Improving PSNR-based Quality Metrics Performance for Point Cloud Geometry

Alireza Javaheri
Catarina Brites
Fernando Pereira
João Ascenso

Instituições Associadas

TÉCNICO LISBOA
universidade de aveiro
UNIVERSIDADE DE COIMBRA
altice labs
NOKIA
UNIVERSIDADE BEIRA INTERIOR
U.PORTO
ISCTE IUL Instituto Universitário de Lisboa
IPL Instituto politécnico de leiria

IEEE 27th International Conference on Image Processing (ICIP)
25th-28th October 2020, Abu-Dhabi, UAE

instituto de telecomunicações

Outline

1. Introduction

Context and Motivation

- Efficient compression is necessary to deal with large amount of data for point cloud (PC) in most applications
- Quality assessment is fundamental to evaluate the performance of the compression schemes

Egyptian Mask 12-bit   Egyptian Mask 20-bit   Frog 12-bit

- **Motivation**
  - PC intrinsic characteristics play an important role on the final perceived quality
  - MPEG D1 and D2 PSNR do not consider the content type, number of points and distribution of the points (sparse vs. dense)

Objective and Contibutions

The objective of this paper is to propose new quality metrics that measure the level of geometry degradation of PCs with different characteristics, e.g. content type, number of points and distribution of the points (sparse vs. dense) to achieve higher performance

- **Contributions**
  - Propose and evaluate several geometry quality PSNR-based metrics that exploit the *intrinsic characteristics* of a PC
  - Propose and evaluate a novel geometry quality PSNR-based metric that exploits the way that PCs are typically rendered

instituto de telecomunicações

TÉCNICO LISBOA

2. PSNR-Based Geometry Quality Metrics

MPEG PC Geometry Quality Metrics – D1 PSNR

- Point-to-point Euclidean distance is measured between each point in *PC A* and its nearest neighbor in *PC B*

$$d_{A,B}^{Po2Po} = \|\vec{e}(i,j)\|_2^2$$

- Directed Mean Squared Error (MSE) between all points to their nearest neighbor is computed in two directions:
  - Original (A) to degraded (B)
  - Degraded (B) to original (A)

$$d_{A,B}^{MSE} = \frac{1}{N_A} \sum_{\forall a_i \in A} d_{A,B}^{Po2Po}(i)$$

$$d_{B,A}^{MSE} = \frac{1}{N_B} \sum_{\forall b_i \in B} d_{B,A}^{Po2Po}(i)$$

- **D1** is the <u>maximum</u> of two directed distances:

$$D1 = max\ (d_{A,B}^{MSE}, d_{B,A}^{MSE})$$

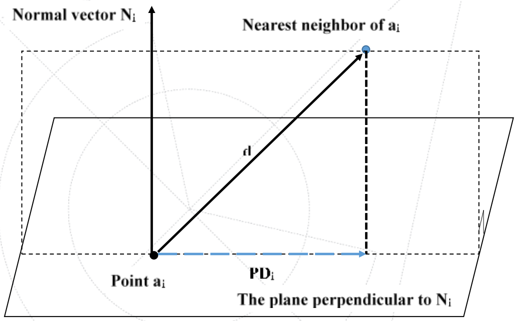
- **D1 PSNR** is computed using D1 distance:

$$D1\ PSNR = 10 \log_{10}(\frac{{p_s}^2}{D1})$$

instituto de telecomunicações

TÉCNICO LISBOA

MPEG PC Geometry Quality Metrics – D2 PSNR



- Point-to-plane distance is computed as projection of the point-to-point Euclidean distance vector onto the normal vector at reference point

$$d_{A,B}^{Po2Po} = \|\vec{e}(i,j)\|_2^2$$

$$d_{A,B}^{Po2Pl} = \|\hat{e}(i,j)\|_2^2 = (\vec{e}(i,j).\vec{n}_j)^2$$

- Directed MSE between all points to their nearest neighbor is computed in two directions:
  - Original (A) to degraded (B)
  - Degraded (B) to original (A)

$$d_{A,B}^{MSE} = \frac{1}{N_A}\sum_{\forall a_i \in A} d_{A,B}^{Po2Pl}(i)$$

$$d_{B,A}^{MSE} = \frac{1}{N_B}\sum_{\forall b_i \in B} d_{B,A}^{Po2Pl}(i)$$

- **D2** is <u>maximum</u> of two <u>projected</u> directed distances:

$$D2 = max\,(d_{A,B}^{MSE}, d_{B,A}^{MSE})$$

- **D2 PSNR** is computed on D2 distance:

$$D2\ PSNR = 10\,log_{10}(\frac{{p_s}^2}{D_2})$$

MPEG PC Geometry Quality Metrics – PSNR Peak

- **Non-voxelized**
  - The largest diagonal (LD) distance of the PC bounding box.

$$p_s = LD = \|(x_{max}, y_{max}, z_{max}) - (x_{min}, y_{min}, z_{min})\|_2$$

- **Voxelized**
  - Point coordinates are bounded between zero and a constant integer related to the PC precision (*b*)
  - Coordinate peak $p_c = 2^b - 1$
  - Signal peak $p_s = \|(p_c, p_c, p_c) - (0,0,0)\|_2 = \sqrt{3}p_c$

3. Intrinsic Resolution PSNR-Based Quality Metrics (I-PSNR)

Intrinsic Resolution PSNR-based Quality Metric

Egyptian Mask 12-bit   Egyptian Mask 20-bit   Frog 12-bit

Intrinsic Resolution

- Measure of distance between points within a PC

Intrinsic Resolution Estimation

- Maximum nearest neighbour[1] (MNN)
  - Sensitive to holes and local sparse areas
- Average nearest neighbor (ANN) - *proposed*
- Average of K nearest neighbors (ANN_k) - *proposed*

$$MNN = \max_{\forall i \in O} d_i$$

$$ANN = \sqrt{\frac{1}{N_O} \sum_{i \in O} {d_i}^2}$$

$$ANN_k = \sqrt{\frac{1}{N_O} \sum_{i \in O} \left(\frac{1}{k} \sum_{j=1}^{k} d_{i,j}^2 \right)}$$

Quality Metric Design

- Intrinsic resolution is used as PSNR peak

$$I\!-\!PSNR = 10\, log_{10} \left(\frac{p_s^2}{d^{MSE}} \right)$$

1 - D. Tian, H. Ochimizu, C. Feng, R. Cohen, and A. Vetro, "Geometric distortion metrics for point cloud compression," *IEEE Int. Conference on Image Processing*, Beijing, China, Sept. 2017.

4. Resolution Adaptive PSNR-Based Quality Metrics (RA-PSNR)

Rendering Resolution

- PCs are rendered as images or videos from one or more viewpoints before being shown on a 2D display
- PCs are always evaluated by the users after rendering:
  - The final perceived quality also strongly depends on the rendering process
- Rendering resolution may vary for different parts of the PC because of the orientation of the PC surfaces in the 3D world relative to the observer viewing location

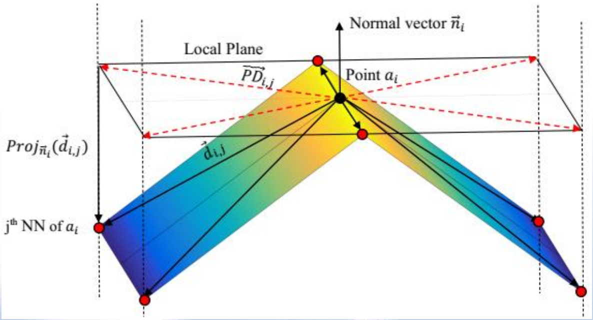
Rendering Resolution Estimation Procedure

1. Define a local neighborhood around point a_i, which includes the k nearest neighboring points
2. Define a local plane tangent at point a_i. This plane is perpendicular to the normal vector $\vec{n}_i$ and represents the PC surface at this point
3. Project all distance vectors ($\vec{d}_{i,j}$) between point a_i and its j^th^ nearest neighbour (planar distance)

$$\overrightarrow{PD}_i = Proj_{plane}(\vec{d}_{i,j}) = \vec{d}_{i,j} - Proj_{\vec{n}_i}(\vec{d}_{i,j})$$

4. Estimate the rendering resolution as the average (planar) distance between point a_i and their k local neighbors on the tangent plane

$$APD_k = \frac{1}{N_O}\sum_{i\in O}\left(\frac{1}{k}\sum_{j=1}^{k}\left\|\overrightarrow{PD}_{i,j}\right\|_2^2\right)$$



RA-PSNR PC Quality Metric Design

- RA-PSNR estimates the PC intrinsic quality by exploiting the intrinsic or rendering resolution and compensates changes in the precision

- Density coefficient μ corresponds to the normalization of the intrinsic/rendering resolution according to the PC precision

$$\mu = \frac{p_c}{r}$$

- RA-PSNR scales MSEs according to μ as well as p

$$RA\text{−}PSNR = 10\, log_{10} \frac{3p_c^2}{\mu d^{MSE}} = 10\, log_{10} \frac{3rp_c}{d^{MSE}}$$

instituto de telecomunicações

TÉCNICO LISBOA

5. Performance Evaluation

IST Rendered Point Cloud (IRPC) Quality Assessment Dataset

PC Name	No. Points	Precision	Category
Egyptian Mask	272,684	12 bit	Inanimate Objects
Frog	3,614,251	12 bit	Inanimate Objects
Facade9	1,596,085	12 bit	Facades & Buildings
House without roof	4,848,745	12 bit	Facades & Buildings
Loot	805,285	10 bit	People
Longdress	857,966	10 bit	People

- **Content:** 6 PCs from MPEG voxelized PCs
- **Codecs and Rates:**
  - Octree-based codec from PCL
  - MPEG G-PCC (TriSoup)
  - MPEG V-PCC codec
  - 3 distinguishable qualities using the rates defined in MPEG CTC
- **RPoint rendering:** PCs are rendered using a point representation with uniform color and shading
- **Subjects:** 20, 18 common between sessions
- **Methodology:** Double Stimulus Impairment Scale (*DSIS)*
- **Camera Path:** Video sequences are created by rotating the object

Correlation Performance of the Proposed Metrics

- I-PSNR outperforms MPEG PSNRs
- I-PSNR using proposed intrinsic resolution estimations is performing better than I-PSNR using MNN

PLCC and SROCC correlation performance of objective metrics after cubic fitting

Metric	Variant	Type	PCL		G-PCC		V-PCC		All	
			PLCC	SROCC	PLCC	SROCC	PLCC	SROCC	PLC	SROCC
PSNR	P	*Po2Po*	87.0	73.9	86.9	87.4	53.1	62.0	67.3	64.7
		Po2Pl	89.6	80.9	83.4	85.6	51.4	49.6	70.3	65.6
	LD	*Po2Po*	83.3	82.3	86.0	89.3	48.9	54.1	70.4	68.6
		Po2Pl	86.7	85.9	75.6	71.9	59.9	58.9	71.4	67.2
I-PSNR	MNN	*Po2Po*	68.7	65.0	40.8	33.3	45.6	14.3	49.7	42.2
		Po2Pl	69.6	66.7	44.1	39.7	49.8	25.4	52.1	43.4
	ANN	*Po2Po*	92.2	89.0	79.3	76.3	66.6	61.0	64.7	52.5
		Po2Pl	92.3	84.5	86.6	79.0	76.2	69.1	66.4	55.6
	ANNk	*Po2Po*	88.8	87.0	78.1	68.4	70.8	62.9	66.5	59.2
		Po2Pl	90.8	87.5	75.3	68.2	**79.6**	**74.0**	67.4	62.6
RA-PSNR	ANN	*Po2Po*	92.8	86.8	84.9	82.5	49.2	45.6	68.9	64.0
		Po2Pl	93.4	86.7	88.5	85.8	67.9	63.0	71.0	67.1
	ANNk	*Po2Po*	94.1	86.2	93.6	94.6	68.5	62.5	74.1	71.1
		Po2Pl	95.1	91.3	94.0	94.0	77.1	73.7	74.9	72.5
	APDk	*Po2Po*	94.1	85.2	93.7	**94.8**	59.9	59.7	74.0	71.4
		Po2Pl	**95.2**	**91.7**	**94.0**	94.0	77.9	72.3	**75.6**	**73.8**

instituto de telecomunicações | TÉCNICO LISBOA

Correlation Performance of the Proposed Metrics

- RA-PSNR outperforms MPEG PSNR metrics and I-PSNR significantly
- APD which considers rendering resolution performs better, especially for All codecs together

PLCC and SROCC correlation performance of objective metrics after cubic fitting

Metric	Variant	Type	PCL		G-PCC		V-PCC		All	
			PLCC	SROCC	PLCC	SROCC	PLCC	SROCC	PLC	SROCC
PSNR	P	*Po2Po*	87.0	73.9	86.9	87.4	53.1	62.0	67.3	64.7
		Po2Pl	89.6	80.9	83.4	85.6	51.4	49.6	70.3	65.6
	LD	*Po2Po*	83.3	82.3	86.0	89.3	48.9	54.1	70.4	68.6
		Po2Pl	86.7	85.9	75.6	71.9	59.9	58.9	71.4	67.2
I-PSNR	MNN	*Po2Po*	68.7	65.0	40.8	33.3	45.6	14.3	49.7	42.2
		Po2Pl	69.6	66.7	44.1	39.7	49.8	25.4	52.1	43.4
	ANN	*Po2Po*	92.2	89.0	79.3	76.3	66.6	61.0	64.7	52.5
		Po2Pl	92.3	84.5	86.6	79.0	76.2	69.1	66.4	55.6
	ANNk	*Po2Po*	88.8	87.0	78.1	68.4	70.8	62.9	66.5	59.2
		Po2Pl	90.8	87.5	75.3	68.2	**79.6**	**74.0**	67.4	62.6
RA-PSNR	ANN	*Po2Po*	92.8	86.8	84.9	82.5	49.2	45.6	68.9	64.0
		Po2Pl	93.4	86.7	88.5	85.8	67.9	63.0	71.0	67.1
	ANNk	*Po2Po*	94.1	86.2	93.6	94.6	68.5	62.5	74.1	71.1
		Po2Pl	95.1	91.3	94.0	94.0	77.1	73.7	74.9	72.5
	APDk	*Po2Po*	94.1	85.2	93.7	**94.8**	59.9	59.7	74.0	71.4
		Po2Pl	**95.2**	**91.7**	**94.0**	94.0	77.9	72.3	**75.6**	**73.8**

Correlation Performance of the Proposed Metrics

- PCL and G-PCC are mix of 10-bit and 12-bit, but V-PCC is all 10-bit

- Normalizing by Precision works as a distractor and decreases the performance

PLCC and SROCC correlation performance of objective metrics after cubic fitting

Metric	Variant	Type	PCL		G-PCC		V-PCC		All	
			PLCC	SROCC	PLCC	SROCC	PLCC	SROCC	PLC	SROCC
PSNR	P	*Po2Po*	87.0	73.9	86.9	87.4	53.1	62.0	67.3	64.7
		Po2Pl	89.6	80.9	83.4	85.6	51.4	49.6	70.3	65.6
	LD	*Po2Po*	83.3	82.3	86.0	89.3	48.9	54.1	70.4	68.6
		Po2Pl	86.7	85.9	75.6	71.9	59.9	58.9	71.4	67.2
I-PSNR	MNN	*Po2Po*	68.7	65.0	40.8	33.3	45.6	14.3	49.7	42.2
		Po2Pl	69.6	66.7	44.1	39.7	49.8	25.4	52.1	43.4
	ANN	*Po2Po*	92.2	89.0	79.3	76.3	66.6	61.0	64.7	52.5
		Po2Pl	92.3	84.5	86.6	79.0	76.2	69.1	66.4	55.6
	ANNk	*Po2Po*	88.8	87.0	78.1	68.4	70.8	62.9	66.5	59.2
		Po2Pl	90.8	87.5	75.3	68.2	**79.6**	**74.0**	67.4	62.6
RA-PSNR	ANN	*Po2Po*	92.8	86.8	84.9	82.5	49.2	45.6	68.9	64.0
		Po2Pl	93.4	86.7	88.5	85.8	67.9	63.0	71.0	67.1
	ANNk	*Po2Po*	94.1	86.2	93.6	94.6	68.5	62.5	74.1	71.1
		Po2Pl	95.1	91.3	94.0	94.0	77.1	73.7	74.9	72.5
	APDk	*Po2Po*	94.1	85.2	93.7	**94.8**	59.9	59.7	74.0	71.4
		Po2Pl	**95.2**	**91.7**	**94.0**	94.0	77.9	72.3	**75.6**	**73.8**

6. Conclusions

Conclusions

- State-of-the-art PC geometry quality assessment metrics perform poorly
- Impact of the following factors on the final perceived PC quality are usually not considered:
  - Intrinsic PC characteristics
  - The rendering process

- In this work, the popular PSNR-based metrics are improved by including a normalization factor that accounts for changes in the intrinsic PC resolution after rendering, as well as the PC precision

- Experimental results show that the proposed metrics outperform state-of-the-art MPEG quality metrics by a significant margin

Thank you
For your Attention

email: alireza.javaheri@lx.it.pt

instituto de telecomunicações

TÉCNICO LISBOA