

Analog Image Signal Processing

By , Aniket Fasate

Master of Science in Internet of Things
Northeastern University, Boston



What is an Image?

- An image is a visual representation of an object or scene captured or created through various means such as photography, painting, drawing, or digital graphics. In the context of technology and digital processing, an image is typically captured by sensors in devices like cameras or scanners and is composed of pixels in a grid layout.

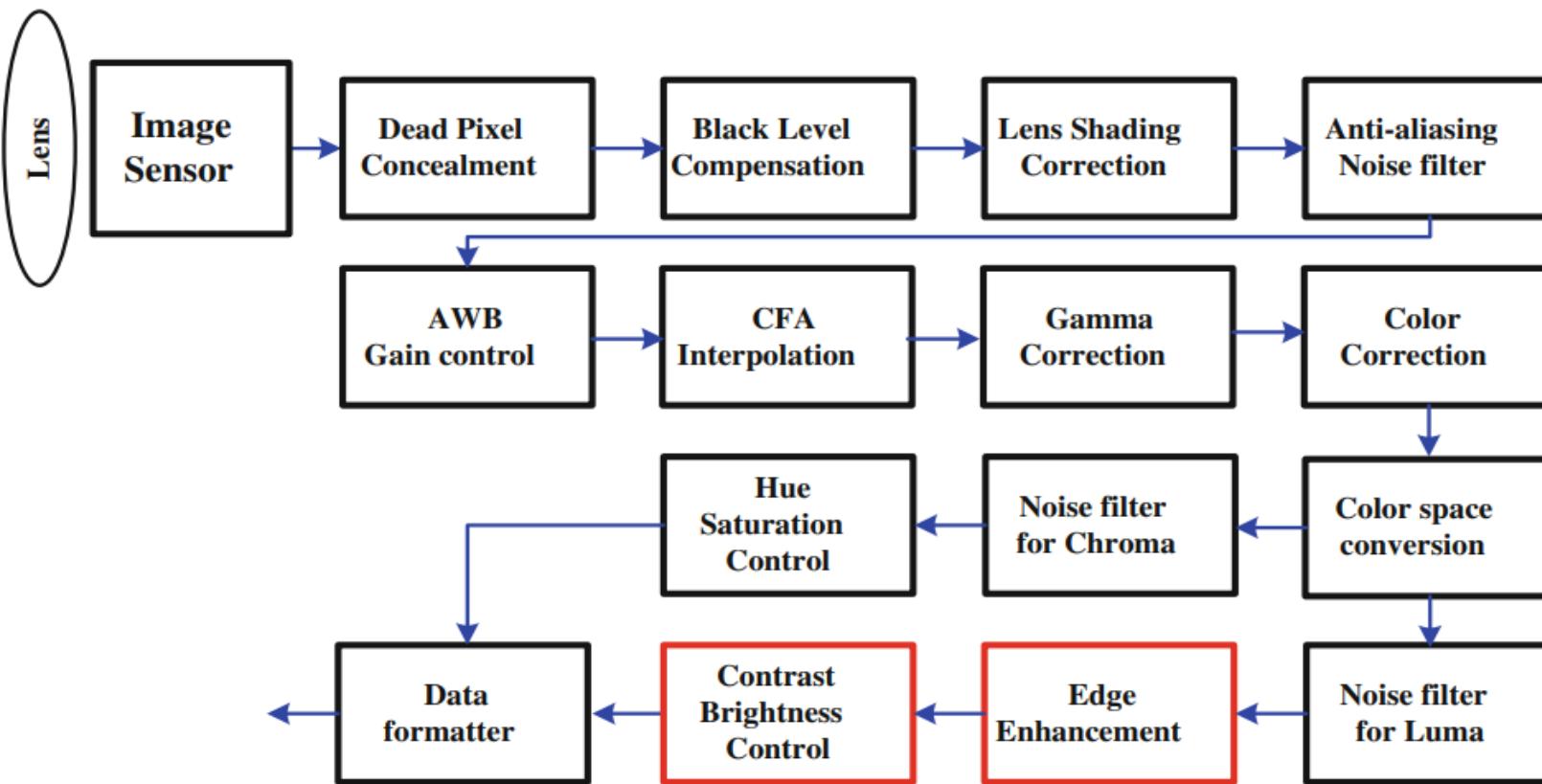
Image Signal Processing

Image Signal Processing (ISP) is a critical component in the field of digital imaging. It is the process of converting raw image data into a usable form, such as a digital image, by adjusting image quality parameters such as brightness, contrast, and color balance. The importance of ISP lies in its ability to enhance the quality of digital images, making them more appealing and usable. This article provides an overview of the Image Signal Processor, its components, types, applications, advancements, and challenges.

Types Of ISP

- 1) **Internal ISP :** An internal Image Signal Processor is integrated into the image sensor, and performs signal processing functions on the image sensor. This type of ISP is typically used in low-end digital cameras, where cost is a major consideration. Internal Image Signal Processors offer a lower image quality and performance compared to the external Image Signal Processors, but they are less expensive and easier to use.
- 2) **External ISP :** An external Image Signal Processor is a standalone device, specifically designed to perform image signal processing functions. It is typically used in high-end digital cameras and other imaging devices that require high image quality. External Image Signal Processors offer the best image quality and performance, but they are also the most expensive and complex to use.

Pipeline of ISP

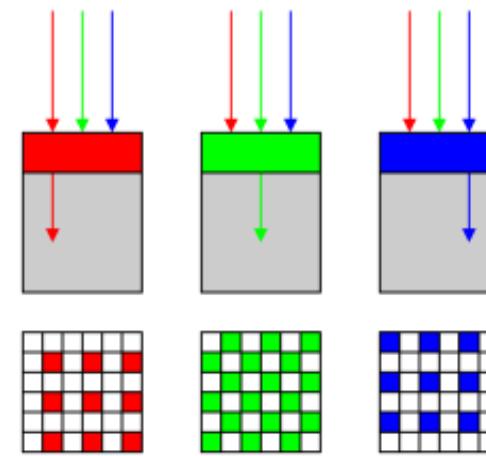
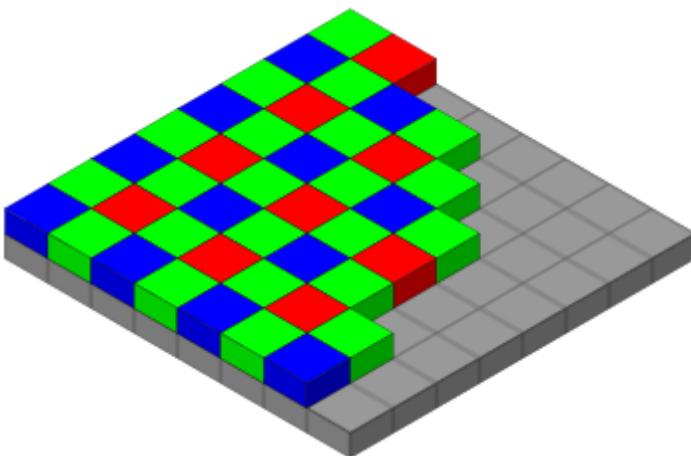


Color Filter Arrays

- It is an array of tiny color filters placed before the image sensor array of a camera.
- The resolution of this array is the same as that of the image sensor array.
- Each color filter may allow a different wavelength of light to pass – this is predetermined during the camera design.

Bayer Filter

- The most common type of CFA is the Bayer pattern which is shown below:



- The Bayer pattern collects information at red, green, blue wavelengths only as shown above

Color Filter Array

- The Bayer pattern uses twice the number of green elements as compared to red or blue elements.
- This is because both the M and L cone cells of the retina are sensitive to green light.
- The raw (uncompressed) output of the Bayer pattern is called as the Bayer pattern image or the mosaiced (*) image.
- The mosaiced image needs to be converted to a normal RGB image by a process called color image demosaicing.

Mosaicing

- Mosaicing, in the context of digital imaging, often refers to the process of assembling multiple images into a composite whole. However, when discussing it in the context similar to demosaicing, it typically means generating a Bayer pattern image from a full-color image. This is essentially the reverse of the demosaicing process.

Mosaicing Code

```
import cv2
import numpy as np

def create_bayer_pattern(rgb_image):
    bayer_pattern = np.zeros(rgb_image.shape[:2], dtype=np.uint8)
    bayer_pattern[1::2, 1::2] = rgb_image[1::2, 1::2, 0] # Blue
    bayer_pattern[1::2, 0::2] = rgb_image[1::2, 0::2, 1] # Green on blue rows
    bayer_pattern[0::2, 1::2] = rgb_image[0::2, 1::2, 1] # Green on red rows
    bayer_pattern[0::2, 0::2] = rgb_image[0::2, 0::2, 2] # Red
    return bayer_pattern

rgb_image = cv2.imread(r'C:\Users\anifa\Desktop\GITB\Image-Signal-Processing-\cute-baby-animals-1558535060.jpg')
bayer_pattern = create_bayer_pattern(rgb_image)

cv2.imwrite('bayer_pattern.png', bayer_pattern)
cv2.imshow('Bayer Pattern', bayer_pattern)
cv2.waitKey(0)
cv2.destroyAllWindows()
```

Mosaicing Output



Mosaicing
→



Demosaicing In ISP

- Demosaicing is the process of converting raw image data from a digital camera's sensor to a full-color image. This process is necessary because most digital cameras use a Bayer filter, capturing only one of the three primary colors (red, green, or blue) at each pixel. Demosaicing algorithms interpolate the missing colors at each pixel to produce a full-color image.

Demosaicong Code

```
import numpy as np
import cv2

def demosaic_bayer_pattern(bayer_pattern):
    height, width = bayer_pattern.shape
    rgb_image = np.zeros((height, width, 3), dtype=np.uint8)

    rgb_image[1::2, 0::2, 1] = bayer_pattern[1::2, 0::2]
    rgb_image[0::2, 1::2, 1] = bayer_pattern[0::2, 1::2]

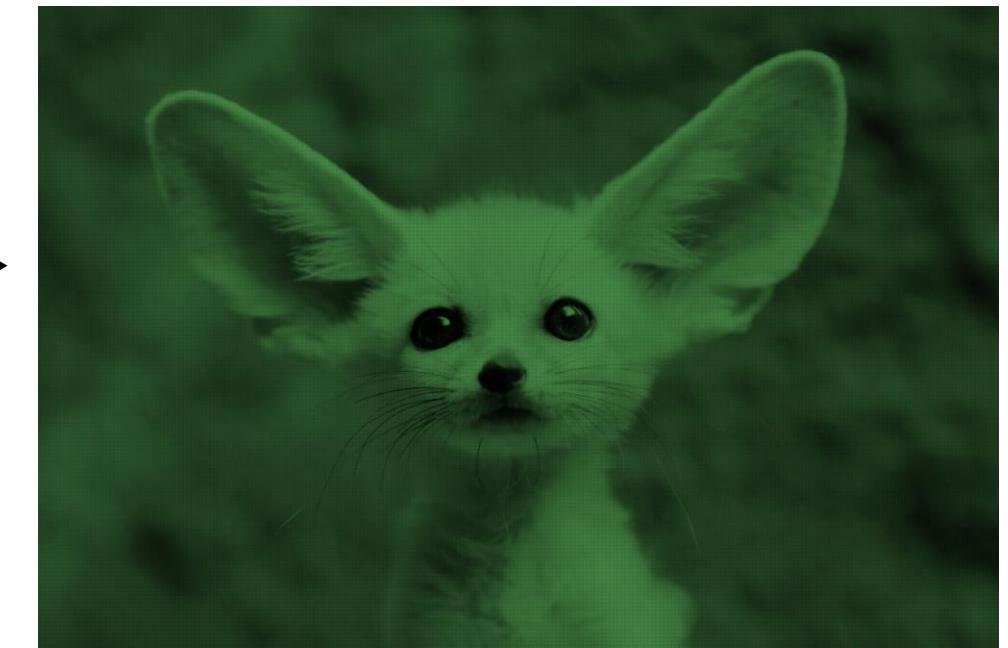
    for row in range(1, height-1):
        for col in range(1, width-1):
            if (row % 2 == 0 and col % 2 == 1) or (row % 2 == 1 and col % 2 == 0):
                rgb_image[row, col, 1] = np.mean([
                    bayer_pattern[row, col-1],
                    bayer_pattern[row, col+1],
                    bayer_pattern[row-1, col],
                    bayer_pattern[row+1, col]
                ]).astype(np.uint8)
            rgb_image[0::2, 0::2, 2] = bayer_pattern[0::2, 0::2]
            rgb_image[1::2, 1::2, 0] = bayer_pattern[1::2, 1::2]
    return rgb_image

bayer_pattern = cv2.imread('C:\Users\anifa\Desktop\GITB\Image-Signal-Processing-\demosained_image.jpg', cv2.IMREAD_GRAYSCALE)
if bayer_pattern is None:
    print("Failed to load the Bayer pattern image.")
else:
    demosained_image = demosaic_bayer_pattern(bayer_pattern)
    cv2.imwrite('demosained_image_fixed.jpg', demosained_image)
    cv2.imshow('Demosained Image Fixed', demosained_image)
    cv2.waitKey(0)
    cv2.destroyAllWindows()
```

Demosaicing output



Demosaicing
→



Applications of ISP

- **Mobile Phones:** Image Signal Processors play a crucial role in mobile phone cameras, as they are responsible for processing the image data captured by the image sensor and producing the final image. With the increasing demand for high-quality images, the ISP in mobile phones is becoming more sophisticated, providing better image quality and performance.
- **Digital Cameras:** Digital cameras rely on Image Signal Processors to produce high-quality images. Dedicated Image Signal Processors are typically used in high-end digital cameras, while integrated Image Signal Processors are used in low-end digital cameras. The type of ISP used in a digital camera will determine the image quality and performance of the camera.
- **Drones and Robotics:** Image Signal Processors are also used in drones and robotics, as they are responsible for processing the image data captured by the image sensor and providing information to the control system. This information is used to navigate the drone or robot and perform other tasks, such as object recognition and obstacle avoidance.

What Image Signal Processing in Analog Signals

- An image signal processor (ISP) is a specialized component in smartphones, webcams, digital cameras, and other imaging systems. Its primary function is to process raw image data the device captures and convert it into a high-quality image. To do this, the processor uses automatic scene and face recognition to enhance the signal output.
- Image signal processors also change the image's quality parameters through contrast, color, and brightness to ensure it's visually appealing.

Analog Image Signal Processing

- The analog image processing is applied on analog signals and it processes only two-dimensional signals. The images are manipulated by electrical signals. In analog image processing, analog signals can be periodic or non-periodic.

Digital Image Signal Processing

- A digital image processing is applied to digital images (a matrix of small pixels and elements). For manipulating the images, there is a number of software and algorithms that are applied to perform changes. Digital image processing is one of the fastest growing industry which affects everyone's life.

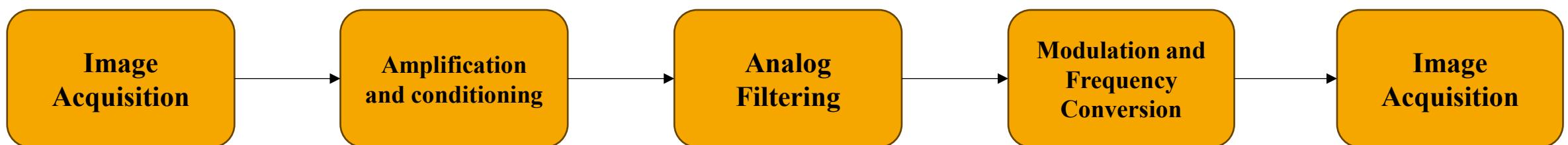
Analog vs Digital Image Processing

Analog Image Processing	Digital Image Processing
The analog image processing is applied on analog signals and it processes only two-dimensional signals.	The digital image processing is applied to digital signals that work on analyzing and manipulating the images.
Analog signal is time-varying signals so the images formed under analog image processing get varied.	It improves the digital quality of the image and intensity distribution is perfect in it.
Analog image processing is a slower and costlier process.	Analog image processing is a slower and costlier process.
Analog signal is a real-world but not good quality of images	Digital image processing is a cheaper and fast image storage and retrieval process.
Digital image processing is a cheaper and fast image storage and retrieval process.	It uses good image compression techniques that reduce the amount of data required and produce good quality of images
It is generally continuous and not broken into tiny components.	It uses an image segmentation technique which is used to detect discontinuity which occurs due to a broken connection path.

Benefits of Analog Signal Processing

- **Real-Time Processing without Latency:** Analog processing allows for immediate image handling without delay, essential for live applications.
- **Continuous Signal Processing:** Analog systems manage continuous ranges of values, ensuring smooth transitions without digital quantization artifacts.
- **Simplicity and Cost:** Analog circuits can be more straightforward and cheaper than digital systems for basic image processing tasks.
- **Power Consumption:** Analog devices typically consume less power, advantageous for battery-operated or remote applications.
- **Aesthetic Qualities:** The unique visual characteristics of analog processing, like film grain and color rendition, are valued for their artistic appeal.
- **No Need for Digitization:** Avoiding digitization preserves the original signal's integrity, crucial in some high-fidelity applications.

Pipeline : Analog Image Signal Processing



Pipeline : Analog Image Signal Processing

- **Image Acquisition:** The image is captured by an analog camera or sensor. This process converts the optical image into an analog electrical signal corresponding to the intensity and color information across the image.
- **Amplification and Conditioning:** The raw analog signal may be very weak and could contain noise. Amplification increases the signal strength, and conditioning might involve filtering out noise or adjusting the signal to a suitable level for further processing.
- **Analog Filtering:** Specific frequencies within the signal are enhanced or attenuated to improve image quality or to extract particular features. For example, low-pass filters might be used to remove high-frequency noise, while high-pass filters could enhance edges within the image.
- **Modulation and Frequency Conversion:** For transmission or further processing, the analog signal might need to be modulated or shifted in frequency. This can involve changing the base frequency of the signal without altering its content.
- **Display or Output:** The processed analog signal can be displayed on an analog display device (like a CRT monitor) or transmitted over analog transmission channels. If the signal has been converted to digital, it may be displayed on digital devices or processed further using digital techniques.

Finding the RGB values of the Image

```
from PIL import Image

# Replace 'Path to Image' with the actual path to your image file.
image_path = r'C:\Users\anifa\Desktop\GITB\Image-Signal-Processing-\b.png'
output_file_path = r'C:\Users\anifa\Desktop\GITB\Image-Signal-Processing-\image_pixels_a.txt' # Path to save the text file

# Open the image and convert it to 'RGB' mode.
with Image.open(image_path) as img:
    img = img.convert('RGB')

    # Retrieve the width and height of the image.
    width, height = img.size

    # Use a list comprehension to populate the list with RGB values of each pixel.
    rgb_values = [img.getpixel((x, y)) for y in range(height) for x in range(width)]

# Now, print all RGB values and save them to a text file.
with open(output_file_path, 'w') as file:
    for rgb in rgb_values:
        # This will print each RGB value to the console
        # print(rgb)
        # This will write each RGB value to the text file, converting the tuple to a string
        file.write(str(rgb) + '\n')

print(f"All pixel RGB values have been saved to {output_file_path}.")
```

GitHub link:

<https://github.com/AniketFasate27/Image-Signal-Processing->

Note: GitHub repository is private.

Finding the RGB values of the Image

- The above code is for finding the RGB values of the image.
- In which we are printing the first pixel value and then we are storing all the pixel values in matrix form in the .text file.

Finding the RGB values of the Image



Output



image_pixels_a.txt

Finding the RGB values of the Image



Output



image_pixels_ab.txt

Finding the RGB values of the Image



Output



image_pixels_b.txt

Why we need RGB values.

- RGB values are essential in analog image processing, as well as in digital image processing, for several reasons related to the way images are captured, processed, and displayed.
- In analog image processing, RGB values can be manipulated to achieve various effects, such as adjusting brightness, contrast, and color balance. For instance, by altering the intensity of the RGB components, you can enhance certain features of an image or correct issues related to lighting and color rendition.

Color Correction

Color correction is a process used in photography, video production, and digital design to adjust and correct the colors of an image or video to make them appear more accurate or aesthetically pleasing. This process involves altering the primary color elements—red, green, and blue (RGB)—as well as their hues, saturation, brightness, and contrast to achieve the desired outcome.

1. Color Balance: Adjusting the colors so that they look natural and balanced, correcting for any color casts or temperature imbalances that may have been caused by the lighting conditions under which the image was taken.

2. Exposure Correction: Ensuring that the image or video's exposure is optimal, with correct highlights, shadows, and mid-tones, making sure that details are visible in all areas.

3. Contrast Adjustment: Modifying the contrast to make the image or video more dynamic and to help the subjects stand out. This often involves deepening shadows and enhancing highlights.

4. Saturation and Vibrancy: Adjusting the intensity of the colors to make them more vivid and alive or more subdued, depending on the desired effect.

5. Skin Tones: Ensuring that skin tones appear natural and consistent throughout the image or video, which is crucial for portrait photography and film.

Color Correction

Original Image



Color-Corrected Image



Color Correction

Original Image



Color-Corrected Image



White Balance

White balance (WB) is the process of removing unrealistic color casts, so that objects which appear white in person are rendered white in your photo. Proper camera white balance has to take into account the "color temperature" of a light source, which refers to the relative warmth or coolness of white light. Our eyes are very good at judging what is white under different light sources, but digital cameras often have great difficulty with auto white balance (AWB) — and can create unsightly blue, orange, or even green color casts. Understanding digital white balance can help you avoid these color casts, thereby improving your photos under a wider range of lighting conditions.

White Balance (*maximum intensity value*)



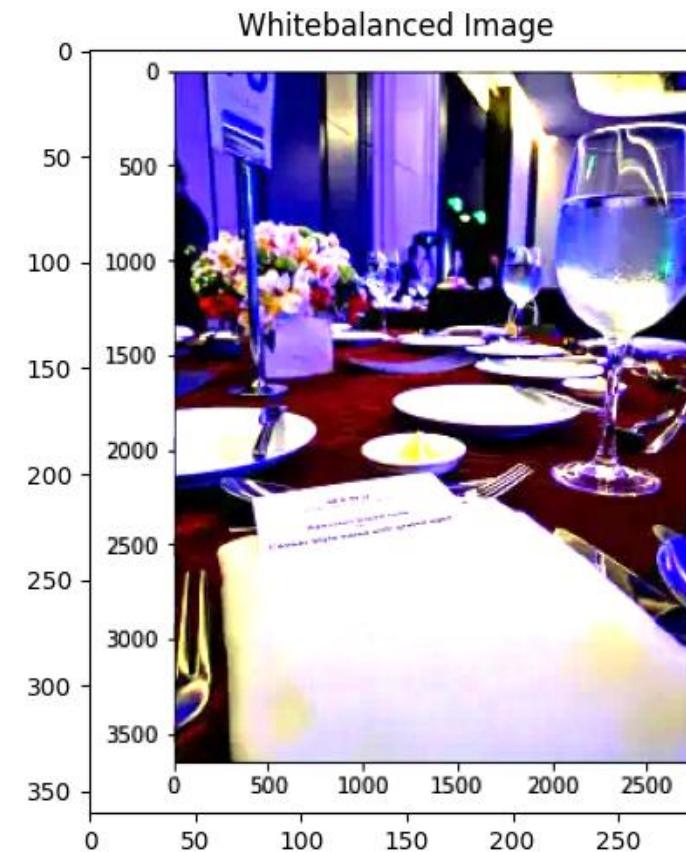
White Balance (*maximum intensity value*)

The "White Patch" algorithm, initially designed to enhance image quality by normalizing each color channel to its maximum intensity value, encounters a significant limitation in scenarios involving bright light sources. Upon analyzing an image using the method `image.max(axis=(0,1))`, we discover that all channels (RGB) exhibit a maximum intensity value of 255. This uniform maximum, often attributed to bright spots such as white lights in the ceiling, indicates that the algorithm cannot effectively perform white balancing in images where bright specks of light dominate. This finding underscores the algorithm's sensitivity to lighting conditions and highlights the need for alternative strategies in such scenarios.

White Balance (*maximum intensity value*)

When utilizing the mean intensity values from each channel to normalize an image's color, it's clear that such a method can indeed adjust the colors towards a more desirable balance. However, an unintended consequence of this approach is the noticeable increase in brightness across the image. The process involves setting the mean intensity value, often represented by a white patch, as a threshold. Consequently, all pixel values meeting or exceeding this mean intensity threshold are adjusted to the maximum intensity value. This adjustment not only corrects the colors but also significantly enhances the brightness, leading to an image that appears overly bright. This outcome underscores the delicate balance required in color correction techniques, where the aim is to achieve color accuracy without compromising on other visual aspects such as brightness and contrast.

White Balance



Gamma Correction

- Gamma correction, or often simply gamma, is a nonlinear operation used to encode and decode luminance or color values in images. It's used in the processing of both still images and video to correct the brightness or to adjust the contrast. The basic idea behind gamma correction is to adjust the brightness of an image's midtones without significantly altering the shadows and highlights. This is crucial because the human eye perceives color and brightness differently than how cameras capture them and monitors display them.

Gamma Correction



What is RAW images?

Raw images are unprocessed digital photographs captured by a camera's sensor. They are called "raw" because they contain all the data captured by the sensor, without any of the modifications (like sharpening, color correction, or compression) that camera software applies when producing a more common JPEG or other compressed image formats

Importance of RAW Images

- 1. Maximum Quality:** Raw files preserve the highest possible quality of an image because they retain all the data from the camera sensor. This level of detail is crucial for high-quality prints and professional-grade work.
- 2. Greater Flexibility in Editing:** Since raw files contain more information about the image, photographers have much more flexibility when it comes to editing. Adjustments to exposure, white balance, and color can be made post-capture without significant loss of quality because you're working with the original data.
- 3. Better Detail:** Raw files can capture more levels of brightness than JPEGs, meaning they can represent more detail in both the shadows and highlights of an image. This is particularly important in high-contrast scenes where you might want to recover details lost in dark or bright areas.
- 4. Non-Destructive Editing:** When you edit a raw file, you're not altering the original data. Instead, you create a set of instructions for processing the image. This means you can always revisit and re-edit the raw file without losing quality, unlike JPEGs, where quality degrades with each edit.
- 5. Advanced Correction Capabilities:** Issues such as over or underexposure, color casts, and digital noise can be more effectively managed and corrected when working with raw files due to the breadth of data available.
- 6. Customization:** Raw files allow for the customization of processing settings according to the photographer's preferences or specific needs of a project, rather than relying on the camera's automatic adjustments.

Sources for RAW Images

- Digital Cameras and DSLRs



[Sony Alpha 7 IV Full-frame Mirrorless Interchangeable Lens Camera with 28-70mm Zoom Lens Kit](#)



[Canon EOS R5 C RF24-105mm F4 L is USM Lens Kit 8K/60P FF Sensor Pro Cinema/Photo Camera, RF Mount, Internal RAW, 8K HDMI RAW Out](#)



[Nikon Z 7II | Ultra-high resolution full-frame mirrorless stills/video camera | Nikon USA Model](#)

Future Planes

- Amplification and conditioning
- Analog Filtering

Amplification and conditioning

- **Amplification:** Amplification refers to the process of increasing the signal strength of an image. This is particularly important in scenarios where the image is captured under less-than-ideal conditions, such as low light. Amplification can help make these images more usable by boosting the signal to a level where details become more visible and distinguishable.
- **Gain Adjustment:** Amplification is often achieved through gain adjustment, where the signal level is multiplied by a factor greater than one. This makes the image appear brighter, but it can also introduce noise.
- **Automatic Gain Control (AGC):** AGC is a technique used to automatically adjust the image signal's amplification based on the input signal's intensity. It's widely used in cameras to ensure that the output image maintains a consistent brightness level, regardless of the lighting conditions of the scene.

Amplification and conditioning

- Conditioning involves various processes aimed at improving the image signal's quality, making it more suitable for further processing or display. Conditioning can include a range of operations, from simple filtering to more complex adjustments.
- Noise Reduction:** After amplification, images often contain increased noise. Noise reduction techniques are applied to clean up the image, removing graininess while preserving as much detail as possible.
- Normalization:** This process involves adjusting the image signal to fit within a specific range. For instance, normalization can ensure that the darkest and brightest parts of an image fall within the display or processing system's dynamic range.
- Color Correction:** In image conditioning, color correction is crucial for ensuring that the colors in an image match their original appearance or meet specific aesthetic requirements. This involves adjusting the balance of colors, correcting for color casts, and ensuring that whites appear white under different lighting conditions.
- Sharpening:** Sharpening is a conditioning process that enhances the edges within an image, making the image appear more detailed. This is particularly useful for images that may appear soft after other processing steps.

Analog Filtering

- Analog filtering in image signal processing plays a pivotal role, particularly in the initial stages of capturing and processing images. Before digital processing takes over, analog filters are employed to condition the image signal directly from the sensor, ensuring optimal quality and reducing the load on digital processing stages.
- **Noise Reduction:** Analog filters are used to remove unwanted frequencies that may represent noise. This is crucial in photography, video capture, and scientific imaging to ensure that the signal is as clean as possible before it is digitized.
- **Anti-aliasing:** Before an analog signal is converted to a digital format, it's essential to ensure that it meets the Nyquist criterion to avoid aliasing. An anti-aliasing filter is used to remove high-frequency content that cannot be properly sampled, thus preventing the creation of artifacts in the digital image.
- **Bandpass Filtering:** In some applications, only a specific range of frequencies is of interest. Bandpass filters allow these frequencies to pass while blocking others, which can be crucial in applications like medical imaging or remote sensing.

Sources for RAW Images

- Sandford University Libraries :

<https://searchworks.stanford.edu/view/hq050zr7488>

Citation

1. [Analog image processing – Wikipedia](#)
2. Carnegie Mellon the Robotic Institute CV 16385 <https://www.cs.cmu.edu/~16385/>
3. University of Rochester <https://cs.rochester.edu/courses/572/fall2022/index.html>
4. Theory and Applications of Smart Cameras by Chong-Min Kyung <https://link.springer.com/book/10.1007/978-94-017-9987-4>
5. Image Formation & Display The Scientist and Engineer's Guide to Digital Signal Processing By Steven W. Smith, Ph.D. https://www.analog.com/media/en/technical-documentation/dsp-book/dsp_book_Ch23.pdf
6. Research paper : A Tone Mapping Algorithm Suited for Analog-Signal Real-Time Image Processing https://northeastern-my.sharepoint.com/personal/fasate_a_northeastern_edu/Documents/Image%20Signal%20processing/A_Tone_Mapping_algorithm_suited_for_analog-signal_real-time_image_processing.pdf?CT=1710893175821&OR=ItemsView
7. United States patent : ANALOG IMAGESIGNAL PROCESSING CIRCUIT FOR CMOS IMAGE SENSOR https://northeastern-my.sharepoint.com/personal/fasate_a_northeastern_edu/Documents/Image%20Signal%20processing/US8125548.pdf?CT=1710893312946&OR=ItemsView

Citation

- GitHub Repository: <https://github.com/mikeroyal/ISP-Guide>
- Color Filter array: https://en.wikipedia.org/wiki/Color_filter_array
- Demousing
<https://github.com/770120041/ComputerVisionPractice>
- https://github.com/colour-science/colour-demoslicing/blob/master/colour_demoslicing/examples/bayer.ipynb

Citation

8. Raw Images : [100% Free Raw Photos - Download Raw Files For Editing Now \(signature edits.com\)](https://signature edits.com)
 9. Raw Images [PASCALRAW: Raw Image Database for Object Detection in SearchWorks catalog \(stanford.edu\)](https://searchworks.stanford.edu/catalog/PASCALRAW)
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- GitHub : <https://github.com/AniketFasate27/Image-Signal-Processing->
 - OneDrive: https://northeastern-my.sharepoint.com/:b/g/personal/fasate_a_northeastern_edu/EVRWaMJjqOtJpXPzgCesGPABW_N8BWxbJxpZx-XyQwEd1Q?e=4dW9ur

Citation

- [PyWavelets - Wavelet Transforms in Python – PyWavelets Documentation](#)
- [Inside the Digital Darkroom: Navigating the Image Signal Processing Pipeline \(visionary.ai\)](#)

Error Faces

- <https://github.com/scipy/scipy/issues/11329>