Real-Time SDR to HDR Up Conversion with Automatic Dynamic Mid-Level Tone Mapping

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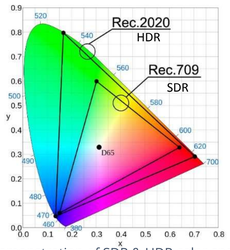
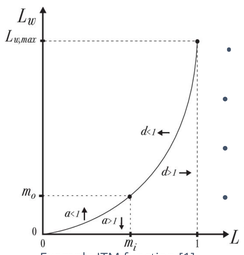
SDR and HDR

- Historically, video contents were primarily produced and displayed in a color space known as Rec. 709 or **Standard Dynamic Range (SDR)**.
- In recent years, TVs with the ability to display Rec.2020, or **High Dynamic Range (HDR)**. contents have become increasingly accessible.
- HDR color space is capable of expressing much more vibrant colors. However, displaying SDR contents on HDR TV to take full advantage of the hardware is a non-trivial problem.



Demonstration of SDR & HDR color space

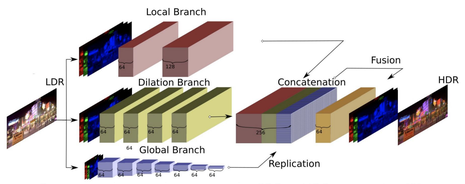
SDR to HDR with ITM



Example ITM function [1]

- One of the commonly used methods for SDR to HDR up-conversion is called **Inverse Tone Mapping (ITM).** [1]
- ITM methods use a mathematical function to map SDR images to HDR color space.
- ITM methods convert an image's luminance channel and promises a fast conversion speed.
- However, the lack of emphasis on image's hue and saturation restricts its performance.

SDR to HDR with Deep Learning



Deep neural network structure for SDR to HDR conversion [2]

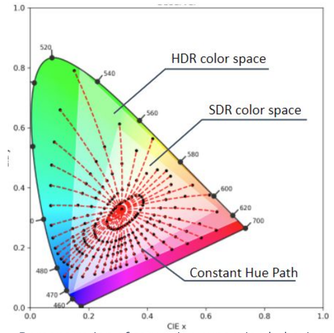
- Recent advancement in deep learning has inspired many neural network-based SDR to HDR conversion methods. [2]
- Neural network-based methods tend to have outstanding performances.
- However, the computational intensity required by neural network inference makes them unsuitable for real-time applications.

Our Work

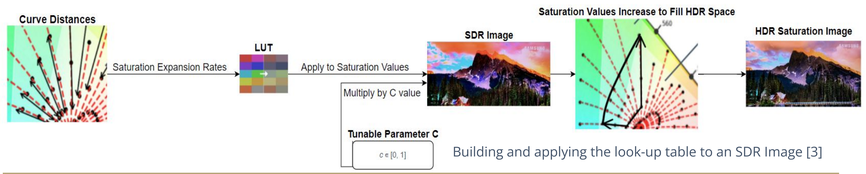
- In the project, we focused on improving the existing ITM methods [1] by:
  - Introducing a lookup table-based saturation expansion procedure.
  - Developing a web platform that facilitates the research in dynamic generation of optimal ITM parameters.
- To evaluate the quality of SDR to HDR conversion, we also created a color test metric which compares a converted HDR image with the reference HDR image.

Saturation Expansion

- Existing ITM method transforms SDR images' luminance and preserves their saturation.
- However, the visual representation of color spaces (shown in the right) indicates a need for saturation increment when expanding from SDR to HDR color space.
- Furthermore, the triangular shape .of color spaces also results in different saturation expansion rate for pixels of different hue.
- Based on these observations, we created a look-up table (LUT) that maps hue values to different saturation expansion rates.
- Applying this LUT to existing ITM method, we can produce HDR images with accurate saturation.



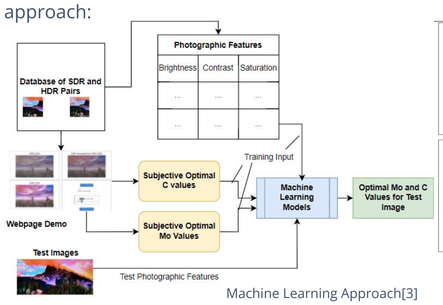
Demonstration of saturation expansion behavior



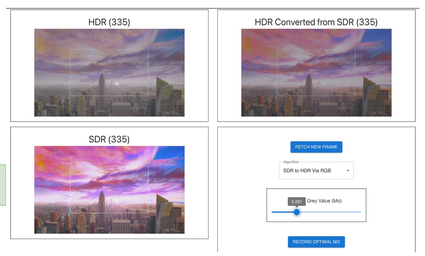
Building and applying the look-up table to an SDR Image [3]

Web Platform for Researching Fully-Automatic Algorithm

- In our method, two parameters impact the quality of converted HDR images: **output image's middle grey level (m_o)** and **saturation expansion constant (c)**.
- For images of different photographic styles, the optimal m_o and c vary.
- To automate the parameter tuning, we tried to algorithmically derive the optimal m_o and c given input SDR and reference HDR images. However, the experimental results are often unideal.
- Inspired by Luzardo et, al. [1], we decided to solve this problem using a machine learning approach:



Machine Learning Approach[3]

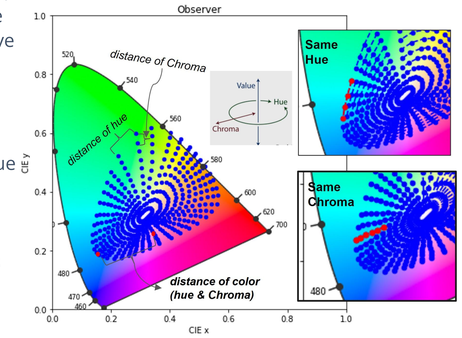


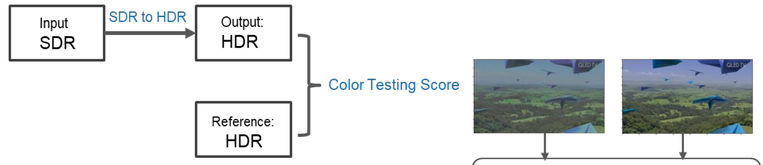
Example of web platform

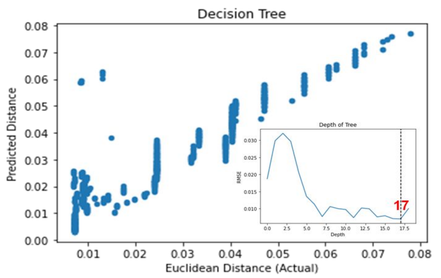
- We implemented a web platform where users can interact with our SDR & HDR image database to determine optimal parameters given input SDR, reference HDR, and generated HDR at any parameter setting.
- Users can upload the optimal m_o and c parameters that they determined and contribute to future research in fully automatic SDR to HDR conversion algorithms.

Color Test Metric

- To assess the performance of our ITM-based SDR to HDR conversion method, novel evaluation metrics need to be developed.
- Existing evaluation metric, SDR-VDP, only measures differences in image illumination. Currently no alternative approaches fairly represent image differences in hue and saturation.
- We proposed a new testing metric that calculates pixels' neighbor distance in terms of chroma and hue value on CIE color space.
- To implement this distance metric, we trained a machine learning model (Decision Tree) that predicts the distance between given pixels.







Future Work, References, and Acknowledgments

- Use the web platform to perform optimal ITM parameter data collection
- Based on collected optimal parameter to develop automatic optimal parameter estimation methods.
- Implement our proposed method on an HDR TV for real-time applications.
- Perform comprehensive evaluation of our proposed method using the novel testing metric.

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[1] G. Luzardo, J. Aelterman, H. Luong, S. Rousseaux, D. Ochoa and W. Philips, "Fully-automatic inverse tone mapping algorithm based on dynamic mid-level tone mapping", *APSIPA Transactions on Signal and Information Processing*, vol. 9, no. 1, 2020.

[2] D. Marnerides, T. Bashford-Rogers, J. Hatchett and K. Debattista, "ExpandNet: A Deep Convolutional Neural Network for High Dynamic Range Expansion from Low Dynamic Range Content", EUROGRAPHICS, vol. 37, no. 2, p. 13, 2018.

[3]Samsung, Wonderland Two HDR. 2020.

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