Assignment 1: Real-world Image Enhancement and Analysis

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1. Introduction (The Problem)

X-rays are one of the most common medical imaging tools used by doctors to check bones, lungs, and other internal structures. However, sometimes these X-ray images have low contrast, which makes it difficult to clearly see important details like small fractures, ribs, or other internal features.

This problem can affect diagnosis because doctors rely on sharp, clear images. My goal in this assignment was to try some image enhancement techniques to improve the visibility of low-contrast X-rays. By doing so, we can make the bones and other important parts appear more clearly, which can help in better analysis.

2. Dataset

For this assignment, I used publicly available chest X-ray images. The dataset I referred to is from Kaggle's Chest X-ray dataset, which contains grayscale images in formats like PNG and JPEG. Most of the images are in the resolution range of 512×512 pixels. I worked with grayscale images only, since X-ray images don't usually contain color. The dataset is good for this task because chest X-rays often have areas that are too dark or too bright, making them perfect examples to test enhancement methods.

3. Methodology & Justification

Technique 1: Histogram Equalization

- **Justification:** Histogram equalization is a simple but powerful method to improve contrast. It works by spreading out the pixel intensity distribution so that dark and bright regions become more balanced. This is good for medical images where the contrast between tissues is important.
- **Transformation Function:** The function can be represented as:

$$s_k = \backslash frac\{(L - 1)\}\{MN\} \sum_{\{j=0\}} {}_{j}^{\{k\}n}$$

$Where$:

- $s\_k \ = \ new\ intensity\ value$
- $L \ = \ total\ number\ of\ intensity\ levels\ (usually\ 256\ for\ grayscale)$
- $M \ \times \ N \ = \ total\ pixels\ in\ the\ image$
- $n\_j \ = \ number\ of\ pixels\ with\ intensity\ j$

Technique 2: Power-Law (Gamma) Transformation

- **Justification:** Gamma correction is useful for adjusting the brightness of images. For X-rays that are too dark or too bright, choosing the right gamma value can reveal hidden details. If gamma < 1, the image becomes brighter, and if gamma > 1, the image becomes darker.
- **Transformation Function:**

$$\boldsymbol{s \ = \ c \ \cdot r^{\{\gamma\}}}$$

This brightened the darker parts of the image and made bones stand out.

4. Results & Analysis

Visual Comparison

Original Image: Looked dull with bones and ribs not very clear.

When applying Histogram Equalization**,** the image became much clearer overall, but sometimes the enhancement was too strong. While bones and tissues became more visible, small noise in the background was also enhanced.

When applying Gamma Transformation (γ = 0.5)**,** the darker parts of the X-ray were brightened in a smoother way. This made subtle details visible without making the image look artificial.

Histogram Analysis

- Original Image: The histogram was clustered in a narrow range, meaning low contrast.
- Histogram Equalization: The histogram spread out more evenly across all intensities, which shows better utilization of the dynamic range.
- Gamma Correction (γ < 1): The histogram shifted towards brighter intensities, which shows that dark pixels became lighter.

Critical Evaluation

Between the two, Gamma Transformation worked better for my X-ray images. Histogram equalization sometimes made the image look too harsh, while gamma correction gave smoother enhancement and revealed hidden details in darker regions.

Technique Combination

I also tried combining the two methods: first applying gamma correction (γ = 0.6), and then histogram equalization. The result was a much brighter image with strong contrast. However, in some cases it over-enhanced the image, which might not be suitable for medical diagnosis. So while the combination can work, it needs to be applied carefully.

5. Conclusion

In conclusion, both histogram equalization and gamma transformation improved the visibility of the X-ray images. For my dataset, gamma correction was more effective because it revealed details in low-intensity regions without adding too much noise. If I had to recommend one method, I would suggest gamma transformation with a carefully chosen value of gamma.

6. Appendix (Code)

The code for this project was written in Python using Tkinter for the GUI. It includes two main options:

1. **Histogram Equalization**
2. **Gamma Transformation**

The program allows the user to load an X-ray image, apply the enhancement, and compare the results with histograms.

Work of Each Library

- tkinter → for building the main GUI.
- Pillow → to display images inside Tkinter.
- OpenCV (cv2) → for image enhancement methods like histogram equalization.
- NumPy → to perform pixel-level array operations.
- Matplotlib → to plot and compare histograms.
- typing → just for cleaner function definitions (not required for execution).

GitHub Repo Link:

https://github.com/crew3302/Medical-Image-Enhancement

GUI Code:

```
import tkinter as tk
from tkinter import ttk, filedialog, messagebox
from PIL import Image, ImageTk
import cv2
import numpy as np
import matplotlib.pyplot as plt
```

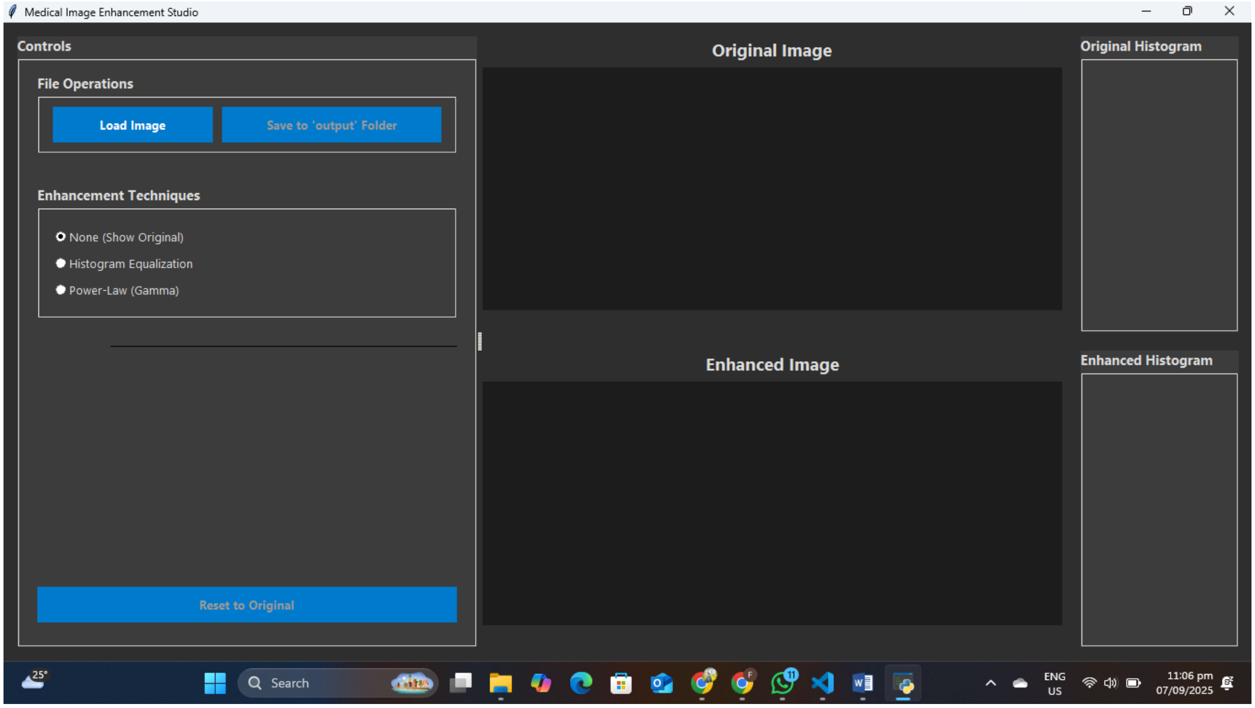
```python
from matplotlib.backends.backend_tkagg import FigureCanvasTkAgg
import os
from typing import Optional

# --- Constants ---
BG_COLOR = "#2e2e2e"
FRAME_COLOR = "#3c3c3c"
TEXT_COLOR = "#dcdcdc"
ACCENT_COLOR = "#007acc"
ACCENT_HOVER = "#009cff"
ERROR_COLOR = "#e74c3c"
CANVAS_BG = "#1c1c1c"

HISTOGRAM_PIXEL_LIMIT = 250000
OUTPUT_DIR = "output"

class ImageEnhancerApp:
    def __init__(self, root: tk.Tk):
        self.root = root
        self.root.title("Medical Image Enhancement Studio")
        self.root.geometry("1600x900")
        self.root.configure(bg=BG_COLOR)

        # --- Instance Variables ---
        self.original_image: Optional[np.ndarray] = None
        self.processed_image: Optional[np.ndarray] = None
        self.tk_original_image: Optional[ImageTk.PhotoImage] = None
        self.tk_processed_image: Optional[ImageTk.PhotoImage] = None
        self.original_filename: Optional[str] = None

        self.debounce_timer: Optional[str] = None
        self.lut_cache: dict = {}
        self.last_canvas_sizes: dict = {}

        self.setup_styles()
        self.setup_gui()

        # --- Create output directory on startup ---
        if not os.path.exists(OUTPUT_DIR):
            os.makedirs(OUTPUT_DIR)

    def setup_styles(self):
        style = ttk.Style()
        style.theme_use('clam')
        style.configure('.', background=BG_COLOR, foreground=TEXT_COLOR,
fieldbackground=FRAME_COLOR, borderwidth=1)
        style.configure('TFrame', background=BG_COLOR)
        style.configure('TLabel', background=BG_COLOR, foreground=TEXT_COLOR,
font=('Segoe UI', 10))
        style.configure('TRadiobutton', background=FRAME_COLOR,
foreground=TEXT_COLOR, font=('Segoe UI', 10))
        style.map('TRadiobutton', background=[('active', BG_COLOR)])
        style.configure('TButton', background=ACCENT_COLOR, foreground='white',
font=('Segoe UI', 10, 'bold'), borderwidth=0)
        style.map('TButton', background=[('active', ACCENT_HOVER)])
        style.configure('TLabelframe', background=FRAME_COLOR,
bordercolor=FRAME_COLOR)
        style.configure('TLabelframe.Label', background=FRAME_COLOR,
foreground=TEXT_COLOR, font=('Segoe UI', 11, 'bold'))
        style.configure('Horizontal.TScale', background=FRAME_COLOR,
troughcolor=BG_COLOR)

    def setup_gui(self):
        main_pane = ttk.PanedWindow(self.root, orient=tk.HORIZONTAL)
        main_pane.pack(fill=tk.BOTH, expand=True, padx=15, pady=15)

        control_frame = ttk.Labelframe(main_pane, text="Controls",
style='TLabelframe')
        main_pane.add(control_frame, weight=2)

        display_frame = ttk.Frame(main_pane, style='TFrame')
        main_pane.add(display_frame, weight=5)

        self.setup_control_widgets(control_frame)
        self.setup_display_widgets(display_frame)

    def setup_control_widgets(self, parent_frame: ttk.Labelframe):
        parent_frame['padding'] = (20, 15)

        file_frame = ttk.LabelFrame(parent_frame, text="File Operations",
style='TLabelframe', padding=10)
        file_frame.pack(fill=tk.X, pady=(0, 20))
        self.load_button = ttk.Button(file_frame, text="Load Image",
command=self.load_image, style='TButton')
        self.load_button.pack(side=tk.LEFT, expand=True, fill=tk.X, padx=5,
ipady=5)
        self.save_button = ttk.Button(file_frame, text="Save to 'output' Folder",
command=self.save_output, state=tk.DISABLED, style='TButton')
```

```
        self.save_button.pack(side=tk.LEFT, expand=True, fill=tk.X, padx=5, 
ipady=5)

        tech_frame = ttk.LabelFrame(parent_frame, text="Enhancement Techniques", 
style='TLabelframe', padding=15)
        tech_frame.pack(fill=tk.X, pady=15)
        self.technique_var = tk.StringVar(value="None")

        techniques = [("None (Show Original)", "None"), ("Histogram 
Equalization", "hist_eq"), ("Power-Law (Gamma)", "gamma")]
        for text, value in techniques:
            ttk.Radiobutton(tech_frame, text=text, variable=self.technique_var, 
value=value, command=self.on_technique_change).pack(anchor=tk.W, pady=3)

        self.params_frame = ttk.LabelFrame(parent_frame, text="Parameters", 
style='TLabelframe', padding=15)
        self.params_frame.pack(fill=tk.X, pady=15)

        self.gamma_label = ttk.Label(self.params_frame, text="Gamma (γ): 1.00")
        self.gamma_var = tk.DoubleVar(value=1.0)
        self.gamma_slider = ttk.Scale(self.params_frame, from_=0.1, to=5.0, 
variable=self.gamma_var, orient=tk.HORIZONTAL, command=self.on_slider_change)

        self.reset_button = ttk.Button(parent_frame, text="Reset to Original", 
command=self.reset_image, state=tk.DISABLED, style='TButton')
        self.reset_button.pack(fill=tk.X, side=tk.BOTTOM, pady=10, ipady=5)
        self.on_technique_change()

    def setup_display_widgets(self, parent_frame: ttk.Frame):
        parent_frame.rowconfigure(0, weight=1); parent_frame.rowconfigure(1, 
weight=1)
        parent_frame.columnconfigure(0, weight=3); 
parent_frame.columnconfigure(1, weight=2)

        original_frame, self.original_canvas, self.original_info_label = 
self._create_display_canvas(parent_frame, "Original Image")
        original_frame.grid(row=0, column=0, sticky="nsew", padx=(0, 10), 
pady=(0, 10))
        processed_frame, self.processed_canvas, self.processed_info_label = 
self._create_display_canvas(parent_frame, "Enhanced Image")
        processed_frame.grid(row=1, column=0, sticky="nsew", padx=(0, 10), 
pady=(10, 0))

        self.hist_original_frame = self._create_histogram_frame(parent_frame, 
"Original Histogram")
```

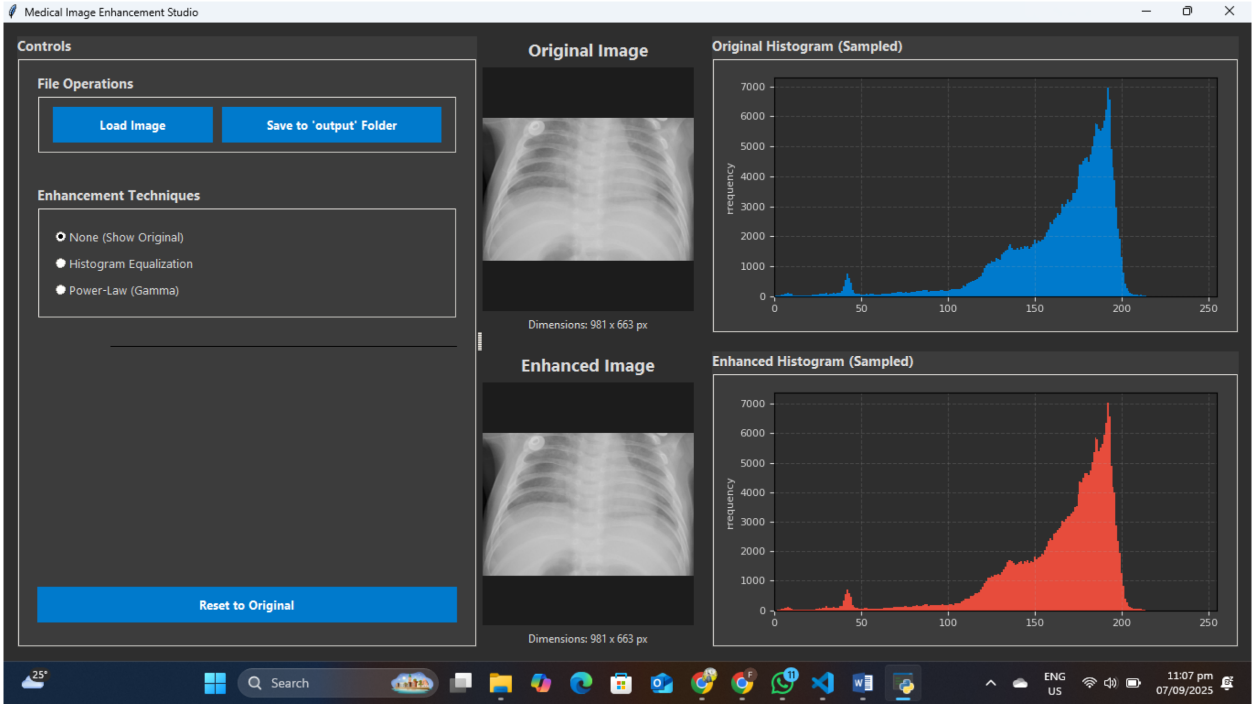
```
        self.hist_original_frame.grid(row=0, column=1, sticky="nsew", padx=(10,
0), pady=(0, 10))
        self.hist_processed_frame = self._create_histogram_frame(parent_frame,
"Enhanced Histogram")
        self.hist_processed_frame.grid(row=1, column=1, sticky="nsew", padx=(10,
0), pady=(10, 0))

        self.original_canvas.bind('<Configure>', self.on_canvas_resize)
        self.processed_canvas.bind('<Configure>', self.on_canvas_resize)

    def _create_display_canvas(self, parent, title):
        frame = ttk.Frame(parent, style='TFrame')
        label = ttk.Label(frame, text=title, font=('Segoe UI', 14, 'bold'))
        label.pack(pady=(0, 5))
        canvas = tk.Canvas(frame, bg=CANVAS_BG, relief=tk.FLAT, bd=0,
highlightthickness=0)
        canvas.pack(fill=tk.BOTH, expand=True)
        info_label = ttk.Label(frame, text="", font=('Segoe UI', 9))
        info_label.pack(pady=(5, 0))
        return frame, canvas, info_label

    def _create_histogram_frame(self, parent, title):
        return ttk.Labelframe(parent, text=title, style='TLabelframe',
padding=10)

    def on_canvas_resize(self, event: tk.Event):
        canvas = event.widget
        canvas_w, canvas_h = canvas.winfo_width(), canvas.winfo_height()
        if self.last_canvas_sizes.get(id(canvas)) == (canvas_w, canvas_h): return
        self.last_canvas_sizes[id(canvas)] = (canvas_w, canvas_h)

        if canvas == self.original_canvas and self.original_image is not None:
            self.display_image(self.original_image, self.original_canvas,
'original', self.original_info_label)
        elif canvas == self.processed_canvas and self.processed_image is not
None:
            self.display_image(self.processed_image, self.processed_canvas,
'processed', self.processed_info_label)

    def on_slider_change(self, _=None):
        if self.technique_var.get() == "gamma":
            self.gamma_label.config(text=f"Gamma (γ):
{self.gamma_var.get():.2f}")
        if self.debounce_timer:
            self.root.after_cancel(self.debounce_timer)
        self.debounce_timer = self.root.after(100, self.apply_enhancement)

    def on_technique_change(self):
        self.gamma_label.pack_forget(); self.gamma_slider.pack_forget()
        if self.technique_var.get() == "gamma":
            self.gamma_label.pack(anchor=tk.W)
            self.gamma_slider.pack(fill=tk.X, pady=(0, 10))
        self.apply_enhancement()

    def apply_enhancement(self):
        if self.original_image is None: return
        technique = self.technique_var.get()

        if technique == "hist_eq":
            self.processed_image = cv2.equalizeHist(self.original_image)
        elif technique == "gamma":
            gamma = round(self.gamma_var.get(), 2)
            cache_key = f"gamma_{gamma}"
            if cache_key not in self.lut_cache:
                inv_gamma = 1.0 / gamma
                table = np.array([((i / 255.0) ** inv_gamma) * 255 for i in
np.arange(256)]).astype("uint8")
                self.lut_cache[cache_key] = table
            self.processed_image = cv2.LUT(self.original_image,
self.lut_cache[cache_key])
        else:
            self.processed_image = self.original_image.copy()

        self.display_image(self.processed_image, self.processed_canvas,
'processed', self.processed_info_label)
        self.update_histograms()

    def display_image(self, image_data, canvas, image_type, info_label):
        canvas.delete("all")
        canvas_w, canvas_h = canvas.winfo_width(), canvas.winfo_height()
        if image_data is None or canvas_w < 2 or canvas_h < 2: return

        img_h, img_w = image_data.shape[:2]; aspect = img_w / img_h
        new_w, new_h = (canvas_w, int(canvas_w / aspect)) if (canvas_w / aspect)
<= canvas_h else (int(canvas_h * aspect), canvas_h)
        if new_w < 1 or new_h < 1: return

        resized_img = cv2.resize(image_data, (int(new_w), int(new_h)),
interpolation=cv2.INTER_AREA)
        photo_img = ImageTk.PhotoImage(image=Image.fromarray(resized_img))
        if image_type == 'original': self.tk_original_image = photo_img
        else: self.tk_processed_image = photo_img

        x, y = (canvas_w - new_w) / 2, (canvas_h - new_h) / 2
        canvas.create_image(x, y, anchor=tk.NW, image=photo_img)
        info_label.config(text=f"Dimensions: {img_w} x {img_h} px")

    def calculate_histogram_fast(self, image):
        if image.size > HISTOGRAM_PIXEL_LIMIT:
            pixels, is_sampled = np.random.choice(image.ravel(),
HISTOGRAM_PIXEL_LIMIT, replace=False), True
        else:
            pixels, is_sampled = image.ravel(), False
        counts, bins = np.histogram(pixels, bins=256, range=[0, 256])
        return counts, bins, is_sampled

    def update_histograms(self):
        if self.original_image is not None:
            counts, bins, sampled =
self.calculate_histogram_fast(self.original_image)
            self.plot_histogram(self.hist_original_frame, counts, bins,
ACCENT_COLOR, "Original Histogram", sampled)
        if self.processed_image is not None:
            counts, bins, sampled =
self.calculate_histogram_fast(self.processed_image)
            self.plot_histogram(self.hist_processed_frame, counts, bins,
ERROR_COLOR, "Enhanced Histogram", sampled)

    def plot_histogram(self, parent_frame, counts, bins, color, title, sampled):
        for widget in parent_frame.winfo_children(): widget.destroy()
        parent_frame['text'] = title + (" (Sampled)" if sampled else "")
        fig, ax = plt.subplots(facecolor=FRAME_COLOR)
        ax.set_facecolor(BG_COLOR)
        ax.bar(bins[:-1], counts, width=1, color=color)
        ax.set_xlim([0, 255]); ax.tick_params(colors=TEXT_COLOR, which='both')
        ax.set_xlabel("Pixel Intensity", color=TEXT_COLOR, fontsize=8)
        ax.set_ylabel("Frequency", color=TEXT_COLOR, fontsize=8)
        ax.tick_params(axis='both', which='major', labelsize=8)
        ax.grid(True, linestyle='--', alpha=0.2); fig.tight_layout(pad=0.5)
        canvas = FigureCanvasTkAgg(fig, master=parent_frame)
        canvas.draw()
        canvas.get_tk_widget().pack(fill=tk.BOTH, expand=True, padx=5, pady=5)
        plt.close(fig)
    def load_image(self):
        file_path = filedialog.askopenfilename(filetypes=[("Image Files",
"*.png;*.jpg;*.jpeg;*.bmp;*.tif;*.dcm")])
        if not file_path: return
        try:
            img = cv2.imread(file_path, cv2.IMREAD_GRAYSCALE)
            if img is None: raise ValueError("File is not a valid image.")
            self.original_image = img
            self.original_filename = os.path.basename(file_path)
            self.lut_cache.clear(); self.last_canvas_sizes = {}
            self.reset_image()
            self.save_button['state'] = tk.NORMAL
            self.reset_button['state'] = tk.NORMAL
        except Exception as e:
            messagebox.showerror("Error", f"Failed to load image: {e}")

    def save_output(self):
        if self.processed_image is None or self.original_filename is None:
            messagebox.showwarning("Warning", "No enhanced image to save.")
            return
        technique = self.technique_var.get()
        if technique == "None":
            messagebox.showinfo("Info", "No enhancement applied. Cannot save.")
            return

        base_name, _ = os.path.splitext(self.original_filename)
        suffix = f"{technique}_gamma{self.gamma_var.get():.2f}" if technique ==
"gamma" else technique

        new_image_filename = f"{base_name}_{suffix}.png"
        new_hist_filename = f"{base_name}_{suffix}_hist.png"
        image_save_path = os.path.join(OUTPUT_DIR, new_image_filename)
        hist_save_path = os.path.join(OUTPUT_DIR, new_hist_filename)

        try:
            cv2.imwrite(image_save_path, self.processed_image)
            self.save_histogram_to_file(self.processed_image, hist_save_path,
ERROR_COLOR, "Enhanced Histogram")
            messagebox.showinfo("Success", f"Outputs saved to '{OUTPUT_DIR}'
folder:\n- {new_image_filename}\n- {new_hist_filename}")
        except Exception as e:
            messagebox.showerror("Error", f"Failed to save files: {e}")

    def save_histogram_to_file(self, image_data, file_path, color, title):
        counts, bins, sampled = self.calculate_histogram_fast(image_data)
        full_title = title + (" (Sampled)" if sampled else "")

        fig, ax = plt.subplots(facecolor=FRAME_COLOR, figsize=(6, 4))
        fig.suptitle(full_title, color=TEXT_COLOR, fontsize=12)
        ax.set_facecolor(BG_COLOR)
        ax.bar(bins[:-1], counts, width=1.0, color=color)
        ax.set_xlim([0, 255]); ax.tick_params(colors=TEXT_COLOR, which='both')
        ax.set_xlabel("Pixel Intensity", color=TEXT_COLOR)
        ax.set_ylabel("Frequency", color=TEXT_COLOR)
        ax.grid(True, linestyle='--', alpha=0.2)
        fig.tight_layout(rect=[0, 0, 1, 0.95])

        fig.savefig(file_path, facecolor=FRAME_COLOR, dpi=150)
        plt.close(fig)

    def reset_image(self):
        if self.original_image is not None:
            self.technique_var.set("None")
            self.last_canvas_sizes = {}
            self.display_image(self.original_image, self.original_canvas,
'original', self.original_info_label)
            self.apply_enhancement()

if __name__ == "__main__":
    root = tk.Tk()
    app = ImageEnhancerApp(root)
    root.mainloop()
```

Outputs:

Before image upload



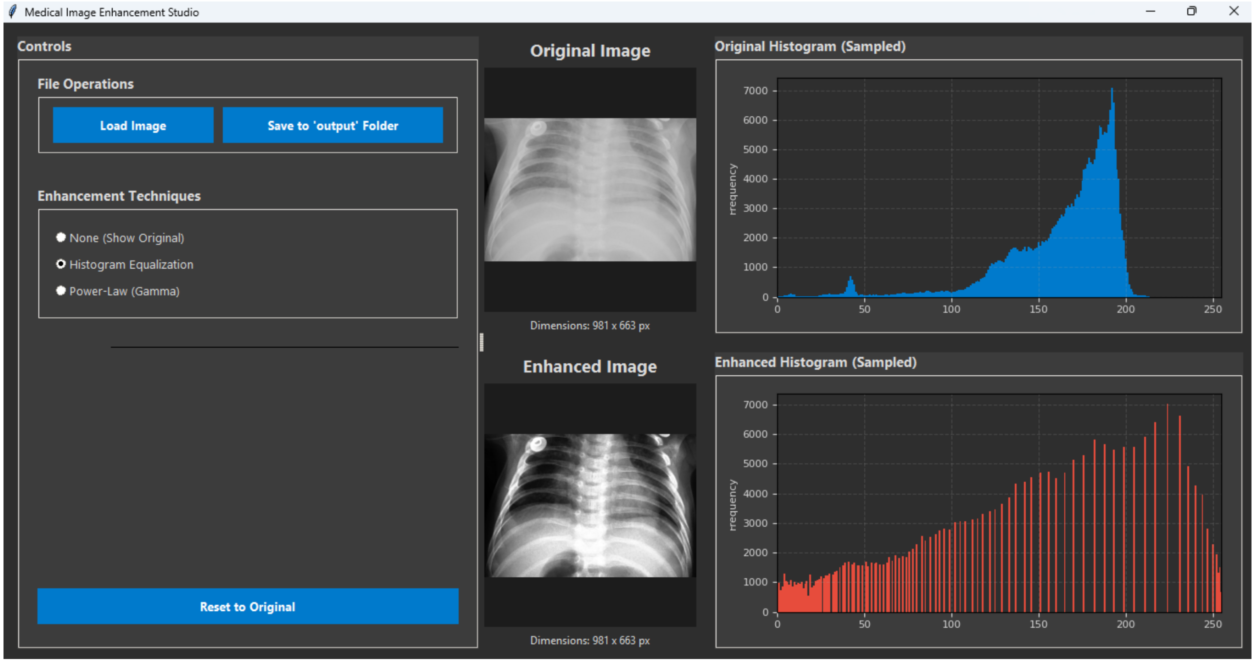
After image upload



Dimensions: 981 x 663 px

Dimensions: 981 x 663 px

Apply histogram Equalization

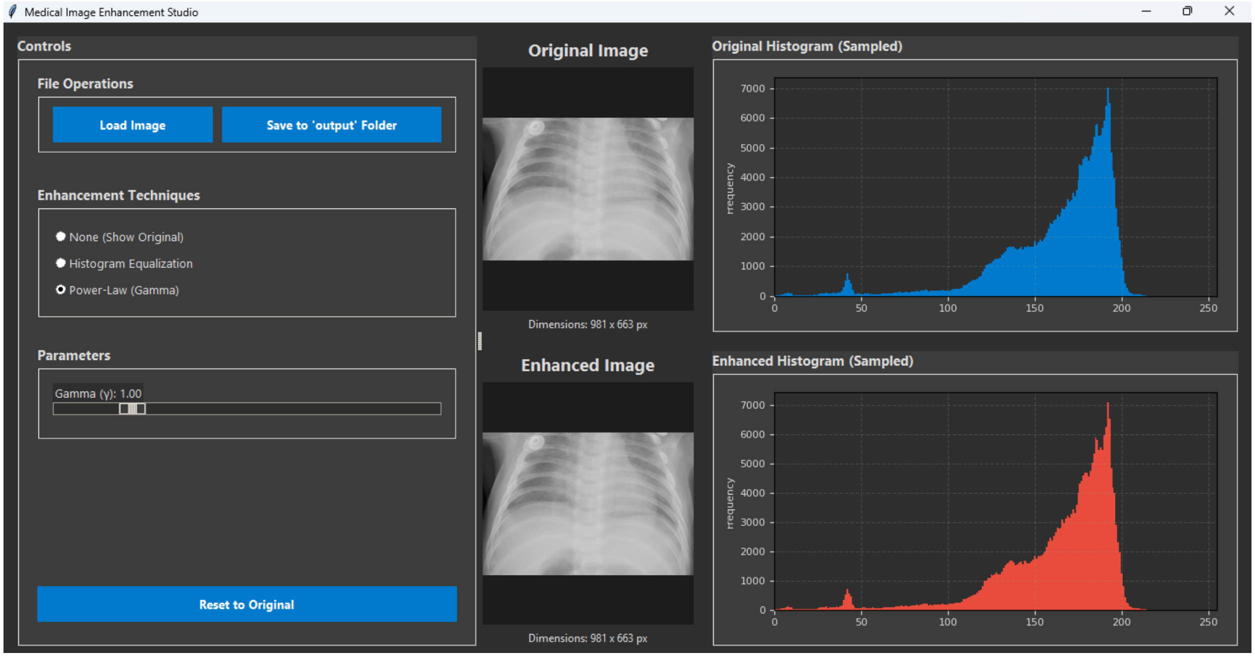


● None (Show Original)
○ Histogram Equalization
● Power-Law (Gamma)

Dimensions: 981 x 663 px

Dimensions: 981 x 663 px

Apply Power-law(Gamma=1.00)



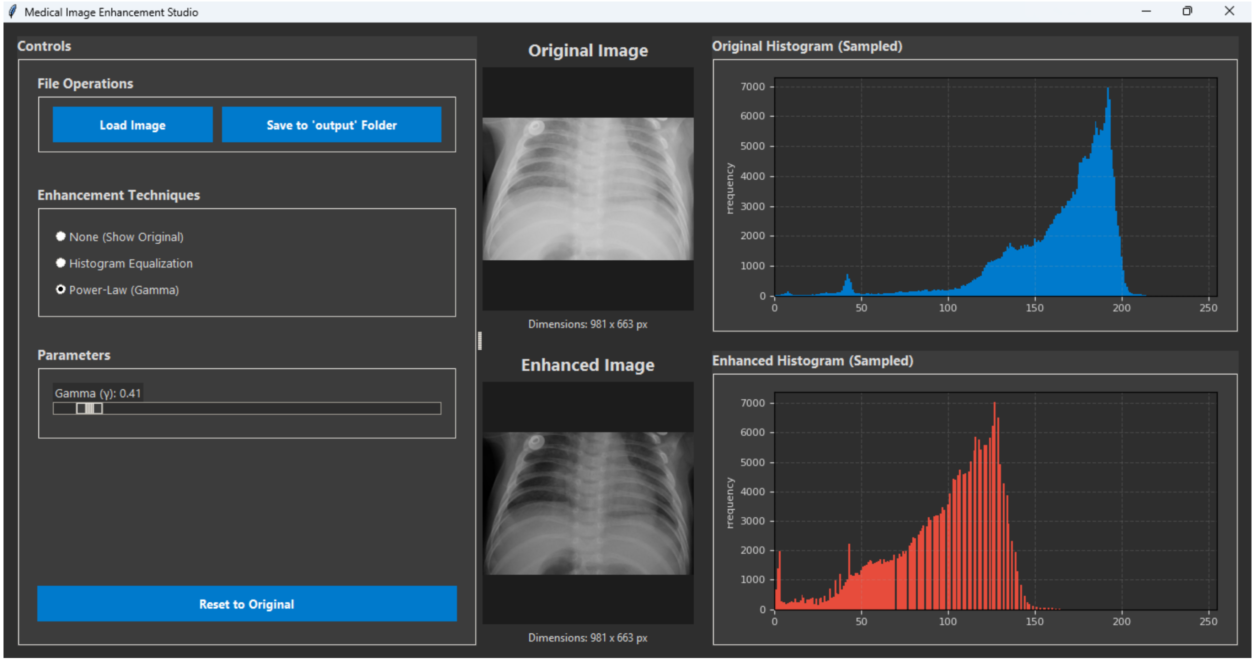
● None (Show Original)
● Histogram Equalization
○ Power-Law (Gamma)

Gamma (γ): 1.00

Dimensions: 981 x 663 px

Dimensions: 981 x 663 px

(Gamma=0.41)



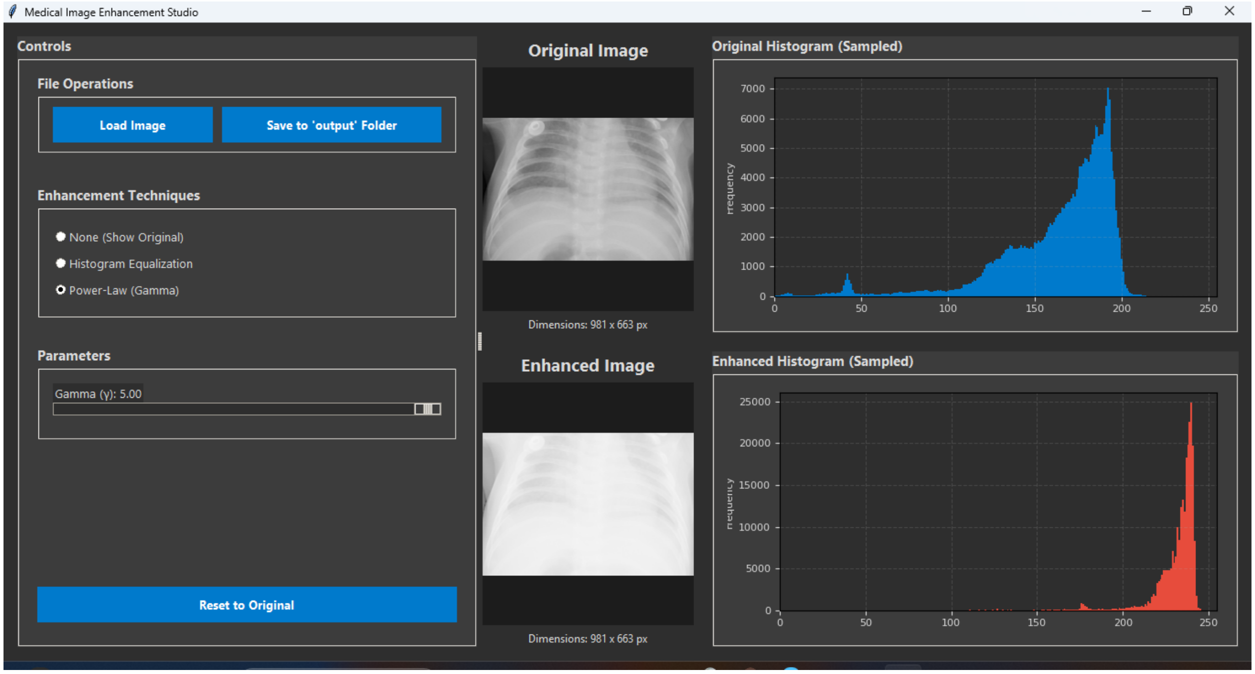
● None (Show Original)
● Histogram Equalization
○ Power-Law (Gamma)

Gamma (γ): 0.41

Dimensions: 981 x 663 px

Dimensions: 981 x 663 px

(Gamma=5.00)



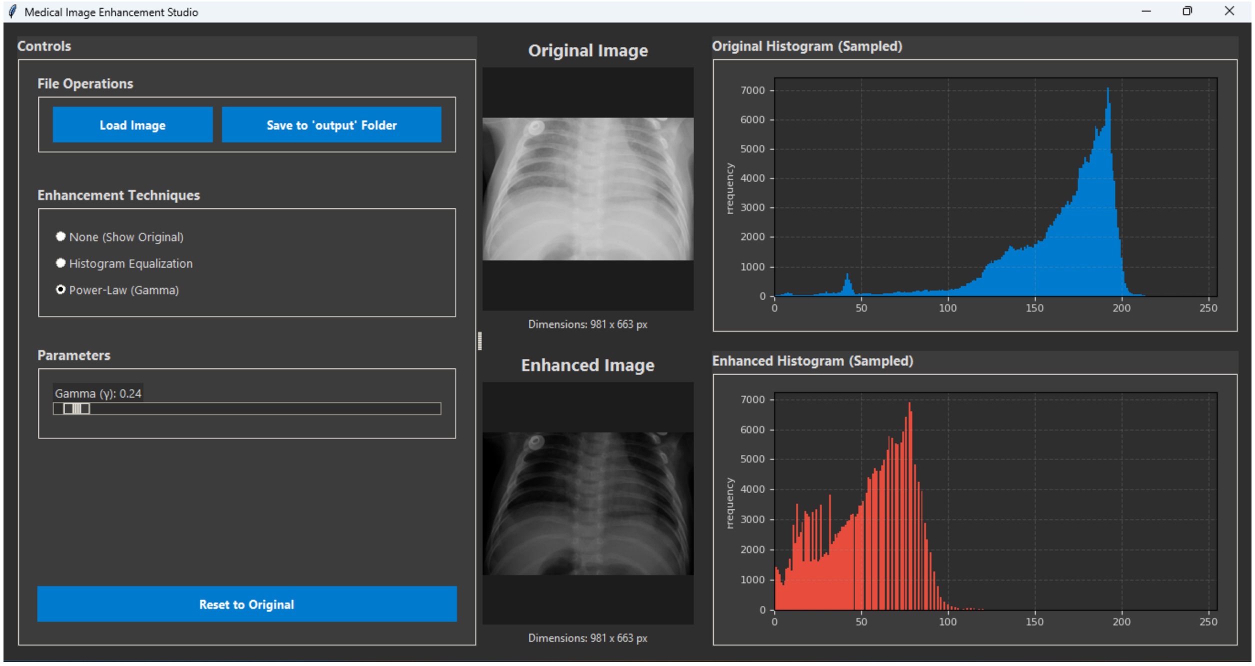
● None (Show Original)
● Histogram Equalization
○ Power-Law (Gamma)

Gamma (γ): 5.00

Dimensions: 981 x 663 px

Dimensions: 981 x 663 px

(Gamma=0.25)

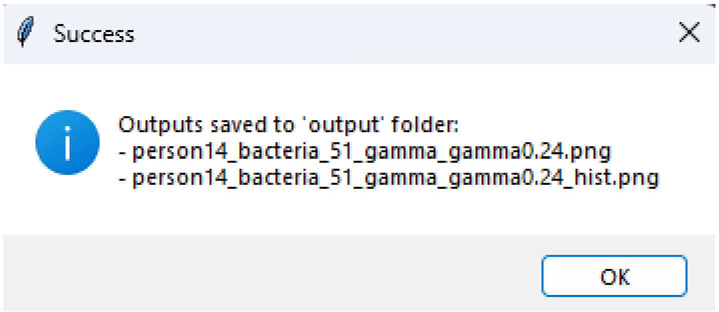


Gamma (γ): 0.24

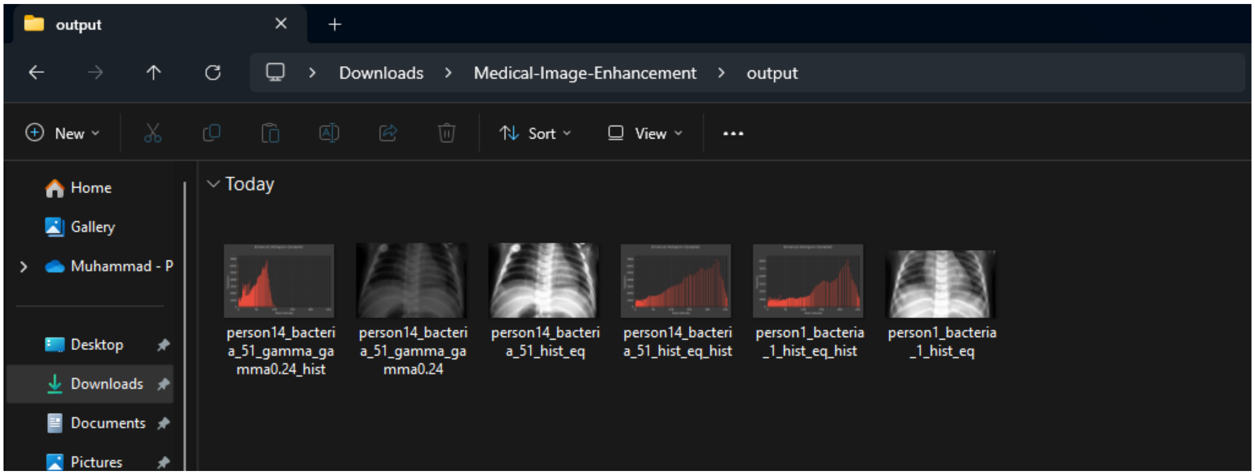
Dimensions: 981 x 663 px

Dimensions: 981 x 663 px

Save Image



Outputs saved to 'output' folder:
- person14_bacteria_51_gamma_gamma0.24.png
- person14_bacteria_51_gamma_gamma0.24_hist.png

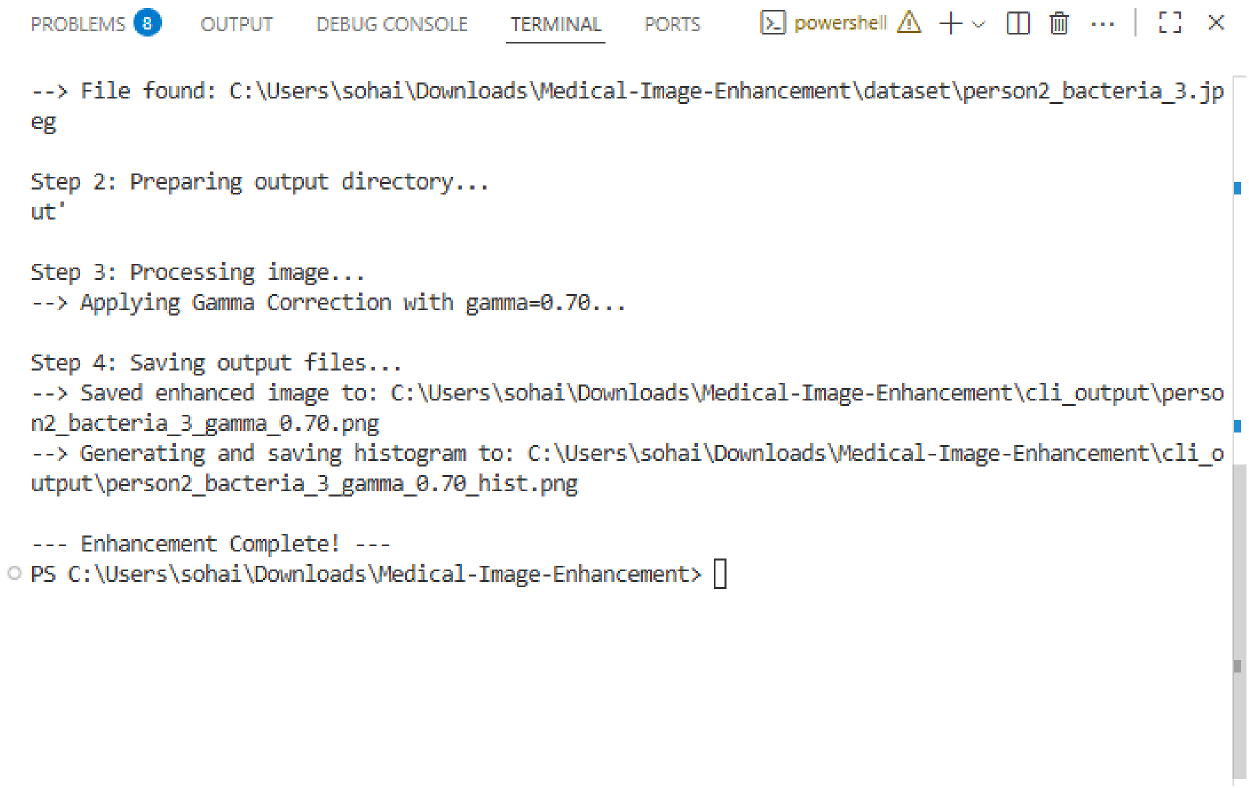

output
Downloads > Medical-Image-Enhancement > output
New
Sort
View
Home
Gallery
Muhammad - P
Desktop
Downloads
Documents
Pictures
Today
person14_bacteria_51_gamma_gamma0.24_hist
person14_bacteria_51_gamma_gamma0.24
person14_bacteria_51_hist_eq
person14_bacteria_51_hist_eq_hist
person1_bacteria_1_hist_eq_hist
person1_bacteria_1_hist_eq

GUI Code:

```
import os
import argparse
import sys
try:
    import cv2
    import numpy as np
    import matplotlib.pyplot as plt
except ImportError as e:
    print(f"--> Error: A required library is missing: {e.name}")
    print("--> Please install the necessary libraries by running this command:")
    print("pip install opencv-python numpy matplotlib")
    sys.exit(1)

# --- Constants ---
BG_COLOR = "#2e2e2e"
FRAME_COLOR = "#3c3c3c"
TEXT_COLOR = "#dcdcdc"
ERROR_COLOR = "#e74c3c"
DEFAULT_OUTPUT_DIR = "cli_output"

def apply_histogram_equalization(image: np.ndarray) -> np.ndarray:
    """Applies Histogram Equalization to a grayscale image."""
    print("--> Applying Histogram Equalization...")
    return cv2.equalizeHist(image)

def apply_gamma_correction(image: np.ndarray, gamma: float) -> np.ndarray:
    """Applies Power-Law (Gamma) transformation to a grayscale image."""
    if gamma <= 0:
        raise ValueError("Gamma value must be greater than zero.")

    print(f"--> Applying Gamma Correction with gamma={gamma:.2f}...")
    inv_gamma = 1.0 / gamma
    table = np.array([((i / 255.0) ** inv_gamma) * 255 for i in
np.arange(256)]).astype("uint8")
    return cv2.LUT(image, table)

def save_histogram_to_file(image_data: np.ndarray, file_path: str, title: str):
    """Calculates and saves the histogram of an image to a file."""
    print(f"--> Generating and saving histogram to: {file_path}")

    counts, bins = np.histogram(image_data.ravel(), bins=256, range=[0, 256])

    fig, ax = plt.subplots(facecolor=FRAME_COLOR, figsize=(6, 4))
    fig.suptitle(title, color=TEXT_COLOR, fontsize=12)
    ax.set_facecolor(BG_COLOR)
    ax.bar(bins[:-1], counts, width=1.0, color=ERROR_COLOR)
    ax.set_xlim([0, 255])
    ax.tick_params(colors=TEXT_COLOR, which='both')
    ax.set_xlabel("Pixel Intensity", color=TEXT_COLOR)
    ax.set_ylabel("Frequency", color=TEXT_COLOR)
    ax.grid(True, linestyle='--', alpha=0.2)
    fig.tight_layout(rect=[0, 0, 1, 0.95])

    fig.savefig(file_path, facecolor=FRAME_COLOR, dpi=150)
    plt.close(fig)

def main():
    parser = argparse.ArgumentParser(
        description="A command-line tool for medical image enhancement.",
        formatter_class=argparse.RawTextHelpFormatter
    )

    parser.add_argument("filepath", type=str, help="Path to the input image
file.")
    parser.add_argument("-t", "--technique", type=str, required=True,
choices=["hist_eq", "gamma"], help="The enhancement technique to
apply:\n'hist_eq': Histogram Equalization\n'gamma':   Power-Law (Gamma)
Correction")
    parser.add_argument("-g", "--gamma", type=float, help="The gamma value for
the 'gamma' technique. Required if technique is 'gamma'.")
    parser.add_argument("-o", "--output_dir", type=str,
default=DEFAULT_OUTPUT_DIR, help=f"The directory to save output files. (Default:
{DEFAULT_OUTPUT_DIR})")

    args = parser.parse_args()

    # --- Argument and File Validation ---
    if args.technique == 'gamma' and not args.gamma:
        parser.error("The --gamma (-g) argument is REQUIRED when using the
'gamma' technique.")

    print(f"Step 1: Validating input file path...")
    # Convert to an absolute path to avoid ambiguity
    absolute_filepath = os.path.abspath(args.filepath)

    if not os.path.exists(absolute_filepath):
        print(f"\n--- FATAL ERROR ---")
        print(f"Input file not found at the specified path.")
        print(f"Attempted to read: {absolute_filepath}")
        print(f"Please check the filename for typos and ensure it's in the
correct folder.")
        return

    print(f"--> File found: {absolute_filepath}")

    try:
        # --- Main Logic ---
        print("\nStep 2: Preparing output directory...")
        # Get the directory of the script to create the output folder there
        script_dir = os.path.dirname(os.path.abspath(__file__))
        output_path = os.path.join(script_dir, args.output_dir)

        if not os.path.exists(output_path):
            os.makedirs(output_path)
            print(f"--> Created output directory: '{output_path}'")
        else:
            print(f"--> Output directory already exists: '{output_path}'")

        print("\nStep 3: Processing image...")
        original_image = cv2.imread(absolute_filepath, cv2.IMREAD_GRAYSCALE)
        if original_image is None:
            print(f"--- FATAL ERROR ---")
            print(f"The file was found, but OpenCV could not read it. It may be
corrupted or in an unsupported format.")
            return

        if args.technique == "hist_eq":
            processed_image = apply_histogram_equalization(original_image)
            suffix = "hist_eq"
        else:
            processed_image = apply_gamma_correction(original_image, args.gamma)
            suffix = f"gamma_{args.gamma:.2f}"

        print("\nStep 4: Saving output files...")
        base_name, _ = os.path.splitext(os.path.basename(absolute_filepath))
        new_image_filename = f"{base_name}_{suffix}.png"
        new_hist_filename = f"{base_name}_{suffix}_hist.png"

        image_save_path = os.path.join(output_path, new_image_filename)
        hist_save_path = os.path.join(output_path, new_hist_filename)

        cv2.imwrite(image_save_path, processed_image)
        print(f"--> Saved enhanced image to: {image_save_path}")
        save_histogram_to_file(processed_image, hist_save_path, f"Enhanced
Histogram ({suffix})")

        print("\n--- Enhancement Complete! ---")

    except Exception as e:
        print(f"\n--- An Unexpected Error Occurred ---")
        print(f"Error details: {e}")

if __name__ == "__main__":
    main()
```

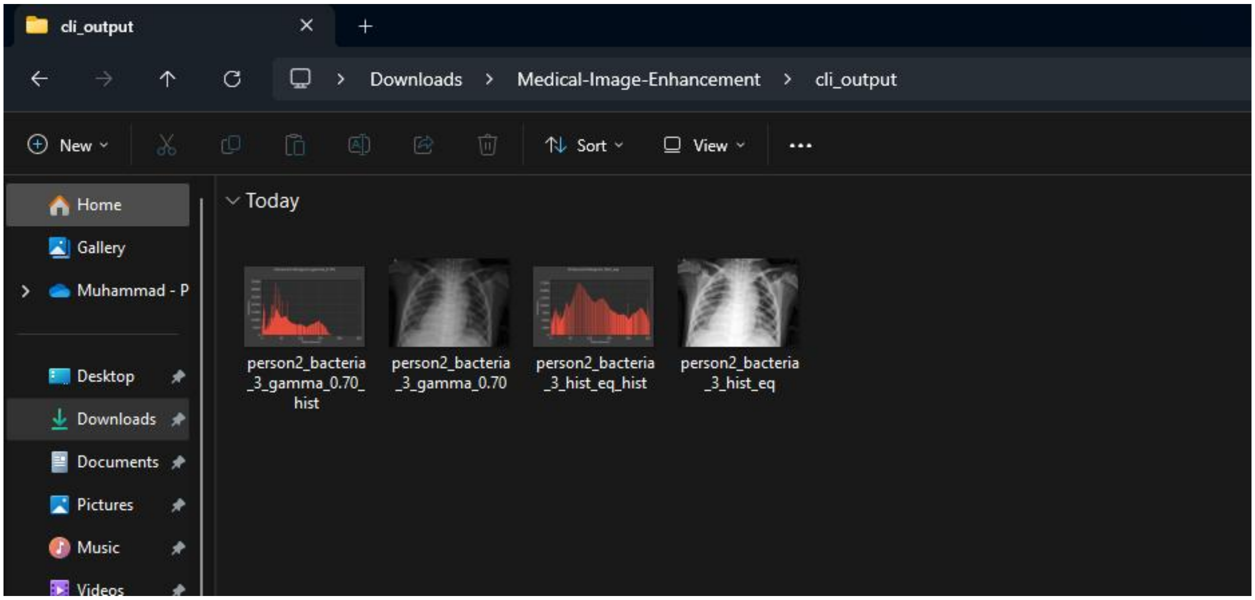
Output:

Save through CLI



```
--> File found: C:\Users\sohai\Downloads\Medical-Image-Enhancement\dataset\person2_bacteria_3.jp
eg

Step 2: Preparing output directory...
ut'

Step 3: Processing image...
--> Applying Gamma Correction with gamma=0.70...

Step 4: Saving output files...
--> Saved enhanced image to: C:\Users\sohai\Downloads\Medical-Image-Enhancement\cli_output\perso
n2_bacteria_3_gamma_0.70.png
--> Generating and saving histogram to: C:\Users\sohai\Downloads\Medical-Image-Enhancement\cli_o
utput\person2_bacteria_3_gamma_0.70_hist.png

--- Enhancement Complete! ---
PS C:\Users\sohai\Downloads\Medical-Image-Enhancement>
```

Saved Outputs


cli_output
Downloads
Medical-Image-Enhancement
cli_output
New
Sort
View
Home
Gallery
Muhammad - P
Desktop
Downloads
Documents
Pictures
Music
Videos
Today
person2_bacteria_3_gamma_0.70_hist
person2_bacteria_3_gamma_0.70
person2_bacteria_3_hist_eq_hist
person2_bacteria_3_hist_eq