Real-Time Neural Filtering for Perceptual Enhancement of Digital Experiences

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Abstract

We present two AI-powered approaches to perceptually enhance visual experiences: RTX HDR, which maps SDR game/video frames to HDR displays, and RTX Dynamic Vibrance, which optimizes frames to improve visibility of e-sports content. We demonstrate how these methods utilize deep neural networks to achieve high-quality results, yet add less than a millisecond per frame. RTX HDR and Dynamic Vibrance are deployed on GPUs via the NVIDIA App [1, 2].

Author Keywords

HDR; inverse tone mapping; debanding; display-aware enhancement; real-time image enhancement; e-sports reaction time

1. Objective and Background

Our objective is to optimize user experience by perceptually improving displayed pixels across interactive (e.g., games/esports) and media (e.g., streaming video) scenarios while maintaining real-time performance on commodity GPUs.

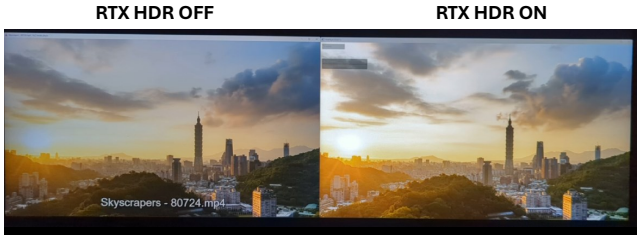
Our first solution, RTX HDR, implements efficient and high-fidelity inverse tone mapping of SDR content for HDR displays. Despite the rapid penetration of high dynamic range (HDR) displays, particularly in the TV and gaming monitor market, most experiences (e.g., games, videos) continue to have limited dynamic range and do not utilize the display capabilities fully. While SDR-to-HDR conversion methods and filters already exist, they usually support a limited subset of experiences, e.g., specific games. Furthermore, such methods suffer from visual artifacts like banding as well as undesirably-rapid brightness transitions. Our solution mitigates these visual artifacts, resulting in an engaging and artifact-free approach that applies broadly to videos and games.

Our second solution, RTX Dynamic Vibrance, enhances content visibility through AI-powered filtering. In competitive esports, the importance of low latency and fast reaction time is paramount. In addition to rendering and display latency, optimizing image visibility and perceptual reaction time—the time elapsed between a visual stimulus appearing and a player reacting to it—is intrinsically dependent on the characteristics of the displayed image, such as target size, contrast, and visual clutter. By dynamically enhancing visibility, RTX Dynamic Vibrance directly contributes to higher visibility and faster effective reaction times. Figure 1 illustrates representative side-by-side outputs for both methods.

2. Overview of Methods

We implement both filters as driver-level post-processing stages exposed through NVIDIA App, and we execute both on RTX Tensor Cores. In our deployment path, filtering occurs after game rendering, which lets us enable the methods without title-specific integration and tune behavior in real time from the in-game overlay.

RTX HDR For RTX HDR, we formulate the pass as AI-assisted inverse tone mapping from SDR game output into an HDR presentation pipeline. Our objective is not only SDR→HDR range expansion, but also suppression of artifacts that appear with naive mappings, especially visible gradient banding and high-frequency temporal brightness changes (see Figure 4). Figure 2 provides an overview of the RTX HDR pipeline, including the neural banding estimation pass, adaptive debanding, and inverse tone mapping followed by color-space conversion to the target display.



(a) RTX HDR is a neural SDR→HDR conversion method that runs live on interactive content. This camera capture shows a baseline frame (left) vs. HDR output (right).

(b) RTX Dynamic Vibrance dynamically improves frame visibility and runs in real time. Baseline frame (left) vs. RTX Dynamic Vibrance output (right), showing higher visibility in a dark scene.

Figure 1. Comparisons of our neural perceptual enhancements against baseline input frames: RTX HDR off vs on (increased dynamic range) and RTX Dynamic Vibrance off vs on (increased visibility).

RTX Dynamic Vibrance method For RTX Dynamic Vibrance, we apply an AI-driven color/contrast mapping that increases scene visibility while preserving perceptual structure in dark and bright chroma regions. Rather than applying a uniform global saturation boost, we use an adaptive transformation look-up-table (LUT), generated by a learned neural network, whose goal is to increase visual salience, improve reaction time, and avoid excessive color crushing. Similar to RTX HDR, this pass is accelerated by implementation on GPU Tensor Cores.

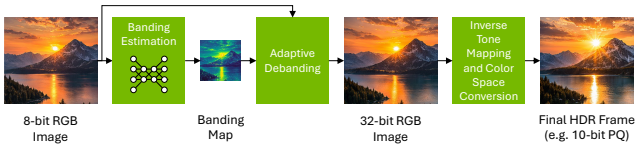


Figure 2. RTX HDR pipeline starts by estimating potential banding in an 8-bit input image with a neural network, applying adaptive debanding to obtain a banding-free 32-bit image, and finally performing inverse tone mapping and converting the result to the target HDR display color space.

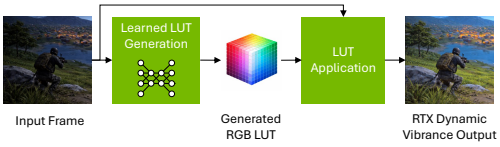


Figure 3. RTX Dynamic Vibrance pipeline starts by analyzing the input frame with a neural network, predicting an RGB 3D look-up-table (LUT) from the scene, and then applying the LUT in real time to produce a higher-visibility output frame.

Figure 4. Visualization of changes in luminance between a baseline HDR conversion and one with debanding as implemented in RTX HDR. Input video by Timo Volz from Pixabay.

Figure 3 describes the RTX Dynamic Vibrance pipeline, which starts by using a neural network to determine an RGB 3D LUT. The pipeline then applies the LUT to the input image, obtaining the output image with increased visibility in real time.

Because both methods share a driver-level insertion point and control path, we can enable either filter independently or run them together without engine-side code changes in games.

3. Results

We evaluate RTX HDR and RTX Dynamic Vibrance on representative game and video content, reporting qualitative and quantitative improvements with real-time runtimes on RTX-class GPUs. Representative visual outcomes are shown in Figure 1.

For RTX HDR, debanding comparisons show reduced visible banding on sky gradients and low-contrast ramps relative to baseline tone mapping and common post-filters while preserving fine textures (Figure 4). Highlights and shadows retain detail under identical peak-luminance constraints. Banding detectors indicate consistent improvement, and inter-frame gradient variance suggests greater temporal stability.

On a GeForce RTX 4090, RTX HDR operates in real time and adds an overhead of roughly 2–4% of the frame rendering time for a 60 Hz game across resolutions ranging from 1080p through 4K, compatible with high-framerate esports. Integration is completely orthogonal to application as the algorithm runs entirely in the display driver. Compared to AutoHDR [3, 4], RTX HDR mitigates banding artifacts and rapid visibility transitions, yielding visible gains in quality while reducing the need for per-title optimization. Our pipeline is robust across games and rendering backends, and via RTX Video HDR [5], applies to video playback as well.

RTX Dynamic Vibrance implements a learned mapping from frame statistics to dynamic image enhancements, which improve players' content visibility and reaction time. It constrains outputs to avoid posterization and halos, and preserves color fidelity. On an RTX 4070, RTX Dynamic Vibrance runs in real time, with 1–3% frame time overhead for resolutions from 1080p through 4K.

Both these technologies are integration-free and work on a wide variety of input experiences. Furthermore, they are compatible with each other and can be enabled simultaneously.

4. Discussion and Impact

Our results indicate that real-time perceptual enhancement can improve both image quality and practical usability without requiring application-level integration. In particular, RTX HDR addresses long-standing SDR-to-HDR quality gaps in an ecosystem of increasingly prevalent HDR displays, while RTX Dynamic Vibrance improves scene readability in fast-paced content. This combination supports a broader conclusion: display-aware, AI-driven post-processing can provide consistent user-visible value across both media and interactive workloads.

RTX HDR has broadened access to HDR-quality experiences by enabling SDR-to-HDR enhancement across games and mainstream video platforms (RTX Video HDR) on RTX-class GPUs. It is widely popular and often preferable to native HDR support in games [6, 7, 8, 9]. Browser-level integrations and app controls have brought HDR upconversion to streaming content, with users and press noting improved clarity, reduced banding, and better highlight/shadow handling [10, 11, 12]. Creator workflows have also adopted RTX Video HDR, enabling SDR-to-HDR transformation in popular tools without re-mastering, which accelerates HDR content availability and improves perceived quality for large SDR back catalogs [13, 14].

Meanwhile, RTX Dynamic Vibrance provides display-aware vibrance and contrast that competitive players historically tuned manually. This technology has helped standardize a popular high-visibility and quick-reaction view for esports and live content.

Overall, momentum around RTX HDR and RTX Dynamic Vibrance [15] and display-aware enhancement points to measurable benefits in experience, strengthening the case for real-time AI-powered perceptual optimization in interactive experiences.

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