

Supplementary Materials

The Effect of Temporal Sub-sampling on the Accuracy of Volumetric Video Quality Assessment

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I. INTRODUCTION

This supplementary document provides additional results for our main paper “The Effect of Temporal Sub-sampling on the Accuracy of Volumetric Video Quality Assessment”. As mentioned in the main paper, to evaluate the effect of temporal sub-sampling on volumetric video quality assessment accuracy, the Pearson correlation coefficient (PCC) and root-mean squared error (RMSE) were used for prediction accuracy and Spearman rank-ordered correlation coefficient (SROCC) was used for prediction monotonicity as recommended in [1]. Due to the page limitations, only PCC could be reported in the main paper.

In this supplementary document, we provide the SROCC and RMSE results that could not be reported in the main paper. The results for different pooling methods and different temporal sub-sampling rates are shown in Tables I-IV. Furthermore, we report our findings on the combined analysis for temporal sub-sampling and temporal pooling.

TABLE I

SROCC VALUES BETWEEN METRIC SCORES AND DMOS FOR DIFFERENT TEMPORAL SAMPLING RATES WITH ARITHMETIC MEAN.

	1-fps	2-fps	3-fps	5-fps	6-fps	10-fps	15-fps	30-fps
MP-PSNR-FR	0.5767	0.4569	0.5127	0.4611	0.4368	0.4051	0.4308	0.4740
MP-PSNR-RR	0.6552	0.6392	0.6337	0.6285	0.6289	0.6323	0.6290	0.6275
MW-PSNR-FR	0.6055	0.6125	0.6132	0.6073	0.6128	0.6130	0.6095	0.6084
MW-PSNR-RR	0.6325	0.6319	0.6392	0.6303	0.6412	0.6341	0.6304	0.6317
PSNR	0.7404	0.7404	0.7422	0.7379	0.7384	0.7407	0.7405	0.7415
SSIM	0.8544	0.8538	0.8533	0.8509	0.8535	0.8529	0.8518	0.8531
NIQSV	0.0610	0.2051	0.1222	0.1080	0.2360	0.2451	0.1130	0.0728
NIQSV+	0.1934	0.1975	0.2038	0.2167	0.2066	0.2028	0.2129	0.2021
APT	0.1156	0.1253	0.1366	0.1336	0.1471	0.0500	0.0634	0.1000
EM-IQM	0.3259	0.3678	0.4231	0.4366	0.4793	0.4462	0.4519	0.4436
SI-IQM	0.8459	0.8386	0.8374	0.8385	0.8380	0.8378	0.8394	0.8374
Color-Y	0.7900	0.7891	0.7815	0.7803	0.7809	0.7799	0.7810	0.7818
Color-Y-PSNR	0.7884	0.7882	0.7799	0.7790	0.7798	0.7799	0.7801	0.7811
Color-U	0.4804	0.4780	0.4799	0.4798	0.4761	0.4772	0.4799	0.4772
Color-U-PSNR	0.4834	0.4800	0.4829	0.4842	0.4802	0.4808	0.4837	0.4807
Color-V	0.4718	0.4664	0.4714	0.4713	0.4661	0.4658	0.4713	0.4658
Color-V-PSNR	0.4717	0.4654	0.4711	0.4710	0.4600	0.4643	0.4712	0.4511
p2point-Haus	0.2793	0.2771	0.2733	0.3316	0.2814	0.2554	0.2935	0.2793
p2point-Haus-PSNR	0.5641	0.5819	0.6000	0.6027	0.6056	0.6045	0.6066	0.6099
p2point-RMS	0.8673	0.8692	0.8694	0.8683	0.8692	0.8671	0.8655	0.8665
p2point-RMS-PSNR	0.7731	0.7991	0.7798	0.7834	0.7814	0.7826	0.7800	0.7704
p2plane-Haus	0.0593	0.1152	0.1220	0.0759	0.1292	0.0781	0.1856	0.1682
p2plane-Haus-PSNR	0.1406	0.1664	0.1403	0.1382	0.1296	0.1460	0.1307	0.1453
p2plane-RMS	0.3677	0.3648	0.3655	0.3666	0.3653	0.3665	0.3620	0.3647
p2plane-RMS-PSNR	0.8426	0.8433	0.8367	0.8363	0.4515	0.8392	0.8376	0.8363
pl2plane-MSE	0.3928	0.3723	0.3717	0.3722	0.3730	0.3651	0.3718	0.3655
pl2plane-RMS	0.3928	0.3739	0.3718	0.3726	0.3730	0.3725	0.3715	0.3726
pl2plane-Mean	0.3340	0.3315	0.3295	0.3297	0.3302	0.3294	0.3290	0.3339
pl2plane-Median	0.3340	0.3315	0.3295	0.3297	0.3302	0.3294	0.3290	0.3339
pl2plane-Min	0.1494	-0.0333	0.1010	0.1089	0.1025	0.0354	0.0177	-0.0009

TABLE II

RMSE VALUES BETWEEN METRIC SCORES AND DMOS FOR DIFFERENT TEMPORAL SAMPLING RATES WITH ARITHMETIC MEAN.

	1-fps	2-fps	3-fps	5-fps	6-fps	10-fps	15-fps	30-fps
MP-PSNR-FR	13.2316	19.1961	13.7214	19.0517	18.5129	18.2415	18.4535	18.9374
MP-PSNR-RR	13.6348	14.0949	13.4371	12.9869	14.0262	12.9527	14.0424	12.9692
MW-PSNR-FR	13.5513	13.3216	14.3563	13.4860	13.3643	13.3840	13.9899	13.4405
MW-PSNR-RR	13.9099	12.9490	13.8577	13.0759	13.6740	13.7775	13.0525	12.9618
PSNR	10.7628	11.1110	10.7241	10.7845	11.0891	11.1124	11.1351	11.1476
SSIM	8.2153	8.2846	8.3087	8.3582	8.3279	8.3329	8.3515	8.3390
NIQSV	19.5910	19.0928	19.6315	19.6706	18.7075	18.6376	19.6554	19.6864
NIQSV+	19.2647	19.1575	19.0806	19.0645	19.1443	19.1556	19.0641	19.1515
APT	18.5571	19.0000	18.8956	18.9132	18.9429	18.9408	18.9370	18.9471
EM-IQM	18.6184	18.3488	18.2175	18.0197	17.5784	17.9672	18.1072	17.9914
SI-IQM	9.0906	9.1860	9.2493	9.2113	9.2276	9.2026	9.1745	9.1916
Color-Y	10.4972	10.5358	10.5724	10.6020	10.6497	10.6476	10.5766	10.6395
Color-Y-PSNR	10.5029	10.6718	10.9625	10.6170	10.6608	10.8819	10.6022	10.6556
Color-U	16.5599	16.5983	16.5832	16.5687	16.6232	16.6036	16.5650	16.6021
Color-U-PSNR	16.6767	16.5648	16.5329	16.2584	16.5961	16.6856	16.5436	16.5810
Color-V	16.2037	16.2550	16.1920	16.1795	16.2454	16.2457	16.1784	16.2440
Color-V-PSNR	16.9023	16.2606	16.9077	16.9037	16.5558	16.3510	16.2348	16.3752
p2point-Haus	19.3829	19.6378	19.5682	18.7670	19.4838	19.8117	19.6865	19.4697
p2point-Haus-PSNR	17.6056	17.4758	17.3888	17.4712	17.3366	17.4702	17.3843	17.3933
p2point-RMS	8.3471	8.3718	8.3395	8.3358	8.3561	8.3928	8.4019	8.3956
p2point-RMS-PSNR	9.6631	9.2117	9.3933	9.4769	9.5471	9.4525	9.4968	9.6374
p2plane-Haus	19.5869	19.7785	19.7047	19.5867	19.7610	19.8899	19.6393	19.7480
p2plane-Haus-PSNR	19.4916	19.4912	19.5075	19.5217	19.5501	19.5198	19.5290	19.5107
p2plane-RMS	17.9921	17.9604	17.9619	17.9828	17.9495	17.8619	18.0118	17.9618
p2plane-RMS-PSNR	11.7182	11.5536	11.6126	11.6129	16.4991	11.5933	11.6250	11.7279
pl2plane-MSE	17.3989	17.4521	17.4117	17.4102	17.3989	17.4135	17.4241	17.3980
pl2plane-RMS	17.3899	17.4286	17.4024	17.3869	17.3932	17.3992	17.3896	17.3897
pl2plane-Mean	17.3828	17.4098	17.3797	17.3662	17.3652	17.3746	17.3665	17.3646
pl2plane-Median	17.3828	17.4098	17.3797	17.3662	17.3652	17.3746	17.3665	17.3646
pl2plane-Min	19.8562	19.7044	19.6293	19.5857	19.6241	19.7227	19.7287	19.7460

II. ANALYSIS OF TEMPORAL SUB-SAMPLING RATE

Table I and Table II report the SROCC and RMSE values, respectively, computed between different objective quality metrics scores and the DMOS values for each of the different sub-sampling rates. Similar to the PCC scores reported in the main paper, the SROCC and RMSE results show that the set of p2point-RMS, Color-Y, and SSIM metrics are found best performing metrics for point-based geometry, point-base color, and image quality metrics.

III. ANALYSIS OF TEMPORAL POOLING METHODS

Table III and Table IV report the SROCC and RMSE values, respectively, computed between different objective quality metrics scores and the DMOS values for each of the different pooling methods. These results are given for the original frame-rate of the volumetric videos, i.e., 30 fps. Similarly, the SROCC and RMSE values follow the same pattern as PCC reported in the main paper.

TABLE III

SROCC VALUES BETWEEN METRIC SCORES AND DMOS FOR DIFFERENT POOLING METHODS WITH 30 FPS.

	Arithmetic mean	Harmonic mean	Minkowski mean	Percentile pooling	Primacy pooling	Recency pooling	VQ Pooling
MP-PSNR-FR	0.4740	0.6489	0.4502	0.4962	0.4876	0.4504	0.7392
MP-PSNR-RR	0.6275	0.6194	0.6336	0.4967	0.6394	0.6337	0.6978
MW-PSNR-FR	0.6084	0.6045	0.6116	0.5079	0.6182	0.6153	0.6640
MW-PSNR-RR	0.6317	0.6236	0.6347	0.5098	0.6440	0.6322	0.6701
PSNR	0.7415	0.7404	0.7416	0.7253	0.7376	0.7476	0.7370
SSIM	0.8531	0.8532	0.8531	0.8649	0.8511	0.8522	0.8955
NIQSV	0.0728	0.1011	0.2371	0.1577	0.2517	0.1064	0.1018
NIQSV+	0.2021	0.2021	0.2075	0.2136	0.2387	0.2006	0.2720
APT	0.1000	0.0568	0.1220	0.0950	0.1567	0.1445	0.0114
EM-IQM	0.4436	0.5293	0.4731	0.4233	0.4272	0.3956	0.2045
SI-IQM	0.8374	0.8384	0.8372	0.8377	0.8422	0.8343	0.8291
Color-Y	0.7818	0.7789	0.7791	0.7807	0.7821	0.7800	0.7607
Color-Y-PSNR	0.7811	0.7817	0.7807	0.7654	0.7842	0.7786	0.7649
Color-U	0.4772	0.4806	0.4760	0.4910	0.4763	0.4805	0.5007
Color-U-PSNR	0.4807	0.4792	0.4808	0.4588	0.4781	0.4799	0.4855
Color-V	0.4658	0.4684	0.4649	0.4727	0.4690	0.4658	0.4813
Color-V-PSNR	0.4511	0.4672	0.4678	0.4512	0.4702	0.4663	0.4711
p2point-Haus	0.2793	0.3461	-0.1189	0.3091	0.2566	0.2012	-
p2point-Haus-PSNR	0.6099	0.5377	0.3821	0.5123	0.5890	0.6158	-
p2point-RMS	0.8665	0.8635	0.8575	0.8579	0.8633	0.8651	0.8615
p2point-RMS-PSNR	0.7704	0.7903	0.7606	0.8397	0.7773	0.7658	0.6765
p2plane-Haus	0.1682	0.0091	-0.0307	0.2386	0.1820	0.1148	-
p2plane-Haus-PSNR	0.1453	0.1360	0.1735	0.0992	0.1527	0.1358	0.1797
p2plane-RMS	0.3647	0.3632	0.3579	0.3655	0.3603	0.3639	0.3695
p2plane-RMS-PSNR	0.8363	0.8321	0.5636	0.7949	0.8428	0.8285	0.8644
pl2plane-MSE	0.3655	0.3726	0.3728	0.2799	0.3613	0.3752	0.3388
pl2plane-RMS	0.3726	0.3726	0.3726	0.3294	0.3670	0.3755	0.3116
pl2plane-Mean	0.3339	0.3286	0.3285	0.3082	0.3392	0.3283	0.3080
pl2plane-Median	0.3339	0.3286	0.3285	0.3082	0.3392	0.3283	0.3080
pl2plane-Min	-0.0009	0.1073	0.0169	0.1460	0.0420	0.0447	0.0245

TABLE IV

RMSE VALUES BETWEEN METRIC SCORES AND DMOS FOR DIFFERENT POOLING METHODS WITH 30 FPS.

	Arithmetic mean	Harmonic mean	Minkowski mean	Percentile pooling	Primacy pooling	Recency pooling	VQ Pooling
MP-PSNR-FR	18.9374	12.6152	14.8858	17.0350	18.8089	18.9961	11.2251
MP-PSNR-RR	12.9692	14.2188	12.7770	16.9044	13.4923	13.8670	12.1240
MW-PSNR-FR	13.4405	14.5667	13.3902	16.7387	14.1999	13.9793	12.8735
MW-PSNR-RR	12.9618	14.0529	13.7104	16.7467	12.8077	13.6272	12.7204
PSNR	11.1476	11.0099	10.7230	11.6741	11.2301	10.5974	10.7176
SSIM	8.3390	8.3364	8.3356	7.8494	8.3556	8.1911	6.6402
NIQSV	19.6864	19.6654	18.6981	19.3453	18.8591	19.6662	19.6458
NIQSV+	19.1515	19.1404	19.1456	19.3655	19.0594	18.8938	18.6312
APT	18.9471	18.9471	18.9471	18.9386	18.9605	18.8747	19.7128
EM-IQM	17.9914	15.0186	17.8175	15.8760	18.3230	18.0233	19.5564
SI-IQM	9.1916	9.1791	9.2005	9.1951	9.1112	9.2587	9.6910
Color-Y	10.6395	10.6152	10.6727	10.3891	10.6634	10.6161	10.7774
Color-Y-PSNR	10.6356	10.6531	10.6512	11.1160	10.7138	10.9713	10.9497
Color-U	16.6021	16.5550	16.6526	16.4346	16.6026	16.5797	16.3672
Color-U-PSNR	16.5810	16.5844	16.5196	16.9215	16.7203	16.4109	16.5690
Color-V	16.2440	16.2144	16.2674	16.0916	16.2491	16.2513	16.0180
Color-V-PSNR	16.3752	16.9061	16.2192	16.5404	16.9524	16.1588	16.2543
p2point-Haus	19.4697	19.0620	19.7264	16.4905	19.7234	19.5651	-
p2point-Haus-PSNR	17.3933	17.8151	18.6076	17.4600	17.5263	17.3368	-
p2point-RMS	8.3956	8.4702	8.6405	8.6567	8.4994	8.4261	8.5917
p2point-RMS-PSNR	9.6374	9.2760	9.9324	7.7939	9.5404	9.7849	11.4426
p2plane-Haus	19.7480	19.6215	19.7582	19.4605	19.7183	19.8122	-
p2plane-Haus-PSNR	19.5107	19.5891	19.9045	19.7141	19.5012	19.5180	19.8053
p2plane-RMS	17.9618	18.0015	17.9753	17.9897	18.0164	17.8330	17.9590
p2plane-RMS-PSNR	11.7279	11.5266	13.5670	12.8267	11.6232	11.8421	9.1364
pl2plane-MSE	17.3980	17.3971	17.3998	17.6650	17.4432	17.2871	17.6062
pl2plane-RMS	17.3897	17.3898	17.3901	17.5201	17.4393	17.2597	17.5970
pl2plane-Mean	17.3646	17.3644	17.3621	17.4948	17.4193	17.3658	17.7410
pl2plane-Median	17.3646	17.3644	17.3621	17.4948	17.4193	17.3658	17.7410
pl2plane-Min	19.7460	19.8395	19.5491	19.7890	19.5881	19.6031	19.4752

The results presented in Tables I-IV show that even though there are small changes in the numerical values, the best performing objective quality metrics do not change. In the next section, we report on the combined analyses of temporal sub-sampling and temporal pooling.

IV. COMBINED ANALYSIS OF TEMPORAL SUB-SAMPLING RATE AND TEMPORAL POOLING

In addition to the separate analyses of temporal sub-sampling of the volumetric video frames and of temporal pooling methods, here we analyze the effect of these two factors combined on volumetric video objective quality assessment. Fig. 1 presents the SROCC values for the combined analysis. Each row shows a different metric. Metric order is the same as rows of Tables I-IV. Each column shows a different com-

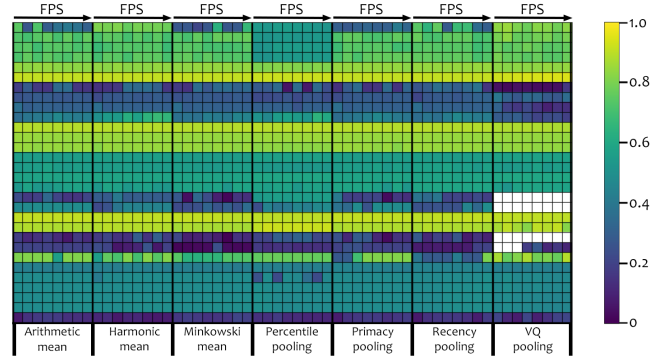


Fig. 1. The effect of both temporal sub-sampling rate and temporal pooling on the performance of the metric in terms of SROCC.

bination of temporal sub-sampling rate and temporal pooling in the following order: $\{P_i(j)\}$, where j is the temporal sub-sampling rate for $j \in \{1, 2, 3, 5, 6, 10, 15, 30\}$, and P_i is the i^{th} pooling method for $i \in \{\text{Mean}_{arith}, \text{Mean}_{harm}, \text{Mean}_{Mink}, \text{Pool}_{perc}, \text{Pool}_{prim}, \text{Pool}_{rece}, \text{Pool}_{VQ}\}$. That is, the order of temporal pooling methods is the same as columns of Tables I-IV.

The Fig. 1 shows that there are no patterns that emerge from the combined analysis. Although some pooling methods helps to obtain better correlation results for some metrics, we don't observe a categorical preference among pooling methods. Similarly, effect of temporal sub-sampling rate on the pooling methods is rather arbitrary. Increasing sub-sampling rate does not necessarily increase the metric accuracy for a given pooling method.

REFERENCES

- [1] ITU-T, "Methods, metrics and procedures for statistical evaluation, qualification and comparison of objective quality prediction models." ITU-T Recommendation P.1401, Jul 2012.