X-RAY IMAGE ENHANCEMENT USING POINT PROCESSING TECHNIQUES

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Contents

1. Introduction

Chest X-rays are widely used in the medical field for diagnosing diseases like pneumonia, tuberculosis, and lung cancer. However, many chest X-ray images suffer from **low contrast** or poor visibility of structures, especially in dark or bright regions. This makes it difficult for radiologists to clearly identify abnormalities.

The goal of this project is to **enhance chest X-ray images** using digital image processing techniques so that details inside the lungs and bone structures become more visible for diagnostic purposes.

2. Dataset

For this project, we used the **Chest X-Ray Images (Pneumonia)** dataset available on Kaggle.

- **Organization**:
  The dataset is structured into three folders: train, test, and val, each containing two subfolders: Pneumonia and Normal. In total, there are **5,863 anterior–posterior chest X-ray images** in JPEG format, divided into two categories:
  - **Normal**: Healthy lungs
  - **Pneumonia**: Lungs showing signs of infection
- **Patient Demographics**:
  The images were collected from pediatric patients aged **1 to 5 years old** at **Guangzhou Women and Children's Medical Center** (Guangzhou, China). All chest radiographs were obtained as part of routine clinical care.
- **Quality Control**:
  To ensure dataset reliability, all radiographs underwent strict quality control.
  - Low-quality or unreadable scans were excluded.
  - Diagnoses were graded by **two expert physicians**, with a **third expert** reviewing the evaluation set to minimize grading errors.
- **Image Properties**:
  - Format: JPEG
  - Mode: Grayscale (single-channel)
  - Resolution: Varies per image, typically around **1024×1024** pixels
- **Suitability for This Project**:
  The dataset is highly suitable for testing image enhancement techniques because:
  1. Medical X-ray images often suffer from low contrast, making details inside the lungs less visible.
  2. Enhanced visibility can directly aid in diagnostic clarity, especially for distinguishing between normal and pneumonia cases.

3. Methodology & Justification

Technique 1: Power-Law (Gamma) Transformation

- **Justification**: Gamma transformation is effective in controlling brightness.
  - If **γ < 1**, dark regions are brightened (useful for lung details hidden in dark areas).
  - If **γ > 1**, bright regions are compressed (useful if image is overexposed).
- **Transformation Function**:

$$s = c * r^{\wedge} \gamma$$

where r = input pixel intensity (normalized [0,1]), γ = gamma value, and c=1.

Technique 2: Histogram Equalization (HE)

- **Justification**: HE redistributes pixel intensities across the full range [0–255]. This enhances global contrast, making bones and tissues more distinguishable.
- **Transformation Function (CDF-based mapping)**:

$$S_k = (L-1) \sum_{j=0}^{k} p\ (r_j)$$

where $p(r_j)$ = probability of intensity level r_j , L=256

Technique 3: Contrast Stretching

- **Justification**: If useful pixel intensities lie in a limited range (say 50–200), contrast stretching maps them to [0,255].
- **Transformation Function**:

$$s = \frac{(r_{max} - r_{min})}{(r - r_{min})} \, .255$$

where *rmin* and *rmax* are chosen thresholds.

Technique 4: Combination (Gamma + Histogram Equalization)

- **Justification**: A two-step process can yield better results:
  1. Gamma correction brightens hidden details in dark lung areas.
  2. Histogram Equalization redistributes them across the full intensity range.
- **Expected Benefit**: Balanced contrast and better visibility of both dark and bright regions.

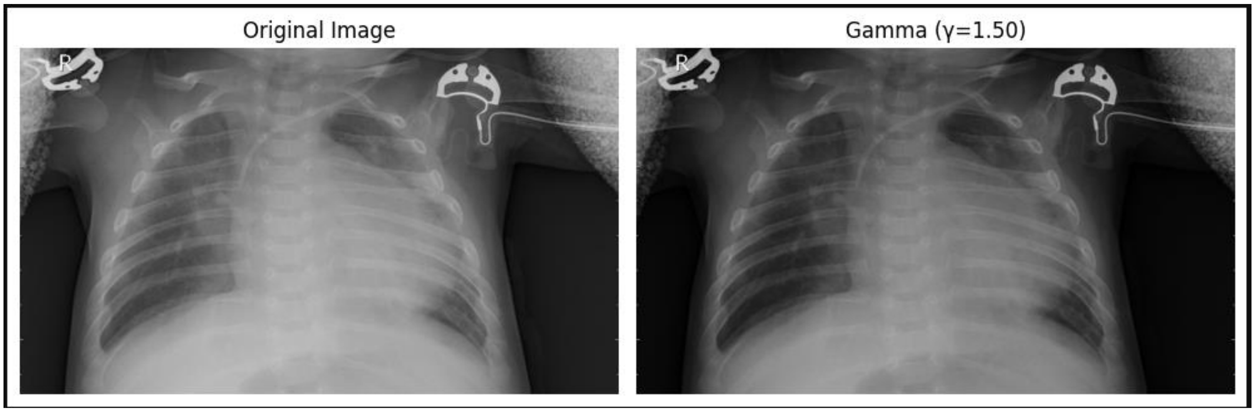
4. Results & Analysis

4.1 Visual Comparison

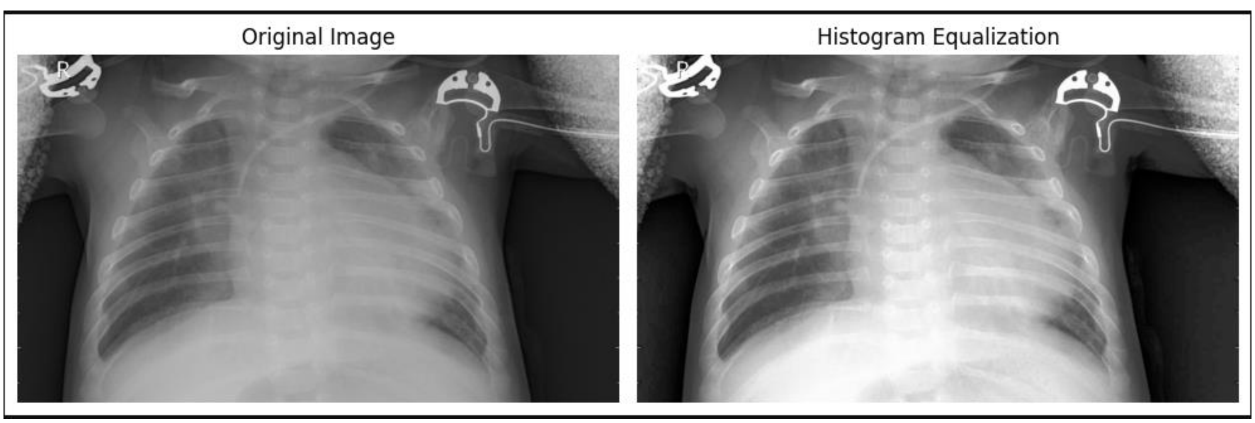
The applied four enhancement techniques for chest X-ray images are:

i. **Gamma Transformation**
ii. **Histogram Equalization**
iii. **Contrast Stretching**
iv. **Gamma Transformation + Histogram Equalization**

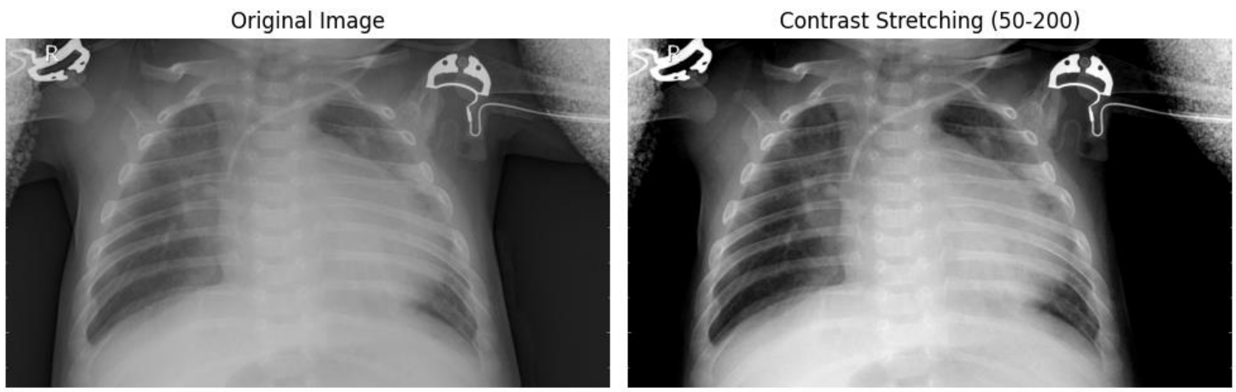
- **Gamma Transformation**: By adjusting the gamma slider, we observed that values **$\gamma < 1$** brightened the dark lung regions, making subtle details more visible. Conversely, **$\gamma > 1$** darkened bright structures like bones, which can sometimes suppress useful diagnostic information.



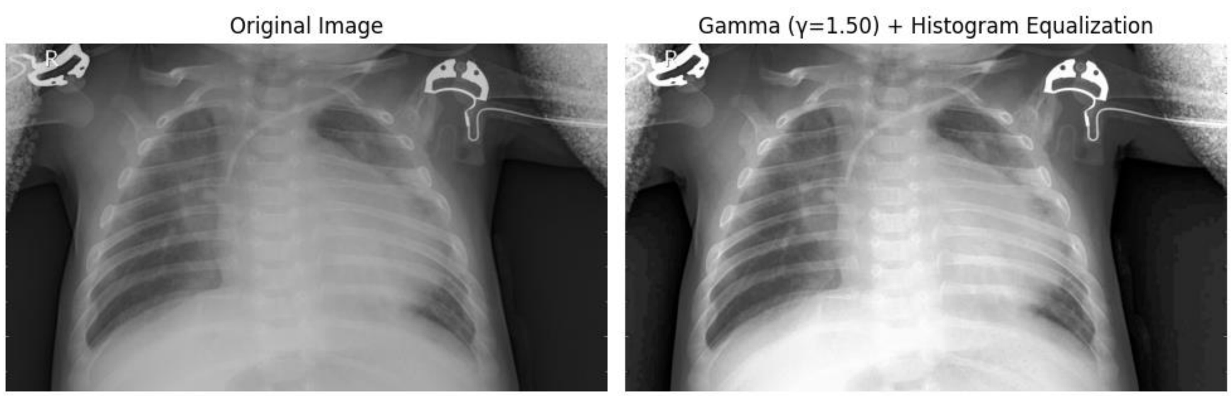
- **Histogram Equalization (HE)**: This method significantly improved **global contrast**, spreading pixel intensities across a wider range. As a result, the overall image appeared sharper, but sometimes with increased noise or unnatural brightness in certain areas.



- **Contrast Stretching**: This technique worked well when intensity values were confined to a narrow range (e.g., [50, 200]). Stretching to the full [0, 255] scale improved visibility of structures, although clipping at the lower and upper ends occasionally caused loss of fine detail.



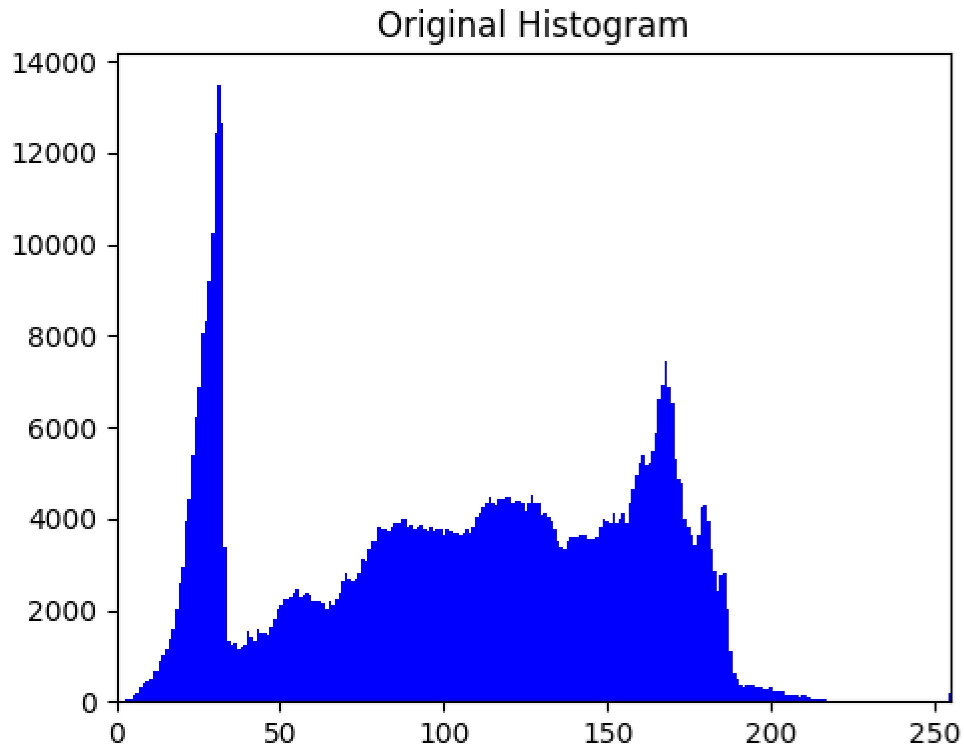
- **Gamma + Histogram Equalization**: Combining the two techniques often gave the **best balance**: gamma correction first revealed hidden structures in dark regions, while histogram equalization redistributed them across the full dynamic range. The final image typically had both improved local detail and balanced global contrast.



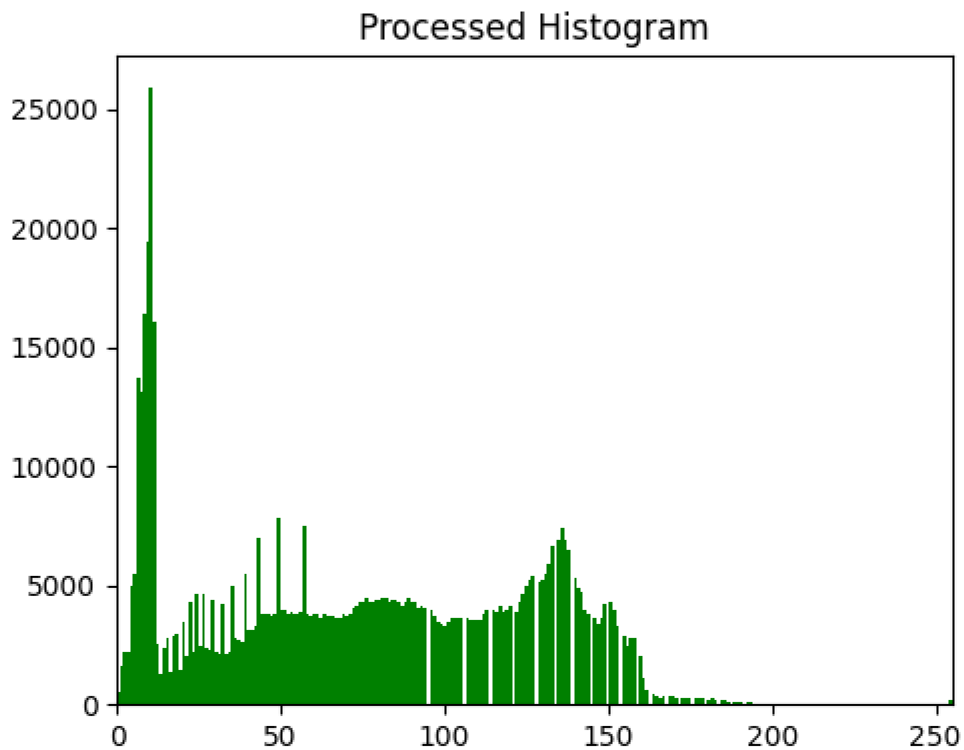
4.2 Histogram Analysis

The histograms provided valuable insights into how pixel intensities were redistributed:

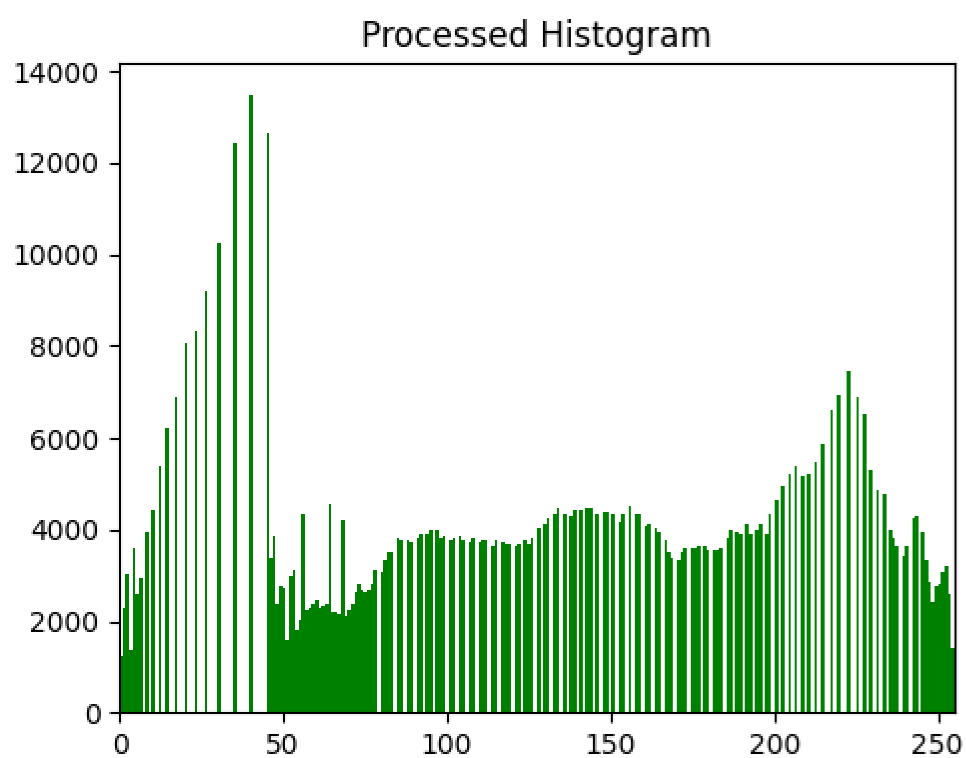
- **Original Image**: Typically concentrated in a narrow band, indicating poor contrast (most pixels were clustered in the mid-gray region).



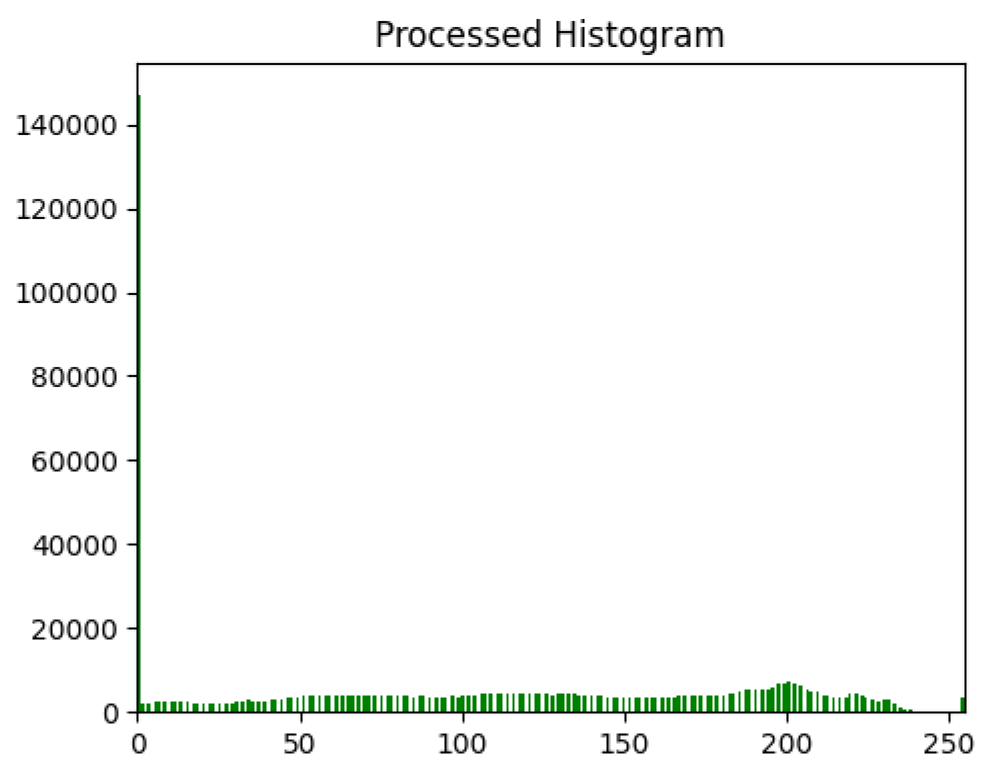
- **Gamma Transformation**:
  - **$\gamma < 1$**: Histogram shifted right, showing more bright pixels.
  - **$\gamma > 1$**: Histogram shifted left, with darker values dominating.
  - Importantly, the histogram did **not necessarily span 0–255**, which is expected.



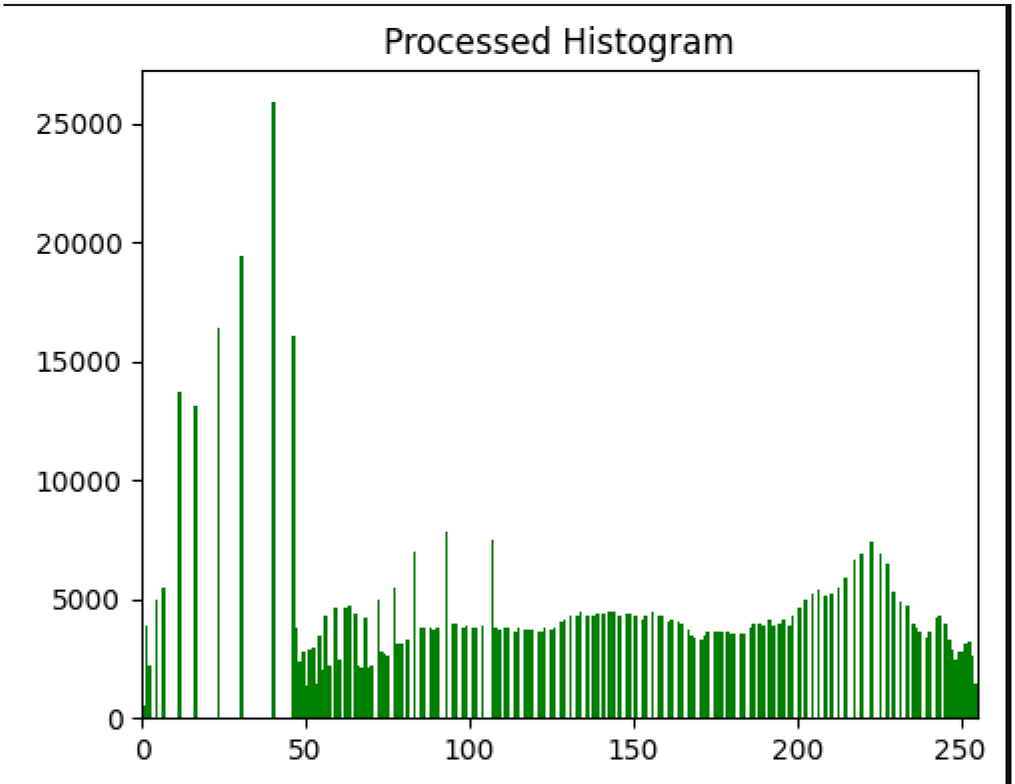
- **Histogram Equalization**: Intensities were spread more uniformly across the entire 0–255 range. The histogram often looked flatter and wider, confirming that pixel contrast was redistributed.



- **Contrast Stretching**: Original narrow histogram range expanded linearly to cover 0–255. Spikes at 0 and 255 indicated clipping.



- **Gamma + Histogram Equalization**: Produced a wide, balanced histogram similar to HE, but starting from a gamma-corrected distribution. This often resulted in more diagnostically useful contrast.



4.3 Critical Evaluation

- **Gamma Transformation** was particularly effective for **highlighting lung tissues** and making darker areas more interpretable, but it sometimes reduced clarity in bone structures.
- **Histogram Equalization** improved overall visibility, but could exaggerate noise in already bright areas, which may confuse interpretation.
- **Contrast Stretching** was simple and effective for images with a limited intensity range, but less adaptable to variations across different X-rays.
- **Gamma + Histogram Equalization** combined the strengths of both methods, offering enhanced visibility of dark details without losing global balance.

For chest X-ray analysis, the **combination method generally provided the most consistent improvement**, although the "best" method can depend on the specific image and diagnostic focus (e.g., highlighting soft tissues vs bones).

5. Conclusion

In this work, we explored multiple image enhancement techniques: **Gamma Transformation**, **Histogram Equalization**, **Contrast Stretching**, and their **Combination**, to address the problem of **improving the visibility of anatomical structures in low-contrast chest X-ray images**.

Our experiments showed that:

- **Gamma Transformation** was effective in revealing subtle details in darker regions, especially within lung fields.
- **Histogram Equalization** significantly improved global contrast, though at times it exaggerated noise in bright regions.
- **Contrast Stretching** was useful when the image intensities were limited to a narrow range, but less flexible for varied datasets.
- **Gamma + Histogram Equalization** consistently provided the best results, balancing local detail enhancement with global contrast distribution.

Overall, the **combination of Gamma Transformation and Histogram Equalization** proved to be the most effective approach. It not only improved the diagnostic visibility of lung structures but also produced a balanced image suitable for both visual inspection and potential downstream automated analysis.

Final Recommendation: For enhancing chest X-ray images, applying **Gamma Transformation followed by Histogram Equalization** offers the most reliable and diagnostically useful improvement, making it the preferred technique among those tested.

6. Appendix

The **full, well-commented dashboard code** can be found here.