Supplement for Latency of 30 ms Matters More Than Refresh Rate Above 60 Hz for First Person Targeting Tasks

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1 HARDWARE DETAILS

High level hardware details are summarized in Table 1. An image of the complete setup is shown in Figure 1.

Mouse. We modified the mouse to connect the left and right mouse buttons along with common ground to the click-to-photon logging tool (event monitor), which was connected over USB to the same PC that ran the `FirstPersonScience` software.

Display. The experimental monitor supports 60, 120, 240 and 360 Hz variable refresh rate (VRR), which was enabled during our experiments.

GPU configuration. We enabled variable refresh rate in our GPU and followed the configuration in Table 2 to minimize latency.

2 CLICK-TO-PHOTON LATENCY MONITORING

To characterize end-to-end system latency, we developed a hardware tool to measure click-to-photon latencies. This tool detects the click event via direct wiring to a modified mouse, while using an amplified photodetector aimed at a location in the vertical center of the screen to measure average arrival time of photon events. An Arduino captures both mouse and display transition time stamps and sends the recorded time-event pairs to a desktop PC over a USB virtual COM port (VCP) as seen in Figure 2.

Our software development process focused on minimizing the latency present in the application in addition to selecting hardware components that gave us greatest control over the latency. While we were able to greatly reduce the latency of our application over what is naively achieved with traditional GPU-based rendering approaches, the majority of savings came from intelligently selecting

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Table 1: Hardware used in experiment setup. Display is Variable Refresh Rate (VRR) which allows careful control of refresh rate.

Component	Specification
CPU	Intel Core i7-9700K
GPU	NVIDIA RTX 2080 Ti
RAM	32GB DDR4 4600
Mouse	Logitech G203
Display	25 inch 1080p VRR
Serial Card	PCIe RS232 Card

Table 2: 3D settings in GPU for our experiment.

Setting Name	Value
Maximum pre-rendered frames	1
Power management mode	Prefer maximum performance
Preferred refresh rate	Highest available
Threaded optimization	Off
Triple buffering	Off

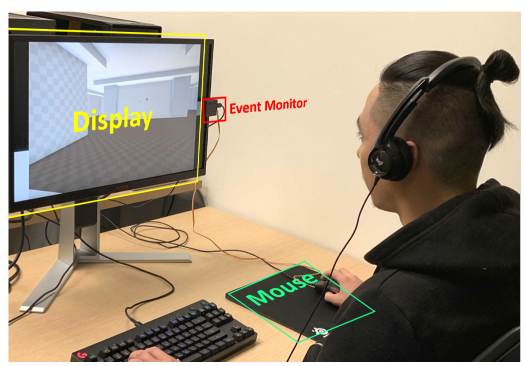

Figure 1: The hardware setup used including the mouse, display, desktop PC and Click-to-Photon logger (Section 2).

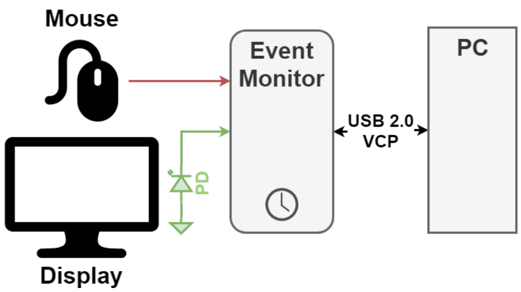

Figure 2: Mouse to photon logger configuration

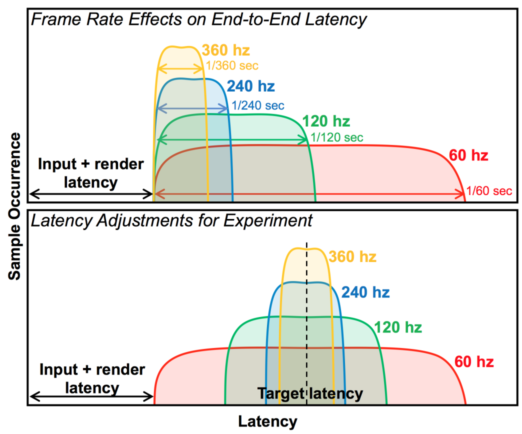

Figure 3: We artificially add latency to cause the average latency experienced to be the same, though the distribution of latencies was necessarily different. The measured averages are in the main submission. Note that there can be other factors that affect the input+render latency and actual latencies tend to vary more than shown in our simplified figure.

when to swap buffers, and ensuring the Windows 10 OS and graphics drivers were configured appropriately. Figure 3 shows how we normalized latency across different refresh rate settings.

3 ADDITIONAL RESULTS

Repeated measures ANOVA were conducted using JASP version 0.9.1, and violations of sphericity were subjected to Greenhouse-Geisser correction. The detailed results of ANOVA are presented in Tables 3 and 4.

In addition to the results presented in the main document, we also examined the effect of motion type on subjects task completion time. Aligned with our expectations, and as discussed above, we observed a significant effect of motion type for both experiments(F(4.00, 28.00)=81.16, p<0.001, η_p^2=0.88 for 1-HIT and F(2.00, 10.00)=64.95, p<0.001, η_p^2=0.93 for TRACK). There were statistically significant interactions between latency and motion type (F(8.00, 56.00)=10.18, p<0.001, η_p^2=0.59 for 1-HIT and F(4.00, 20.00)=20.30, p<0.001, η_p^2=0.80 for TRACK). The interaction between refresh rate and motion type was found significant for TRACK (F(6.00, 30.00)=2.98, p=0.021, η_p^2=0.373) but it did not reach significance for 1-HIT (F(12.00, 84.00)=0.741, p=0.71, η_p^2=0.096). Our results show that the refresh rate and latency effects, if present, were more pronounced for unpredictable target motions (namely *Stray* and *Jump*) than simplistic (*Static* and *Straight*). In some cases, a latency advantage of a few tens of milliseconds can be turned into a competitive advantage on the order of seconds depending on weapon type and motion strategy. Thus we accept our hypothesis that latency and refresh rate effects are more pronounced when target motion is complicated and unpredictable, where timely and accurate visual feedback become more critical for aiming.

Table 3: Results of ANOVA for the 1-HIT experiment

	Sum of Squares	df	Mean Square	F	p	η^2
Frame Rate	0.300	3	0.100	0.934	0.442	0.118
Residual	2.251	21	0.107			
Latency	20.044	2	10.022	49.674	< .001	0.876
Residual	2.825	14	0.202			
Motion Type	197.544	4	49.386	81.165	< .001	0.921
Residual	17.037	28	0.608			
Frame Rate * Latency	1.251	6	0.208	1.235	0.308	0.150
Residual	7.090	42	0.169			
Frame Rate * Motion Type	0.359	12	0.030	0.741	0.707	0.096
Residual	3.388	84	0.040			
Latency * Motion Type	3.919	8	0.490	10.181	< .001	0.593
Residual	2.694	56	0.048			
Frame Rate * Latency * Motion Type	0.855	24	0.036	0.998	0.471	0.125
Residual	5.992	168	0.036			

Table 4: Results of ANOVA for the TRACK experiment

	Sum of Squares	df	Mean Square	F	p	η^2
Frame Rate	1.047	3	0.349	4.592	0.018	0.479
Residual	1.140	15	0.076			
Latency	9.295	2	4.648	59.280	< .001	0.922
Residual	0.784	10	0.078			
Motion Type	31.197	2	15.599	64.947	< .001	0.929
Residual	2.402	10	0.240			
Frame Rate * Latency	0.316	6	0.053	1.233	0.317	0.198
Residual	1.283	30	0.043			
Frame Rate * Motion Type	0.231	6	0.039	2.980	0.021	0.373
Residual	0.388	30	0.013			
Latency * Motion Type	1.040	4	0.260	20.300	< .001	0.802
Residual	0.256	20	0.013			
Frame Rate * Latency * Motion Type	0.120	12	0.010	0.895	0.557	0.152
Residual	0.668	60	0.011			