

Hologram Representation via Quadratic Phase Gaussian Splatting

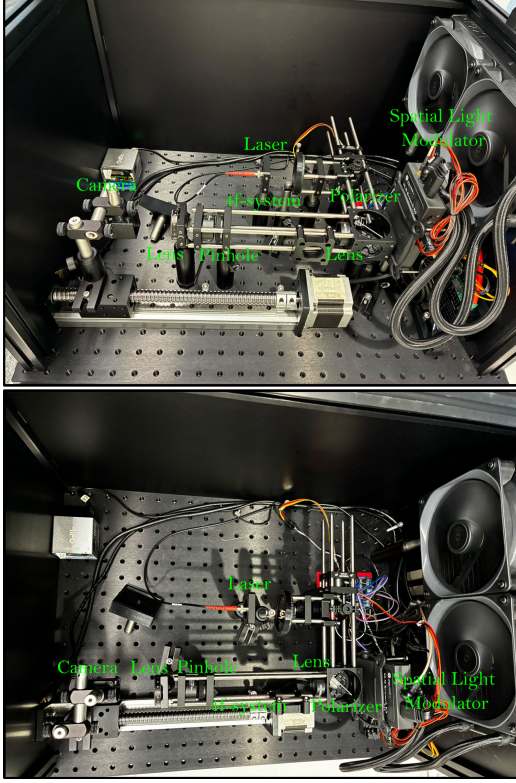


Fig. 1. Holographic display prototype used to display reconstructed holograms.

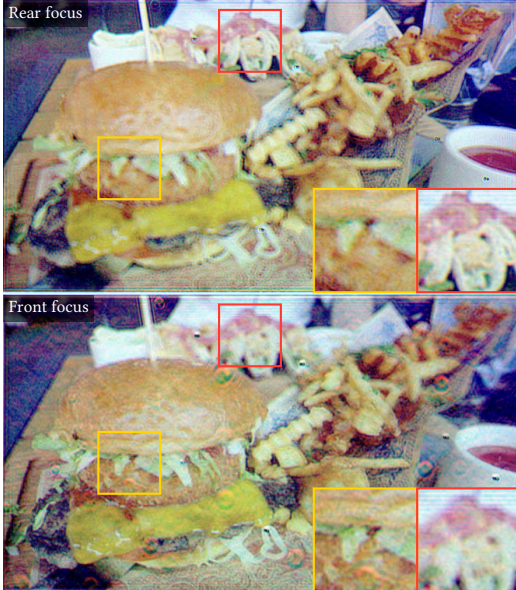


Fig. 2. Experimentally captured reconstruction result of the Burger scene on our prototype. We display phase-only holograms encoded from the CVQPG representation and photograph the reconstruction at each depth plane. (Source Image: kennejima)

1 Holographic Display Prototype

We employ a holographic display prototype to display reconstructed holograms in our experiments (Fig. 1). A laser source (LASOS MCS4) combines three laser lines and couples them into a single-mode fiber. A plano-convex lens (Thorlabs LA1708-A, $f = 200$ mm) collimates the light from the fiber, and a beamsplitter (Thorlabs BP245B1) reflects the collimated, linearly polarized beam onto a phase-only SLM (Jasper JD7714, 2400×4094 resolution, $3.74 \mu\text{m}$ pixel pitch). The modulated beam propagates through two lenses (Thorlabs LA1908-A and LB1156-A, $f = 500$ mm and $f = 250$ mm), and a pinhole (Thorlabs SM1D12C) in their common focal plane performs spatial filtering. A lensless image sensor (Point Grey GS3-U3-23S6M-C) mounted on an X-stage (Thorlabs PT1/M) captures the reconstructed holographic images. We further fit CVQPG at 3840×2160 , encode the holograms into phase-only patterns, and demonstrate them on our display prototype. Fig. 2 shows an example of the experimentally captured result.

2 Runtime and Memory Consumption

We profile the PyTorch pipelines of the models. CVQPG trains in 8.7–26.5 min using 5.5–18.9 GiB of memory, adding at most 3.4% time and 5.9% memory overhead over the Baseline at equal primitive counts (Tab. 1). Under equal-parameter evaluation, CVQPG trains 3.4–5.4% faster and uses 3.8–6.8% less memory than Baseline⁺ while achieving higher reconstruction quality.

Table 1. Training time and peak GPU memory averaged over the ten scenes (PyTorch pipeline, 2000 steps, 640×480 , two depth planes, a single NVIDIA TITAN RTX). #Params counts the trainable parameters. Δ columns show the relative change with respect to the standard Baseline.

Setting	Method	N	#Params	Time (min)	Δ Time	Memory (GiB)	Δ Memory
RGB 20%	Baseline	30,720	368,640	26.6	—	18.9	—
	Baseline ⁺	33,280	399,360	28.1	+5.7%	20.3	+7.2%
	CVQPG	30,720	399,360	26.5	0.0%	18.9	−0.1%
RGB 10%	Baseline	15,360	184,320	17.0	—	10.9	—
	Baseline ⁺	16,640	199,680	17.8	+4.5%	11.6	+5.7%
	CVQPG	15,360	199,680	17.0	0.0%	10.9	−0.1%
Grayscale 20%	Baseline	15,360	122,880	13.0	—	9.0	—
	Baseline ⁺	17,280	138,240	14.1	+8.2%	9.9	+10.3%
	CVQPG	15,360	138,240	13.4	+3.0%	9.5	+5.9%
Grayscale 10%	Baseline	7,680	61,440	8.4	—	5.2	—
	Baseline ⁺	8,640	69,120	9.0	+7.1%	5.7	+9.4%
	CVQPG	7,680	69,120	8.7	+3.4%	5.5	+5.2%

3 Per-Scene Results

Tab. 2 reports the results of all three models on every scene and setting. CVQPG improves upon the Baseline in all 200 comparisons and upon the Baseline⁺ in 182 of them. The results show that CVQPG provides consistent improvements at equal primitive counts, and these gains are unbiased across the dataset.

Table 2. Per-scene results for all four settings, averaged over the two depth planes. Each cell lists Baseline / Baseline⁺ / CVQPG. Our approach CVQPG is the best of the three in 182 of the 200 cells.

Scene	Setting	PSNR↑	SSIM↑	LPIPS↓	FLIP↓	CVVDP↑
Pencil	RGB 20%	26.967/27.094/27.115	.7737/.7766/.7792	.2946/.2893/.2876	.1528/.1516/.1508	8.749/8.770/8.780
	RGB 10%	25.798/25.935/25.931	.7391/.7441/.7434	.3295/.3284/.3239	.1700/.1660/.1684	8.488/8.534/8.520
	Grayscale 20%	26.788/27.032/27.074	.7738/.7820/.7861	.3829/.3783/.3690	.0856/.0826/.0831	8.592/8.673/8.683
	Grayscale 10%	25.364/25.602/25.557	.7319/.7365/.7403	.4268/.4203/.4118	.1006/.0991/.0982	8.176/8.243/8.256
Sushi	RGB 20%	33.646/33.766/33.904	.9199/.9222/.9242	.2555/.2542/.2504	.0826/.0817/.0804	9.511/9.519/9.536
	RGB 10%	32.364/32.527/32.589	.8955/.8987/.9002	.2888/.2848/.2836	.0935/.0916/.0913	9.347/9.371/9.381
	Grayscale 20%	34.382/34.647/34.843	.9286/.9323/.9355	.3227/.3202/.3132	.0518/.0504/.0492	9.412/9.447/9.483
	Grayscale 10%	32.928/33.122/33.369	.9023/.9077/.9116	.3577/.3506/.3455	.0609/.0589/.0574	9.133/9.186/9.228
Flower	RGB 20%	32.554/32.682/32.793	.9105/.9131/.9158	.2469/.2409/.2373	.0843/.0839/.0826	9.540/9.555/9.579
	RGB 10%	31.179/31.307/31.413	.8797/.8831/.8858	.2916/.2868/.2834	.0959/.0945/.0939	9.285/9.313/9.340
	Grayscale 20%	33.111/33.362/33.522	.9190/.9237/.9273	.3204/.3167/.3095	.0642/.0631/.0620	9.417/9.451/9.491
	Grayscale 10%	31.523/31.807/31.945	.8820/.8895/.8946	.3643/.3561/.3477	.0744/.0722/.0714	9.054/9.126/9.174
Straw	RGB 20%	32.322/32.457/32.531	.9018/.9041/.9062	.2306/.2282/.2263	.0926/.0919/.0914	9.352/9.376/9.371
	RGB 10%	31.082/31.214/31.310	.8777/.8805/.8829	.2640/.2599/.2570	.1011/.1003/.0989	9.243/9.236/9.279
	Grayscale 20%	32.696/32.976/33.074	.9097/.9143/.9173	.3415/.3354/.3293	.0604/.0589/.0584	9.208/9.254/9.286
	Grayscale 10%	31.023/31.335/31.387	.8770/.8832/.8866	.3760/.3689/.3651	.0716/.0691/.0685	8.826/8.904/8.935
Dragon	RGB 20%	27.448/27.560/27.604	.8306/.8337/.8363	.2916/.2865/.2854	.1395/.1389/.1379	9.071/9.093/9.103
	RGB 10%	26.152/26.330/26.328	.7952/.8002/.8013	.3273/.3206/.3220	.1566/.1543/.1534	8.810/8.856/8.856
	Grayscale 20%	27.873/28.134/28.139	.8386/.8435/.8476	.3801/.3773/.3716	.0883/.0866/.0860	8.802/8.849/8.869
	Grayscale 10%	26.282/26.565/26.580	.7922/.8009/.8045	.4182/.4101/.4049	.1051/.1013/.1005	8.375/8.455/8.479
Tiger	RGB 20%	28.991/29.096/29.141	.8549/.8568/.8599	.3008/.2967/.2930	.1087/.1081/.1071	9.252/9.271/9.283
	RGB 10%	27.968/28.070/28.109	.8272/.8314/.8330	.3391/.3325/.3280	.1205/.1189/.1184	8.996/9.032/9.042
	Grayscale 20%	29.124/29.332/29.377	.8574/.8625/.8670	.3840/.3801/.3719	.0732/.0715/.0712	9.015/9.069/9.098
	Grayscale 10%	28.027/28.201/28.303	.8278/.8335/.8385	.4165/.4116/.4049	.0830/.0810/.0799	8.693/8.756/8.797
Windmill	RGB 20%	24.709/24.840/24.886	.6859/.6902/.6956	.3326/.3290/.3259	.1388/.1371/.1361	8.826/8.851/8.880
	RGB 10%	23.441/23.579/23.650	.6450/.6493/.6551	.3702/.3658/.3615	.1590/.1571/.1556	8.509/8.547/8.579
	Grayscale 20%	24.995/25.244/25.284	.6784/.6874/.6965	.4680/.4604/.4528	.0952/.0920/.0914	8.348/8.414/8.462
	Grayscale 10%	23.785/23.987/24.099	.6339/.6407/.6504	.5032/.4978/.4895	.1107/.1075/.1056	7.909/7.993/8.043
Statue	RGB 20%	23.586/23.732/23.749	.6556/.6605/.6652	.3784/.3699/.3701	.1561/.1543/.1533	8.634/8.670/8.709
	RGB 10%	22.401/22.538/22.588	.6136/.6184/.6231	.4375/.4304/.4302	.1835/.1800/.1778	8.225/8.279/8.334
	Grayscale 20%	23.398/23.619/23.729	.6506/.6562/.6677	.5037/.4969/.4867	.1055/.1017/.0993	8.243/8.327/8.393
	Grayscale 10%	22.215/22.361/22.454	.6022/.6096/.6180	.5598/.5513/.5428	.1285/.1248/.1219	7.669/7.767/7.830
Burger	RGB 20%	32.860/32.940/33.030	.8947/.8966/.8985	.2758/.2736/.2700	.0745/.0740/.0730	9.576/9.583/9.600
	RGB 10%	31.738/31.890/31.931	.8679/.8716/.8730	.3106/.3074/.3014	.0843/.0824/.0826	9.358/9.393/9.403
	Grayscale 20%	32.967/33.185/33.306	.8993/.9035/.9070	.3531/.3494/.3447	.0545/.0528/.0521	9.413/9.450/9.482
	Grayscale 10%	31.687/31.889/32.044	.8689/.8746/.8794	.3794/.3724/.3668	.0636/.0615/.0603	9.101/9.168/9.214
Bento	RGB 20%	29.567/29.693/29.746	.8797/.8822/.8832	.2879/.2850/.2823	.1142/.1125/.1123	9.166/9.168/9.189
	RGB 10%	28.218/28.403/28.401	.8515/.8570/.8549	.3336/.3243/.3257	.1275/.1255/.1252	8.907/8.935/8.926
	Grayscale 20%	29.703/29.997/29.995	.8841/.8886/.8908	.3567/.3513/.3453	.0746/.0734/.0720	8.899/8.946/8.947
	Grayscale 10%	27.925/28.302/28.242	.8463/.8536/.8552	.4025/.3953/.3901	.0897/.0862/.0862	8.545/8.614/8.620
Mean	RGB 20%	29.265/29.386/29.450	.8307/.8336/.8364	.2895/.2853/.2828	.1144/.1134/.1125	9.168/9.186/9.203
	RGB 10%	28.034/28.179/28.225	.7992/.8034/.8053	.3292/.3241/.3217	.1292/.1271/.1265	8.917/8.950/8.966
	Grayscale 20%	29.504/29.753/29.834	.8340/.8394/.8443	.3813/.3766/.3694	.0753/.0733/.0725	8.935/8.988/9.019
	Grayscale 10%	28.076/28.317/28.398	.7964/.8030/.8079	.4204/.4134/.4069	.0888/.0862/.0850	8.548/8.621/8.658