Supplemental Material for
"Development of a Voxel-based Radiomics Calculation Platform for Medical Image Analysis"

A set of quantitative Radiomics features are described in our calculation platform. The set of features largely builds upon the feature sets proposed by Alex Zwanenburg ([1]) and Hatt et al ([2]). The set of features can be divided into a number of families, of which *intensity* & *intensity histogram-based*, *gray level co-occurrence matrix (GLCOM)-based*, gray level run lengths matrix (GLRLM)-based, and neighbourhood gray tone difference matrix (NGTDM) based.

I. INTENSITY BASED AND INTENSITY HISTOGRAM BASED FEATURES

Preliminaries:

- $\mathbf{X}_{gl} = \{X_{gl,1}, X_{gl,2}, \ldots, X_{gl,N_v}\}$: the set of gray levels of the N_v voxels in the ROI.
- $\mathbf{X}_d = \{X_{d,1}, X_{d,2}, \ldots, X_{d,N_v}\}$: the set of discretised gray levels of the N_v voxels.
- $\mathbf{H} = \{n_1, n_2, \ldots\}$: the histogram by discretising gray level i in $\mathbf{X}_d$, where the n_i is the frequency count.
- N_g: the number of gray level bins of the histogram.
- $p_i = n_i/N_v$: the occurrence probability of gray level bin i.

A. Energy

$$F_{stat.energy} = \sum_{j=1}^{N_v} X_{gl,j}^2. \tag{1}$$

Energy measures the overall intensity.

B. Entropy

$$F_{ih.entropy} = -\sum_{i=1}^{N_g} p_i \log_2 p_i. \tag{2}$$

Entropy measures the degree of randomness present in the image content, and indicate the tumor heterogeneity.

C. Kurtosis

$$F_{stat.kurt} = \frac{\frac{1}{N_v}\sum_{j=1}^{N_v}\left(X_{gl,j}-\mu\right)^4}{\left(\frac{1}{N_v}\sum_{j=1}^{N_v}\left(X_{gl,j}-\mu\right)^2\right)^2} - 3 \tag{3}$$

Kurtosis measures the peakedness in the grey level distribution.

D. Skewness

$$F_{stat.skew} = \frac{\frac{1}{N_v}\sum_{j=1}^{N_v}\left(X_{gl,j}-\mu\right)^3}{\left(\frac{1}{N_v}\sum_{j=1}^{N_v}\left(X_{gl,j}-\mu\right)^2\right)^{3/2}} \tag{4}$$

Skewness measures degree of histogram asymmetry, and indicates the density weighting high/low about the mean HU.

II. FINE TEXTURAL FEATURES - GREY LEVEL CO-OCCURRENCE BASED FEATURES

Preliminaries:

- p_{i-j}: the diagonal probabilities, and it is expressed as

$$p_{i-j}(k) = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p_{ij}\delta(k-|i-j|) \quad k = 0,\ldots,N_g-1.$$

- p_{i+j}: the cross-diagonal probabilities, and it can be defined as

$$p_{i+j}(k) = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p_{ij}\delta(k-(i+j)) \quad k = 2,\ldots,2N_g.$$

- $p_{i.} = \sum_{j=1}^{N_g} p_{ij}$: the row marginal probability.
- $p_{.j} = \sum_{j=1}^{N_g} p_{ij}$: the column marginal probability.
- $\mu_{i.} = \sum_{i=1}^{N_g} ip_{i.}$: the mean value of row marginal probability.
- $\mu_{.j} = \sum_{j=1}^{N_g} jp_{.j}$: the mean value of column marginal probability.
- $\sigma_{i.} = \left(\sum_{i=1}^{N_g}\left(i-\mu_{i.}\right)^2 p_{i.}\right)^{1/2}$: the standard deviation of row marginal probability.
- $\sigma_{i.} = \left(\sum_{j=1}^{N_g}\left(j-\mu_{.j}\right)^2 p_{.j}\right)^{1/2}$: the standard deviation of column marginal probability.
- $HX = -\sum_{i=1}^{N_g} p_i.\log_2 p_i.$
- $HXY = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p_{ij}\log_2 p_{ij}.$
- $HXY_1 = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p_{ij}\log_2\left(p_i, p_{.j}\right)$
- $HXY_2 = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} p_{i.p.j}\log_2\left(p_{i.}p_{.j}\right)$

A. Autocorrelation

$$F_{cm.auto.corr} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} ijp_{ij} \tag{5}$$

Autocorrelation measures the linear dependency of gray levels within probability distribution. High values indicate a linearly proportional relationship between gray level intensities and their joint frequency of occurrence.

B. Cluster prominence

$$F_{cm.clust.prom} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \left(i + j - \mu_{i.} - \mu_{.j}\right)^4 p_{ij} \tag{6}$$

Cluster prominence measures of the skewness and asymmetry of the GLCOM. A higher values implies more asymmetry about the mean while a lower value indicates a peak near the mean value and less variation about the mean.

C. Cluster shade

$$F_{cm.clust.shade} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \left(i + j - \mu_{i.} - \mu_{.j}\right)^3 p_{ij} \tag{7}$$

Cluster shade measures the skewness and uniformity of the GLCOM. A higher cluster shade implies greater asymmetry about the mean.

D. Cluster tendency

$$F_{cm.clust.tend} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \left(i + j - \mu_{i.} - \mu_{.j}\right)^2 p_{ij} \tag{8}$$

Cluster tendency measures the groupings of voxels with similar gray-level values.

E. Contrast

$$F_{cm.contrast} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} (i - j)^2 p_{ij} \tag{9}$$

Contrast measures local gray level variations within probability distribution between voxel pairs (i.e., local image variations). And it indicates the tumor heterogeneity: high contrast values indicate heterogeneous fine texture by capturing large intensity differences in probability distribution.

F. Correlation

$$F_{cm.corr} = \frac{1}{\sigma_{i.}\sigma_{.j}} \left(-\mu_{i.}\mu_{.j} + \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} ij p_{ij} \right) \tag{10}$$

Correlation is a value between 0 (uncorrelated) and 1 (perfectly correlated) showing the linear dependency of gray level values to their respective voxels in the GLCOM.

G. Difference entropy

$$F_{cm.diff.entr} = -\sum_{k=0}^{N_g-1} p_{i-j}(k) \log_2 p_{i-j}(k) \tag{11}$$

Difference entropy measures the randomness/variability in neighborhood intensity value differences.

H. Dissimilarity

$$F_{cm.dissimilarity} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} |i-j| p_{ij} \tag{12}$$

Dissimilarity measures the local intensity variation defined as the mean absolute difference between the neighbouring pairs. A larger value correlates with a greater disparity in intensity values among neighboring voxels.

I. Energy

$$F_{cm.Energy} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} (p_{i,j})^2 \tag{13}$$

Energy measures the homogeneous patterns in the image. A greater Energy implies that there are more instances of intensity value pairs in the image that neighbor each other at higher frequencies.

J. Entropy

$$F_{cm.Entropy} = -\sum_{i=1}^{N_g} \sum_{j=1}^{N_g} p_{i,j} \log_2(p_{i,j}) \tag{14}$$

Entropy measures degree of randomness present in the image content and the expectation value of the images information content. High values indicate heterogeneous fine texture; entropy is maximized when all of the elements of probability distribution are equal.

K. Homogeneity 1

$$F_{cm.Homogeneity.1} = \sum_{i=1}^{N_G} \sum_{j=1}^{N_G} \frac{p_{i,j}}{1+|i-j|} \tag{15}$$

Homogeneity 1 measures linear similarity between the distribution of values in probability distribution and the principle diagonal. High values indicate homogeneous fine texture. As homogeneity increases and contrast typically decreases.

L. Homogeneity 2

$$F_{cm.Homogeneity.2} = \sum_{i=1}^{N_G}\sum_{j=1}^{N_G} \frac{p_{i,j}}{1+|i-j|^2} \tag{16}$$

Homogeneity 2 measures square power similarity between the distribution of values in probability distribution and the principle diagonal. High values indicate homogeneous fine texture. As homogeneity increases and contrast typically decreases.

M. First measure of information correlation

$$F_{cm.info.corr.1} = \frac{HXY - HXY_1}{HX} \tag{17}$$

First measure of information correlation measures non-linear gray level dependency.

N. Second measure of information correlation

$$F_{cm.info.corr.2} = \sqrt{1 - \exp\left(-2\left(HXY_2 - HXY\right)\right)} \tag{18}$$

Second measure of information correlation measures non-linear gray level dependency.

O. Inverse difference moment normalised

$$F_{cm.inv.diff.mom.norm} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} \frac{p_{ij}}{1+(i-j)^2/N_g^2} \tag{19}$$

Inverse difference moment normalised measures square power similarity between the distribution of values in probability distribution and the principle diagonal. High values indicate homogeneous fine texture relative to the image's grayscale content.

P. Inverse difference normalised

$$F_{cm.inv.diff.norm} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} \frac{p_{ij}}{1+|i-j|/N_g} \tag{20}$$

Inverse difference normalised measures linear similarity between the distribution of values in probability distribution and the principle diagonal. High values indicate homogeneous fine texture relative to the image's grayscale content.

Q. Inverse variance

$$F_{cm.inv.var} = 2\sum_{i=1}^{N_g}\sum_{j>i}^{N_g} \frac{p_{ij}}{(i-j)^2} \tag{21}$$

R. Maximum Probability

$$F_{cm.max.pro} = \max(p_{i,j}) \tag{22}$$

Maximum Probability is occurrences of the most predominant pair of neighboring intensity values.

S. Sum average

$$F_{cm.sum.avg} = \sum_{k=2}^{2N_g} k p_{i+j}(k) \tag{23}$$

Sum average measures average of the sum of the gray levels of voxel-pairs distribution. And it indicates overall image brightness

T. Sum entropy

$$F_{cm.sum.entr} = -\sum_{k=2}^{2N_g} p_{i+j}(k) \log_2 p_{i+j}(k) \tag{24}$$

Sum entropy is a sum of neighborhood intensity value differences.

U. Sum variance

$$F_{cm.sum.var} = \sum_{k=2}^{2N_g} (k-\mu)^2 p_{i+j}(k) \tag{25}$$

Sum variance measures the spread in the sum of the gray levels of voxel-pairs distribution. And It indicates the overall image brightness variations.

III. COARSE TEXTURAL FEATURES - GREY LEVEL RUN LENGTH BASED FEATURES

Preliminaries:

- N_v: the total number of voxels.
- $N_s = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} r_{ij}$: the sum over all elements in run length matrix.
- $r_{i.} = \sum_{j=1}^{N_r} r_{ij}$: the marginal sum of the runs over lengths j for gray level intensity i.
- $r_{.j} = \sum_{j=1}^{N_g} r_{ij}$: the marginal sum of the runs over gray level intensity i for run length j.
- $p_{ij} = r_{ij}/N_s$: the joint probability for gray level intensity i with run length j.
- $\mu_i = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} i p_{ij}$: mean gray level intensity.
- $\mu_j = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} j p_{ij}$: mean run length.

A. Short runs emphasis

$$F_{rlm.sre} = \frac{1}{N_s} \sum_{j=1}^{N_r} \frac{r_{.j}}{j^2} \tag{26}$$

Short runs emphasis measures the distribution of short runs within an image. And High values indicate heterogeneous coarse structural texture.

B. Long runs emphasis

$$F_{rlm.lre} = \frac{1}{N_s} \sum_{j=1}^{N_r} j^2 r_{.j} \tag{27}$$

Long runs emphasis measures distribution of long runs within an image. And high values indicate homogeneous coarse structural texture.

C. Grey level non-uniformity

$$F_{rlm.glnu} = \frac{1}{N_s} \sum_{i=1}^{N_g} r_{i.}^2 \tag{28}$$

Grey level non-uniformity measures the similarity of gray-level intensity values in the image, where a lower value correlates with a greater similarity in intensity values.

D. Grey level non-uniformity normalised

$$F_{rlm.glnu.norm} = \frac{1}{N_s^2} \sum_{i=1}^{N_g} r_{i.}^2 \tag{29}$$

Grey level non-uniformity normalised is a normalised version of the grey level non-uniformity feature

E. Run length non-uniformity

$$F_{rlm.rlnu} = \frac{1}{N_s} \sum_{j=1}^{N_r} r_{.j}^2 \tag{30}$$

Run length non-uniformity measures the similarity of run lengths throughout the image, with a lower value indicating more homogeneity among run lengths in the image.

F. Run length non-uniformity normalised

$$F_{rlm.rlnu.norm} = \frac{1}{N_s^2} \sum_{j=1}^{N_r} r_{.j}^2 \tag{31}$$

Run length non-uniformity normalised is normalised version of the run length non-uniformity feature.

G. Run percentage

$$F_{rlm.r.perc} = \frac{N_s}{N_v} \tag{32}$$

Run percentage assesses the fraction of the number of realised runs and the maximum number of potential runs. Strongly linear or highly uniform ROI volumes produce a low run percentage.

H. Low grey level run emphasis

$$F_{rlm.lgre} = \frac{1}{N_s} \sum_{i=1}^{N_g} \frac{r_{i.}}{i^2} \tag{33}$$

Low grey level run emphasis measures the distribution of runs with low gray level content. High values indicate a lower overall density distribution apparent in the coarse texture

I. High grey level run emphasis

$$F_{rlm.hgre} = \frac{1}{N_s} \sum_{i=1}^{N_g} i^2 r_{i.} \tag{34}$$

High grey level run emphasis measures the distribution of runs with high gray level content. High values indicate a higher overall density distribution apparent in the coarse texture.

J. Short run low grey level emphasis

$$F_{rlm.srlge} = \frac{1}{N_s} \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} \frac{r_{ij}}{i^2 j^2} \tag{35}$$

Short run low grey level emphasis measures the joint distribution of short runs with low gray level content. High values indicate low density, heterogeneous coarse structural texture.

K. Short run high grey level emphasis

$$F_{rlm.srhge} = \frac{1}{N_s} \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} \frac{i^2 r_{ij}}{j^2} \tag{36}$$

Short run high grey level emphasis measures the joint distribution of short runs with high gray level content. High values indicate high density, heterogeneous coarse structural texture.

L. Long run low grey level emphasis

$$F_{rlm.lrlge} = \frac{1}{N_s} \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} \frac{j^2 r_{ij}}{i^2} \tag{37}$$

Long run low grey level emphasis measures the joint distribution of long runs with low gray level content. High values indicate low density, homogeneous coarse structural texture.

M. Long run high grey level emphasis

$$F_{rlm.lrhge} = \frac{1}{N_s} \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} i^2 j^2 r_{ij} \tag{38}$$

Long run high grey level emphasis measures the joint distribution of long runs with high gray level content. High values indicate high density, homogeneous coarse structural texture.

N. Grey level variance

$$F_{rlm.gl.var} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} (i - \mu)^2 p_{ij} \tag{39}$$

Grey level variance estimates the variance in runs for the grey levels.

O. Run length variance

$$F_{rlm.rl.var} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_r} (j - \mu)^2 p_{ij} \tag{40}$$

Run length variance estimates the variance in runs for run lengths.

P. Run entropy

$$F_{rlm.rl.entr} = -\sum_{i=1}^{N_g}\sum_{j=1}^{N_r} p_{ij}\log_2 p_{ij} \tag{41}$$

Run entropy measures the uncertainty/randomness in the distribution of run lengths and gray levels. A higher value indicates more heterogeneity in the texture patterns.

IV. COARSE TEXTURAL FEATURES - GREY LEVEL SIZE ZONE BASED FEATURES

Preliminaries:

- N_v: the total number of voxels.
- $N_s = \sum_{i=1}^{N_g}\sum_{j=1}^{N_z} s_{ij}$: the sum over all elements in size zone matrix.
- $s_{i.} = \sum_{j=1}^{N_z} s_{ij}$: the marginal sum of the number of the zones for gray level intensity i.
- $s_{.j} = \sum_{i=1}^{N_g} s_{ij}$: the marginal sum of the number of the zones for size j.
- $p_{ij} = s_{ij}/N_s$: the joint probability for discretised gray level i with zone size j
- $\mu_i = \sum_{i=1}^{N_g}\sum_{j=1}^{N_r} ip_{ij}$: mean gray level intensity.
- $\mu_j = \sum_{i=1}^{N_g}\sum_{j=1}^{N_r} jp_{ij}$: mean size zone.

A. Small zone emphasis

$$F_{szm.sze} = \frac{1}{N_s}\sum_{j=1}^{N_z}\frac{s_{.j}}{j^2} \tag{42}$$

Small zone emphasis measures distribution of small zones within an image. High values indicate heterogeneous texture.

B. Large zone emphasis

$$F_{szm.lze} = \frac{1}{N_s}\sum_{j=1}^{N_z} j^2 s_{.j} \tag{43}$$

Large zone emphasis measures distribution of large zones within an image. High values indicate homogeneous texture.

C. Grey level non-uniformity

$$F_{szm.glnu} = \frac{1}{N_s}\sum_{i=1}^{N_g} s_{i.}^2 \tag{44}$$

Grey level non-uniformity assesses the distribution of zone counts over the grey values. The feature value is low when zone counts are equally distributed along grey levels.

D. Grey level non-uniformity normalised

$$F_{szm.glnu.norm} = \frac{1}{N_s^2} \sum_{i=1}^{N_g} s_{i.}^2 \tag{45}$$

Grey level non-uniformity normalised is a normalised version of the grey level non-uniformity feature.

E. Zone size non-uniformity

$$F_{szm.zsnu} = \frac{1}{N_s} \sum_{j=1}^{N_z} s_{.j}^2 \tag{46}$$

Zone size non-uniformity assesses the distribution of zone counts over the different zone sizes. The feature value is low when zone counts are equally distributed along zone sizes.

F. Zone size non-uniformity normalised

$$F_{szm.zsnu.norm} = \frac{1}{N_s^2} \sum_{i=1}^{N_z} s_{.j}^2 \tag{47}$$

Zone size non-uniformity normalised is a normalised version of the zone size non-uniformity feature.

G. Zone percentage

$$F_{szm.z.perc} = \frac{N_s}{N_v} \tag{48}$$

Zone percentage measures the number of runs per number of voxels. Low values indicate strongly linear or highly uniform ROI volumes. Zone percentage is maximized when the size of zones is 1 for all gray levels.

H. Low grey level zone emphasis

$$F_{szm.lgze} = \frac{1}{N_s} \sum_{i=1}^{N_g} \frac{s_{i.}}{i^2} \tag{49}$$

Low grey level zone emphasis measures the distribution of zones with low gray level content. High values indicate a lower overall density distribution apparent in the coarse texture.

I. High grey level zone emphasis

$$F_{szm.hgze} = \frac{1}{N_s} \sum_{i=1}^{N_g} i^2 s_{i.} \tag{50}$$

High grey level zone emphasis measures the distribution of zones with high gray level content. High values indicate a higher overall density distribution apparent in the coarse texture.

J. Small zone low grey level emphasis

$$F_{szm.szlge} = \frac{1}{N_s} \sum_{i=1}^{N_g} \sum_{j=1}^{N_z} \frac{s_{ij}}{i^2 j^2} \tag{51}$$

Small zone low grey level emphasis measures the joint distribution of small zones with low gray level content. High values indicate low density, heterogeneous coarse structural texture.

K. Small zone high grey level emphasis

$$F_{\mathrm{szm.szhge}} = \frac{1}{N_s} \sum_{i=1}^{N_g} \sum_{j=1}^{N_z} \frac{i^2 s_{ij}}{j^2} \tag{52}$$

Small zone high grey level emphasis measures the joint distribution of small zones with high gray level content. High values indicate high density, heterogeneous coarse structural texture.

L. Large zone low grey level emphasis

$$F_{szm.lzlge} = \frac{1}{N_s} \sum_{i=1}^{N_g} \sum_{j=1}^{N_z} \frac{j^2 s_{ij}}{i^2} \tag{53}$$

Large zone low grey level emphasis measures the joint distribution of large zones with low gray level content. High values indicate low density homogeneous coarse structural texture.

M. Large zone high grey level emphasis

$$F_{szm.lzhge} = \frac{1}{N_s} \sum_{i=1}^{N_g} \sum_{j=1}^{N_z} i^2 j^2 s_{ij} \tag{54}$$

Large zone high grey level emphasis measures the joint distribution of large zones with high gray level content. High values indicate high density, homogeneous coarse structural texture.

N. Grey level variance

$$F_{szm.gl.var} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_z} (i - \mu)^2 p_{ij} \tag{55}$$

Grey level variance measures the variance in zone counts for different grey levels. High values indicate a higher variance of grey levels.

O. Zone size variance

$$F_{szm.zs.var} = \sum_{i=1}^{N_g} \sum_{j=1}^{N_z} (j - \mu)^2 p_{ij} \tag{56}$$

Zone size variance measures the variance in zone counts for different zone sizes. High values indicate a higher variance of zone sizes within the image.

P. Zone size entropy

$$F_{szm.zs.entr} = -\sum_{i=1}^{N_g} \sum_{j=1}^{N_z} p_{ij} \log_2 p_{ij} \tag{57}$$

Zone size entropy measures the degree of randomness present in the image content, and indicates the heterogeneity.

V. COARSE TEXTURAL FEATURES - NEIGHBOURHOOD GREY TONE DIFFERENCE BASED FEATURES

Preliminaries:

- N_g: the number of discretised gray levels.
- $N_v = \sum n_i$
- $p_i = n_i / N_v$: gray level probabilities.
- $N_{g,p} \leq N_g$: the number of discretised gray levels with $p_i > 0$.

A. Coarseness

$$F_{ngt.coarseness} = \frac{1}{\sum_{i=1}^{N_g} p_i s_i} \tag{58}$$

Coarseness measures the degree of spatial change rate in intensity in the image. Higher coarseness values indicate a high level of spatial rate of change in intensity.

B. Contrast

$$\begin{aligned} F_{ngt.contrast} &= \left(\frac{1}{N_{g,p} \left(N_{g,p} - 1 \right)} \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} p_i p_j (i - j)^2 \right) \\ &\times \left(\frac{1}{N_v} \sum_{i=1}^{N_g} s_i \right) \end{aligned} \tag{59}$$

Contrast measures the dynamic range of the grey levels and the intensity changes within the volume. Higher contrast values indicate high intensity difference between neighboring regions and great amount of local intensity variations.

C. Busyness

$$F_{ngt.busyness} = \frac{\sum_{i=1}^{N_g} p_i s_i}{\sum_{i=1}^{N_g} \sum_{j=1}^{N_g} i p_i - j p_j}, \quad p_i \neq 0 \text{ and } p_j \neq 0 \tag{60}$$

Busyness measures the changes between neighboring voxels. Higher busyness values indicate rapid changes of intensity from one pixel to its neighbor, i.e., a high spatial frequency of intensity changes.

D. Complexity

$$F_{ntg.complexity} = \frac{1}{N_v} \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} |i-j| \frac{p_i s_i + p_j s_j}{p_i + p_j}, \quad p_i \neq 0 \text{ and } p_j \neq 0 \tag{61}$$

High *complexity* may indicate many sharp edges and/or lines.

E. Strength

$$F_{ngt.strength} = \frac{\sum_{i=1}^{N_g} \sum_{j=1}^{N_g} (p_i + p_j)(i-j)^2}{\sum_{i=1}^{N_g} s_i}, \quad p_i \neq 0 \text{ and } p_j \neq 0 \tag{62}$$

High *strength* values emphasize the boldness or distinctiveness of intensity values.

[1] H. J. W. L. Aerts, E. R. Velazquez, R. T. H. Leijenaar, C. Parmar, P. Grossmann, S. Carvalho, J. Bussink, R. Monshouwer, B. Haibe-Kains, D. Rietveld, F. Hoebers, M. M. Rietbergen, C. R. Leemans, A. Dekker, J. Quackenbush, R. J. Gillies, and P. Lambin, “Decoding tumour phenotype by noninvasive imaging using a quantitative radiomics approach,” *Nature Communications*, vol. 5, jun 2014.

[2] M. Hatt, F. Tixier, L. Pierce, P. E. Kinahan, C. C. L. Rest, and D. Visvikis, “Characterization of PET/CT images using texture analysis: the past, the present... any future?,” *European Journal of Nuclear Medicine and Molecular Imaging*, vol. 44, pp. 151–165, jun 2016.