# Hybrid Multi-Frequency Image Illusion

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***Abstract*—Our code presents an automated multifrequency hybrid image generation pipeline that combines Gaussian/Laplacian pyramid processing with Particle Swarm Optimization (PSO) to enhance near-view and far-view image blending. The method converts inputs to YUV color space, applies multi-level decomposition, and optimizes fusion parameters using PSO to achieve higher visual clarity. The approach reduces manual tuning and produces consistently improved fused outputs across different image pairs.**

***Index Terms*—Index Terms—Hybrid Images, Multiresolution Analysis, YUV Color Space, Low-Pass / High-Pass Filtering, Laplacian Pyramid Fusion, Gaussian Filtering, Particle Swarm Optimization (PSO), Parameter Tuning, Image Fusion, Spatial Frequency Decomposition, Grayscale and Color Pipelines, Perceptual Image Representation**

## I. Introduction

HYBRID images are illusionary images which are a product of combination of two images in such a manner that one identity is seen at close viewing distances (high-frequency details) and other identity is seen at distance (low-frequency structure). This effect exploits spatial frequency performance of the human visual system, and is used both in perception research and in the compact visual encoding.

This code implements an automated hybrid-image generation pipeline using Gaussian and Laplacian pyramids in the YUV color space, enabling controlled separation and fusion of frequency components. To further enhance visual quality, Particle Swarm Optimization (PSO) is integrated to automatically tune fusion parameters, maximizing structural similarity with a pyramid-based reference target. The resulting system provides a robust, parameter-optimized hybrid-image generator capable of producing high-quality perceptual blends with minimal manual adjustment..

## II. Methodology

### *A. Grayscale Hybrid Image Pipeline (Marilyn / Einstein)*

The grayscale hybrid pipeline operates in YUV colour space but starts from grayscale inputs. The aim is to embed low-frequency content of one image and high-frequency content of another into a single hybrid image.

1) **Pre-processing and colour-space conversion**
   a) Input grayscale images are converted to 3-channel BGR to allow standard colour transforms.
   b) Both images are resized to the same spatial resolution so that corresponding pixels are aligned.
   c) The aligned BGR images are converted to YUV format, separating luminance (Y) from chrominance (U, V).
2) **Low and high-frequency separation**
   a) A Gaussian low-pass filter is applied to the Y channel of the “far” (low-frequency) image to extract its smooth, coarse content.
   b) A blurred version of the “near” (high-frequency) image is subtracted from its original Y channel, yielding a high-pass (edge and detail) component.
   c) The final Y channel is formed as a weighted sum of the low-pass Y from the far image and the high-pass Y from the near image, with a fixed detail-strength factor.
3) **Chrominance blending and reconstruction**
   a) The U and V channels of both images are blended using fixed weights so that colours are dominated by the far image, with a small contribution from the near image.
   b) The fused Y, U, and V channels are merged back into a single YUV image, which is then converted to BGR to obtain the grayscale hybrid in displayable colour format.
4) **Y-channel pyramid visualization**
   a) For analysis, the Y channels of the far and near images are individually decomposed into Gaussian and Laplacian pyramids.
   b) The Gaussian pyramid levels show how coarse information evolves across scales, while the Laplacian levels highlight detail bands.
   c) Visual inspection of these pyramids illustrates how low-frequency content comes predominantly from the far image and high-frequency content from the near image at different spatial scales.

### *B. Colour Hybrid Image Pipeline with Laplacian Pyramid and PSO (Dog / Cat)*

The colour pipeline extends the hybrid-image idea to full-colour inputs and uses a Laplacian pyramid fusion as a reference target. A parametric YUV-based hybrid model is then tuned using Particle Swarm Optimization (PSO) to approximate this target.

1) **Colour pre-processing and Laplacian target construction**
   a) Colour inputs are loaded, converted to BGR if needed, and resized to a common resolution.
   b) Both images are converted to float and decomposed into multi-level Gaussian and Laplacian pyramids.

c) At each Laplacian level, high-frequency bands are taken primarily from the “near” image with a small contribution from the “far” image, while the coarsest (base) level is taken primarily from the far image with a small contribution from the near image.
d) The fused Laplacian pyramid is reconstructed to form a reference hybrid image that serves as a target for parameter tuning.

2) **Parametric YUV hybrid model**
   a) A YUV-based hybrid construction is defined with four continuous parameters:
      - scaling factor for the low-pass blur of the far image ($\sigma_{low}$ multiplier),
      - scaling factor for the high-pass blur of the near image ($\sigma_{high}$ multiplier),
      - *detail_strength* controlling the high-frequency contribution of the near image in Y,
      - *far_uv_weight* controlling the relative mixing of far vs. near colours in the U and V channels.
   b) For any choice of these parameters, both images are converted to YUV, the far Y channel is low-pass filtered, the near Y channel is high-pass filtered, and the two are combined.
   c) The U and V channels are blended according to *far_uv_weight*, and the fused YUV image is converted back to BGR to yield a candidate colour hybrid.
3) **Objective function for PSO**
   a) Each candidate hybrid is compared to the Laplacian-pyramid reference hybrid using a structural-similarity-like (SSIM-style) measure computed on grayscale versions of the images.
   b) A contrast measure (standard deviation of the grayscale candidate) is added to penalize overly flat or washed-out results.
   c) The final score is defined as a weighted combination of structural similarity and contrast; the PSO algorithm minimizes the negative of this score (equivalently, maximizes the score).
4) **Particle Swarm Optimization of hybrid parameters**
   a) A swarm of particles is initialized over the four-dimensional parameter space with specified bounds on blur scales, detail intensity, and colour-mixing weight.
   b) At each iteration, every particle generates a candidate hybrid image via the YUV model, evaluates the objective, and updates its personal best.
   c) The global best solution is tracked, and particle positions and velocities are updated using standard PSO rules (inertia, cognitive, and social terms).
   d) After a fixed number of iterations, the globally best parameter set is selected, and the corresponding hybrid image is taken as the optimized colour hybrid.
5) **Colour Y-channel pyramid visualization**
   a) The Y channels corresponding to the far and near inputs in the colour pipeline are decomposed into Gaussian and Laplacian pyramids.
   b) These visualizations make explicit how different spatial frequencies from each colour image are arranged in the final hybrid and how the PSO-tuned parameters affect the balance between low- and high-frequency content.

## III. Results and Discussion

Figure 1 shows an example colour input pair used in the multi-frequency hybrid pipeline: the high-frequency (near-view) image and the low-frequency (far-view) image, resized and aligned in YUV space. These inputs are treated asymmetrically in the YUV domain: the Y channel encodes intensity structure, while U and V carry chrominance. Figure 2 then shows the Laplacian-pyramid fusion used as a reference hybrid, and Figure 3 shows the PSO-optimized YUV hybrid generated by the parameterized pipeline.

Visually, the colour results confirm that the PSO-tuned hybrid reproduces the desired illusion: at close viewing distances (or when zoomed in), the high-frequency identity from the ”near” image is dominant, while at larger viewing distances or after downsampling, the low-frequency identity from the ”far” image becomes clearer. The PSO search operates over four interpretable parameters: far-image blur, near-image blur, detail strength, and colour mixing weight, and keeps tuning these values where the PSO hybrid in Figure 3 closely matches the Laplacian-pyramid target in Figure 2.

The SSIM-like (Structural Similarity Index Measure) score and MSE between these two outputs indicate high similarity with low distortion. The added contrast term helps make sure that the result doesn’t become over-smooth or look washed-out.

The multiscale action behind the scenes is depicted in the grayscale-centric pipeline, which involves the Marilyn/Einstein couple, in a more understandable way. Figure 4 shows the corresponding ”far” and ”near” inputs, and Figure 5 presents the resulting hybrid. Gaussian and Laplacian pyramids of the Y channel (Figures 6 and 7) show the distribution of spatial frequencies: the levels with larger levels keep the overall outline and face structure of the image at distance, and the levels with smaller levels hold wrinkles, edges and high frequency content of the image at near. Such visualizations ensure that the hybrid effect is achieved through the synchronized redistribution of the energy across the multiple levels of the pyramid and not through a fixed-cutoff filter.

Overall, the side-by-side comparison of input images, Laplacian-pyramid reference hybrids, and PSO-optimized hybrids shows that the YUV-based, PSO-driven fusion strategy can automatically produce visually convincing multi-frequency illusions for both colour and grayscale pairs. The colour pipeline concentrates on automatic parameter tuning to estimate a powerful reference fusion whereas the grayscale pipeline concentrates on interpretability via the exposure of Gaussian and Laplacian pyramid levels. Together, the figures demonstrate that the method simultaneously achieves the intended perceptual behaviour (different identities at near and far distances) and provides a clear spatial-frequency explanation of how these hybrid images are constructed.

Fig. 1: PSO Optimized YUV Hybrid Image

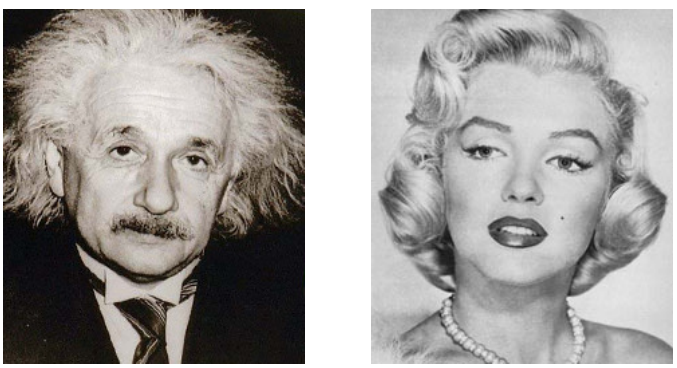


Fig. 2: Input images used for hybrid image generation

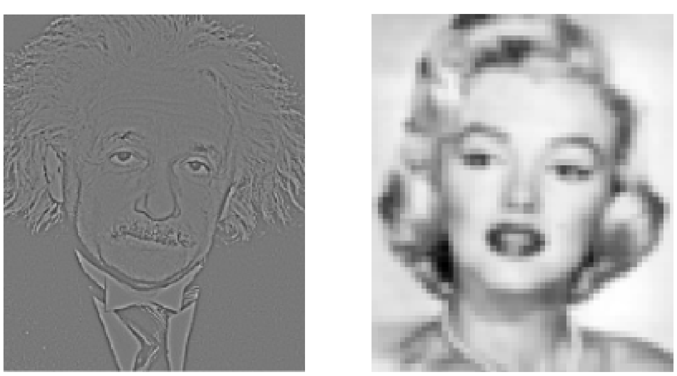


Fig. 3: Intermediate images

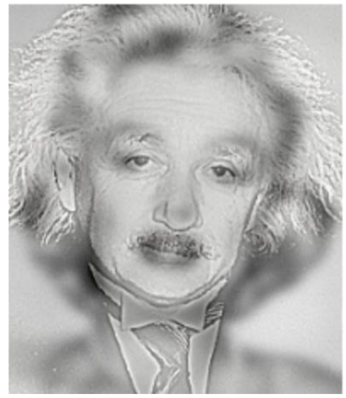
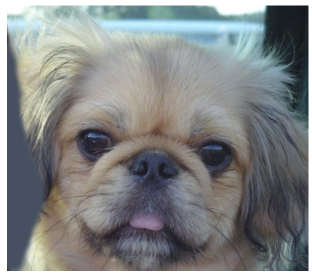


Fig. 4: Resulting hybrid image



(a) Dog

(b) Cat

Fig. 5: Original input images used for hybrid image generation.

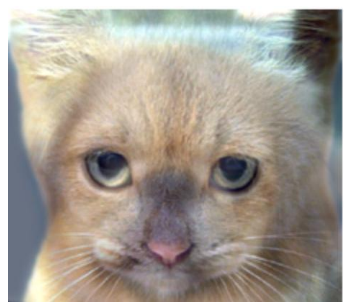


Fig. 6: Laplacian Pyramid Fusion

## IV. Conclusion

Through this project, we have managed to create an automated system of generating hybrid images by taking low-frequency information of one image and high-frequency information of another image. Laplacian-pyramid fusion, frequency separation using YUV, and Particle Swarm Optimization allowed us to create the perceptual hybrid images with high quality without any manual parameter optimization.

The parameter sets found by the PSO optimizer reached consistently balanced and visually interpretable hybrids, which confirmed the usefulness of automated search strategy in this task.

The colour (Cat-Dog) as well as the grayscale (Marilyn-Einstein) experiments showed the anticipated dual-perception effect, which confirmed the theoretical basis of the principle of visual interpretation based on spatial-frequency.

All in all, our method did not just increase the quality and consistency of hybrid image formation, but also provided the basis of a completely general, input-agnostic hybrid image generator which can optimize itself adaptively to any pair of images.

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