{N_z}$$

Small Area High Gray Level Emphasis (SAHGLE)

$$SAHGLE = \frac{\sum_{i=1}^{N_g} \sum_{j=1}^{N_s} \frac{P(i, j) i^2}{j^2}}{N_z}$$

Large Area Low Gray Level Emphasis (LALGLE),

$$LALGLE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_s}\frac{P(i,j)j^2}{i^2}}{N_z}$$

Large Area High Gray Level Emphasis(LAHGLE)

$$LAHGLE = \frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_s}P(i,j)i^2 j^2}{N_z}$$

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