A Novel Point Cloud Quality Assessment Metric Based On Perceptual Color Distance Patterns

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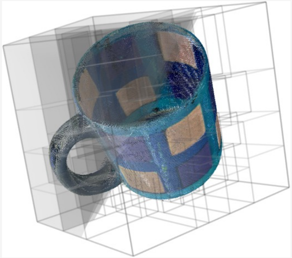
Summary

- Point Cloud Quality Assessment
- Proposed Method
- Experimental Setup
- Results
- Conclusions

Point Clouds

- Point Clouds have points with 3D position information (x, y, z), color information (R, G, B), and possibly attributes such as normal vector, time of acquisition, reflectance of laser, etc.



Point Cloud Subjective Quality Assessment

- Subjective Quality Assessment experiments - Measure humans perceived PC quality for different stimuli conditions
- Psychophysical experiments with human participants are labor-intensive and time-consuming
    - P. Stuart, H. P. Cong, L. A. da Silva Cruz, J. Prazeres, M. Pereira, A. Pinheiro, E. Dumic, E. Alexiou, and T. Ebrahimi, **Quality evaluation of static point clouds encoded using MPEG codecs**, in 2020 IEEE International Conference on Image Processing (ICIP), pp. 3428-3432. IEEE, 2020.
    - E. M. Torlig, E. Alexiou, T. A. Fonseca, R. L. de Queiroz, and T. Ebrahimi, **A novel methodology for quality assessment of voxelized point clouds**, in Applications of Digital Image Processing XLI, vol. 10752. International Society for Optics and Photonics, 2018, p. 107520I.
    - E. Alexiou, I. Viola, T. M. Borges, T. A. Fonseca, R. L. de Queiroz, and T. Ebrahimi, **A comprehensive study of the rate-distortion performance in mpeg pointcloud compression**, APSIPA Transactions on Signal and Information Processing, vol. 8, 2019.

Point Cloud Objective Quality Assessment

- Objective Quality Assessment Metrics - automatically predict visual quality
- Eg. Based on point-to-point, point-to-plane or plane-to-plane spatial and texture distances. Also projection-based metrics which leverage standard 2D image metrics
  - E. Alexiou and T. Ebrahimi, **Point cloud quality assessment metric based on angular similarity**, in 2018 IEEE International Conference on Multimedia and Expo (ICME). IEEE, 2018, pp. 1–6.
  - E. M. Torlig, E. Alexiou, T. A. Fonseca, R. L. de Queiroz, and T. Ebrahimi, **A novel methodology for quality assessment of voxelized point clouds**, in Applications of Digital Image Processing XLI, vol. 10752. International Society for Optics and Photonics, 2018, p. 107520I.
  - G. Meynet, J. Digne, and G. Lavoué, **Pc-msdm: A quality metric for 3d point clouds**, in 2019 Eleventh International Conference on Quality of Multimedia Experience (QoMEX). IEEE, 2019, pp. 1–3.

Proposed Method

- Prior work: R. Diniz, P. G. Freitas, and M. C. Farias, **Local Luminance Patterns for Point Cloud Quality Assessment**, in 2020 IEEE 22nd International Workshop on Multimedia Signal Processing (MMSP) 2020 Sep 21 (pp. 1-6). IEEE.

- The proposed objective full-reference PCQA method is based on the previous approach, and has the following steps:
  - Voxelization Methodology
  - The novel Perceptual Color Distance Patterns (PCDP) operator creates a Feature Map (FM)
  - Compute distance between FM histograms (reference vs test)
  - Quality prediction model based on a regression algorithm

1. Voxelization Methodology

- Points are sparsely distributed in the 3D space without volumetric meaning
- Voxelization convert point(s) to discrete volumetric units (voxels)
- We test with different voxel sizes, based on the average distance of the k-nearest neighbors of each point in a PC
- Details in: R. Diniz, P. G. Freitas and M. C. Q. Farias, **Towards a Point Cloud Quality Assessment Model using Local Binary Patterns**. In Twelfth International Conference on Quality of Multimedia Experience (QoMEX) IEEE, 2020, pp. 1-6.

1. Voxelization Methodology

- The voxel size (VS) is obtained through the Edge Size[3] (ES):

$$\text{ES} = \frac{k}{S} \cdot \sum_{n=1}^{S} \left(\frac{1}{k_{nn}} \cdot \sum_{i=1}^{k_{nn}} \mathbf{d}\left(N_i(P_n), P_n\right) \right)$$

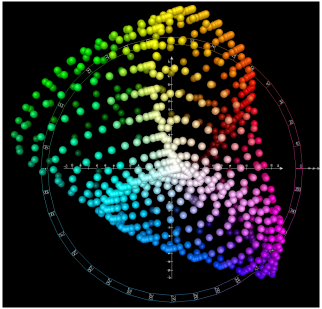
- S is the number of points of the PC
- k is a constant tested with different values (a multiplier of ES)
- P_n is the *n*-th point of a PC
- $N_i(P_n)$ gives the coordinates of the i-th nearest point to P_n
- $\mathbf{d}\left(P_a, P_b\right)$ gives the Euclidean distance of points P_a and P_b
- k_{nn} is the k-nearest neighbors and is set to 8 in this work.

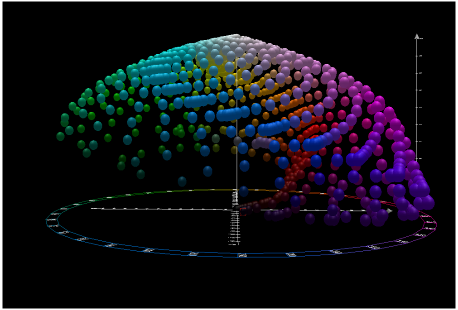
2. Perceptual Color Distance Patterns (PCDP) Feature Map extraction

- Voxels converted from RGB to CIELab color space
- For each voxel P_n, the CIELab Delta-E (CIEDE2000) perceptual color distances to each P_i N-nearest voxels are calculated
- A label of size B bits is extracted for each voxel based on the perceptual distances of the neighbors
- We adopt $N = 12$ and $B = 8$ in this work.
- The label is a bit vector in which each bit is set according to the Delta-E distances of the neighbors. If the distance is less than 2.5 (JND threshold), no bit is set. If it is between 2.5 and 5, bit 0 is set, if between 5 and 7.5, bit 1 is set, and so on, until bit 6 which is set if the distance is between 17.5 and 20, and finally bit 7 is set if distance is greater than 20.

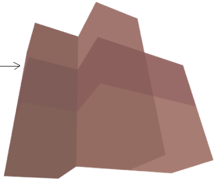
2. Perceptual Color Distance Patterns - CIEDE2000

- CIELab color space - intended as a perceptually uniform space - has 3 channels: $L*$ for perceptual lightness, $a*$ is relative to green-red opponent colors, and $b*$ for the blue-yellow axis.
- CIELab color space is not really uniform - CIEDE2000 (CIELab Delta-E 2000) distance was introduced to fix CIELab perceptual non-linearities
- A numerical change corresponds to similar perceived change in color





2. Perceptual Color Distance Patterns Example



	RED	GREEN	BLUE	delta-E	label bit
TARGET	130	91	88	0	/
	139	96	92	2.533617	0
	128	92	88	1.0756	/
	153	107	104	7.109899	1
	161	118	111	11.038319	3
	149	108	98	7.247803	1
	130	97	88	3.977761	0
	141	102	94	4.633231	0
	167	124	114	13.56139	4

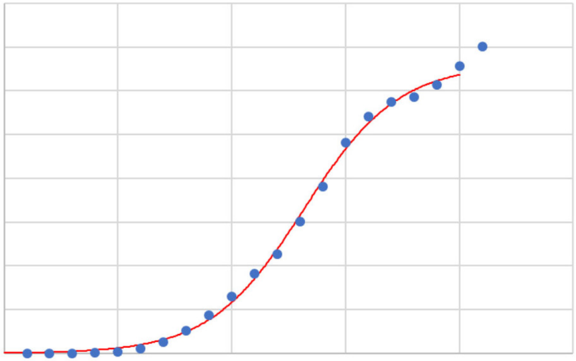
LABEL: 00011011b
bit position: 76543210

3. Histogram distances calculation

- Feature Map (FM) contains PC PCDP labels
- The histograms are obtained from the statistics of reference and test PC FMs
- Different distance measures for the references and test PCs were evaluated, namely: Bray-Curtis, Canberra, Chebyshev, City Block, Cosine, Euclidean, Jensen-Shannon, Wasserstein and Energy.

4. Quality prediction model

- Logistic function adopted for our quality prediction model
- As discussed in prior work, Logistic function provides the best results among traditional regressors



Experimental setup - Subjective scores

We used the proposed data-set, named D1 to D4 and subjective scores as follows:

- D1: Torlig 2018 [a]
- D2: Cruz 2019 [b]
- D3: Alexiou 2019 [c]
- D4: Stuart 2020 [d]

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[a] A novel methodology for quality assessment of voxelized point clouds
[b] Point cloud quality evaluation: Towards a definition for test conditions
[c] A comprehensive study of the rate-distortion performance in mpeg pointcloud compression
[d] Quality evaluation of static point clouds encoded using MPEG codecs

Experimental setup - Objective PCQA metrics

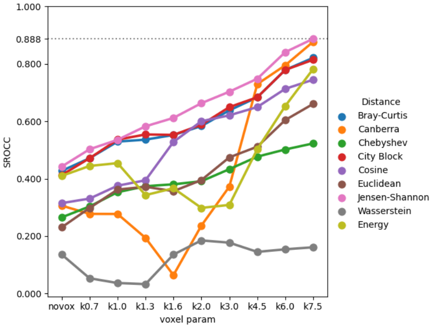
We opted to use the MPEG-released PC metrics software as the benchmark. It contains the following metrics:

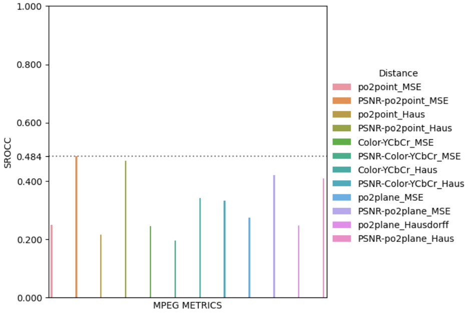
po2point$_{MSE}$	PSNR-po2point$_{MSE}$	po2point$_{Haus}$	PSNR-po2point$_{Haus}$
Color-YCbCr$_{MSE}$	PSNR-Color-YCbCr$_{MSE}$	Color-YCbCr$_{Haus}$	PSNR-Color-YCbCr$_{Haus}$
po2plane$_{MSE}$	PSNR-po2plane$_{MSE}$	po2plane$_{Hausdorff}$	PSNR-po2plane$_{Haus}$

Experimental Results

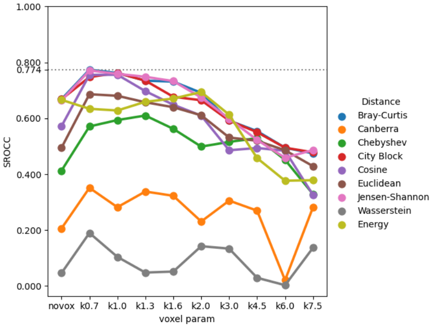
- Calculated PCC, SROCC and RMSE of metrics with 4 datasets.
- We show the SROCC for our metrics with different voxel sizes and FM distances calculation, and for the MPEG metrics

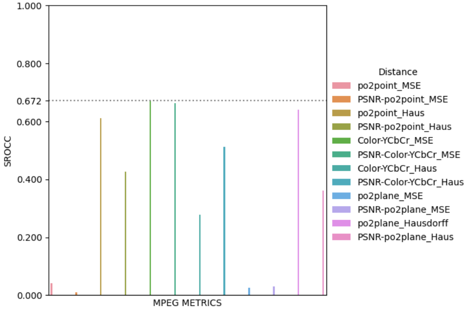
Experimental Results - Dataset D1

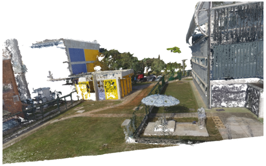




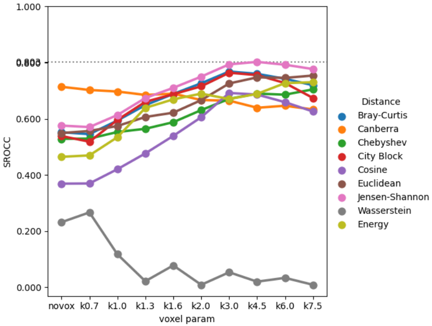
Experimental Results - Dataset D2

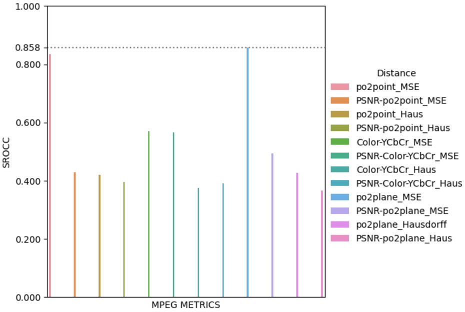




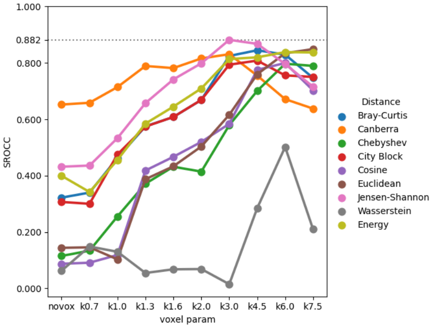


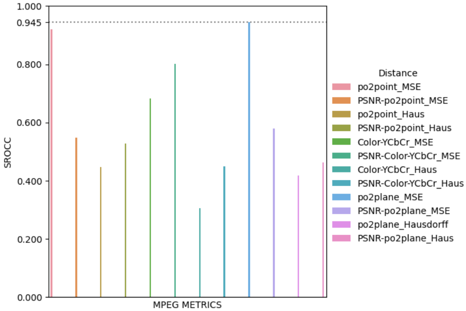
Experimental Results - Dataset D3





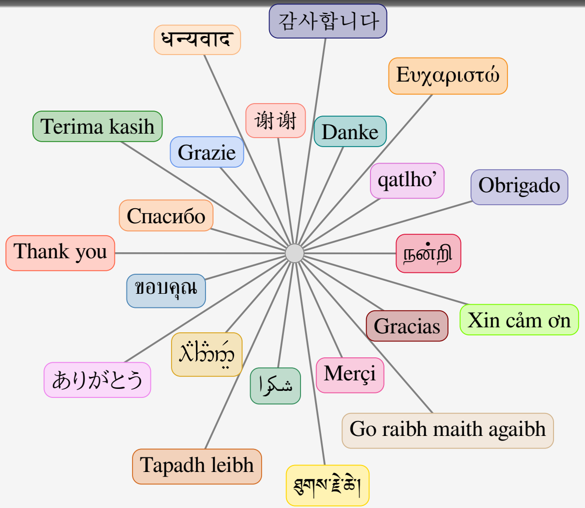
Experimental Results - Dataset D4





Results and Conclusions

- The Jensen-Shannon distance presented the best results with our PCDP operator
- The voxel size influences the performance of the operator. A way to optimize its selection is desirable, as different data-sets had different subjective procedures assessment methods
- When using the Jensen-Shannon distance, our proposal outscores all MPEG reference metrics in D1 and D2, in almost any k voxel setting
- In D3 and D4 we are third best with optimum k setting, after Point-to-Plane MSE and Point-to-Point MSE
- The MPEG metrics seem to work well when the content is degraded with the MPEG PC encoders, in which test conditions degrade geometry and color with analogous intensity
- Introduces a novel scale and rotation invariant PCQA method based on perceptual color differences
- Promising results with strong performance when compared to other metrics



Questions?

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