Tonal quality and dynamic range in digital cameras

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Abstract:
The diversity of display technologies and introduction of high dynamic range imagery introduces the necessity of studying images of radically different dynamic ranges. Current quality assessment exposure metric systems in digital cameras are not suitable for this task, as they do not respond to all brightness variations in the original scene limited by its dynamic range.
The research investigates high dynamic range (HDR) technique and how to approach high tonal quality images compared to the original scene range of brightness, it presents advantages of using Raw file format in storing digital images and using curves to adjust tones by using descriptive method, then An Experiment was carried out using HDR technique as an attempt to achieve higher tonal quality in the final image.
The paper concluded that HDR photography is one of the best working techniques to work with when capturing images with digital camera in scenes containing variable brightness levels than the digital camera sensor ability to record AS outdoors and landscape scenes using specific steps shown in the paper and using raw file format to approach best results.
Also, the researcher believes that a further work should be carried out on more enhancements in digital camera tonal range response using sophisticated camera sensors.

Keywords:
Image quality metrics, HDR (high dynamic range images), LDR (low Dynamic range images), Visual perception, and Tone reproduction.

Introduction

Images captured with digital cameras can have extraordinary tonal quality, comparable to the finest full-toned traditional images. But to reach their full potential they must be processed properly, which involves changing default camera settings and moving away from standard file formats. This study covers the key steps for Converting and editing images using file formats with a bit depth of 16 (48-bit color or 16-bit B&W), and Using curves to adjust tones.

In storing images as RAW format advantage can be taken of camera's hidden dynamic range; and can access tones that may be obscured or lost when images are stored in a standard file format such as a JPEG which is the default for most digital cameras.

JPEG is a loss compressed format that sacrifices a small amount of information to achieve a large savings in storage. but information loss is not the problem here; it is the loss of tonal levels that takes place when the image sensor's digital output is converted to any standard 24-bit color file format; JPEG is merely the most common. Image sensors in high quality digital cameras have a bit depth of at least 12; they have 2^{12} = 4096 discrete tonal levels. Standard 24-bit color files have a bit depth of only 8; they have only 2^8 = 256 discrete tonal levels. Tonal levels are lost in the conversion. The techniques presented here minimize this loss-- and maximizing tonal

detail throughout the RAW conversion and image editing process.[Adair2010]
Therefore, the problem of this study is the human eye observes light in various shades and the camera should too but the digital camera sensor is not able to capture acceptable details and good tonal range in all capturing situations, and obtaining optimum tonal quality from digital camera requires taking advantage of its hidden dynamic range.
The analytical descriptive method was used to demonstrate how to improve the tonal quality of the digital image using dynamic range. Also an experiment was carried out using HDR technique as an attempt to achieve higher tonal quality in the final image.
The main objectives have been to achieve a better appearance of the original scene in brightness levels and color rendition by using HDR technique, to investigate digital camera response and dynamic range and to study a RAW conversion program to allow a high degree of control over image tones and colors & A Curves control is particularly desirable.

RAW conversion

Digital sensors (both CCD and CMOS) are linear. That means the voltage generated in each pixel, and hence the pixel level emerging from the A-to-D converter. [Adair2010] (the device that converts the sensor output to discrete bits), is proportional to exposure-- to the light energy reaching the pixel. But neither human vision nor CRT monitors are linear. Hence the color spaces (rules that map pixel levels to visible colors) used for standard image files are intentionally nonlinear. The luminance represented by a pixel is not proportional to the pixel level. Luminance in a print or monitor is related to pixel level by the following simplified equation,
Output luminance = (pixel level) ^{gamma}
To obtain the pixels, the raw output of the image sensor, which is proportional to exposure, must be converted to a file with a standard color space using the inverse of the above operation.
Pixel level = (RAW pixel level)$^{1/gamma}$ ~= exposure$^{1/gamma}$
Gamma.[Simon 2004] is the exponent of the equation that relates luminance to pixel level. Every color space has a characteristic gamma. Gamma = 2.2 for sRGB, which is the default color space for Windows, the World Wide Web, and most digital cameras. sRGB has a color gamut that approximates typical CRT monitors. Another popular color space is Adobe RGB (1998), which has a slightly larger color gamut. It also has gamma = 2.2. (Older Macintosh computers have a default gamma of 1.8, but newer models seem to have switched to 2.2.) In the illustration below, the first process-- converting light energy (RAW data) to file pixels-- is shown on the left. The second process-- converting file pixels to print or display-- is shown on the right. The two processes are complimentary; when you combine them you get a straight line.[Simon 2004]

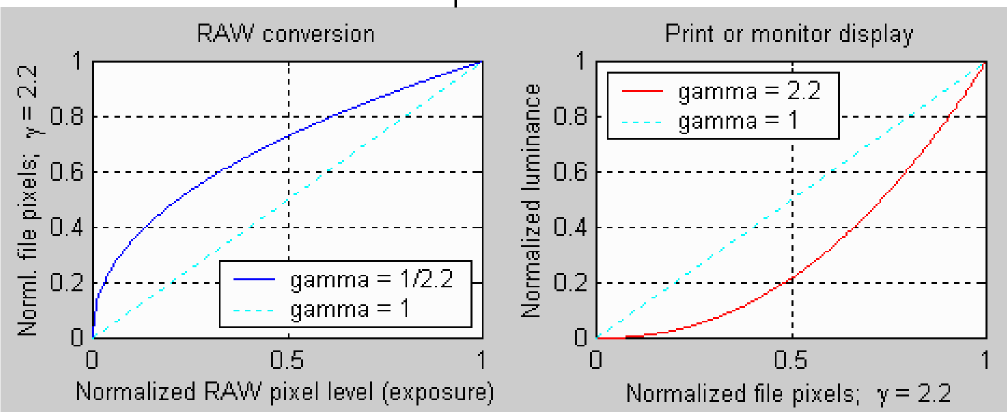


Figure (1)
File pixel level normalized to 1 as a function of output luminance
Exposure (raw pixel levels) function of normalized

Gamma correction is one of several functions of RAW conversion- the process of converting the output of an image sensor to a standard file format, such as JPEG or TIFF. Depending on digital camera's Storage or Quality setting, RAW conversion takes place inside the camera, immediately after the exposure, or afterwards on a computer. (Figure 1)

It should be evident from these graphs that RAW conversion compresses pixel levels representing high luminance and expands pixel levels representing low luminance. This means that the converted file, with gamma = 2.2, has relatively fewer pixel levels in the highlights and more in the shadows. This turns out to be an advantage when human vision is considered.

RAW conversion performs several additional functions.

Bayer array interpolation (de-mosaicing) is the most important function. Virtually all image sensors (except for sensors used in the Sigma digital camera SD9/SD10) use the Bayer array pattern, where alternate rows of pixels represent RGRGRG... and GBGBGB..., but each pixel in standard image files (JPEG, TIFF, etc.) represents all three colors. RAW data is converted using a sophisticated process called interpolation, where data from the green sensors (twice as plentiful as red and blue) is used to enhance the resolution of the red and blue channels. The best Bayer interpolation routines-- the routines that result in the highest resolution and the fewest artifacts-- use iterative calculations, which are too slow to run on digital cameras, but present no problem for modern computers.[Busch 2005]

Sharpening. Unsharpened digital camera images tend to look soft; photographers benefit strongly from sharpening. But images, especially in some inexpensive compact digital cameras, are often over sharpened, resulting in blurry details near edges. (Digital SLRs tend to be more conservative.) Over sharpened images look good in small enlargements straight out of the camera, but over sharpening creates artifacts that can be hard to get rid of. It's always best to sharpen late in the image editing process.

Digital cameras adjust white balance with different light sources that have a wide range of color temperature. This must be addressed when the RAW conversion is performed. Otherwise the image may look too blue or yellow. Most cameras have several custom White Balance settings in addition to an automatic setting that estimates the White Balance based on the spectral content of an image. Automatic White Balance algorithms work well most of the time, but they can fail for unusual subjects, for example, where a strong color dominates the scene. When an image is saved in RAW format and converted later, the right white balance can be calibrated.

Dynamic range

Dynamic Range of digital camera Sensor

The dynamic range of a sensor is defined. [Busch 2005] By the largest possible signal divided by the smallest possible signal it can generate. The largest possible signal is directly proportional to the full well capacity of the pixel. The lowest signal is the noise level when the sensor is not exposed to any light, also called the "noise floor. (Figure 2)

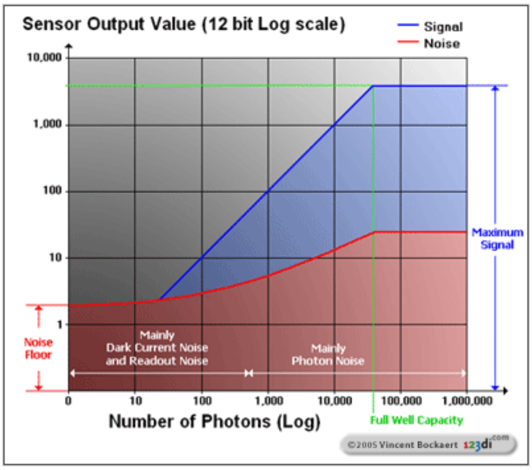


Figure 2

Practically cameras with a large dynamic range are able to capture shadow details and highlight details at the same time.

Dynamic range of an image

When shooting in JPEG, the rather contrasty tonal curves applied by the camera may clip shadow and highlight detail which was presented in the RAW data. RAW images preserve the dynamic range of the sensor and allow to compress the dynamic range and tonal range by applying a proper tonal curve so that the whole dynamic range is represented on a monitor or print in a way that is pleasing to the eye. [Sinclair 2007]

Pixel Size and Dynamic Range

The digital camera sensor has millions of pixels collecting photons during the exposure of the sensor. This process can be compared to millions of tiny buckets collecting rain water. The brighter the captured area, the more photons are collected. After the exposure, the level of each bucket is assigned a discrete value Empty and full buckets are assigned values of "0" and "255" respectively, and represent pure black and pure white, as perceived by the sensor. The conceptual sensor below has only 16 pixels. Those pixels which capture the bright parts of the scene get filled up very quickly. (Figure 3)

First diagram (3-A) the dynamic range of the camera was able to capture the dynamic range of the scene the histogram indicates that both shadow and highlight details are captured. [Bandoh 2010]

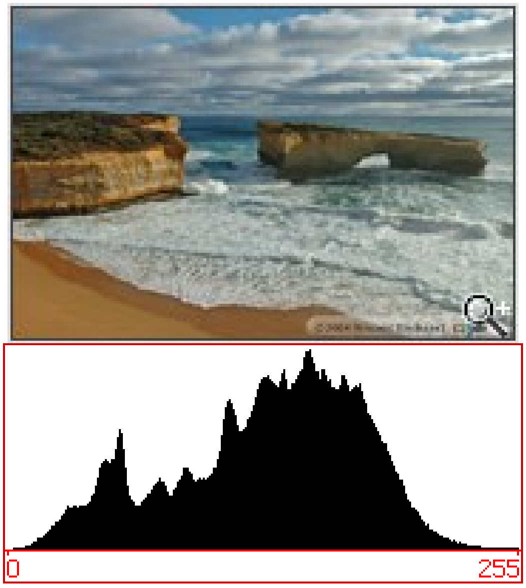


Figure (3-A)

In figure (3-B) the dynamic range of the camera was smaller than the dynamic range of the scene. The histogram indicates that some shadow and highlight detail is lost

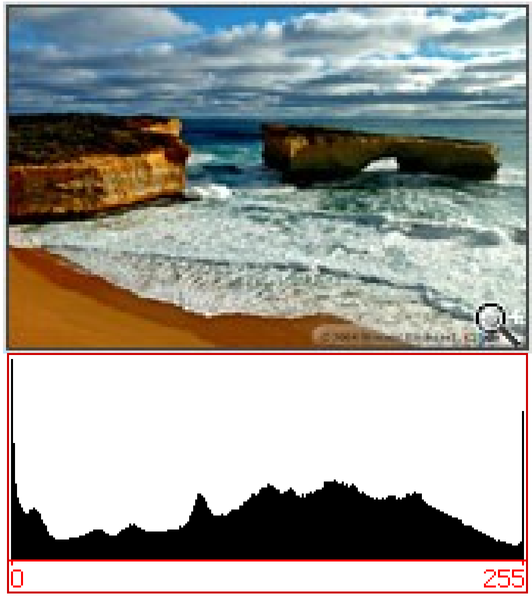


Figure (3-B)

The limited dynamic range figure (3-D) of this camera was used to capture highlight detail at the expense of shadow detail. The short exposure needed to prevent the highlight buckets from overflowing gave some of the shadow buckets insufficient time to capture any photons.

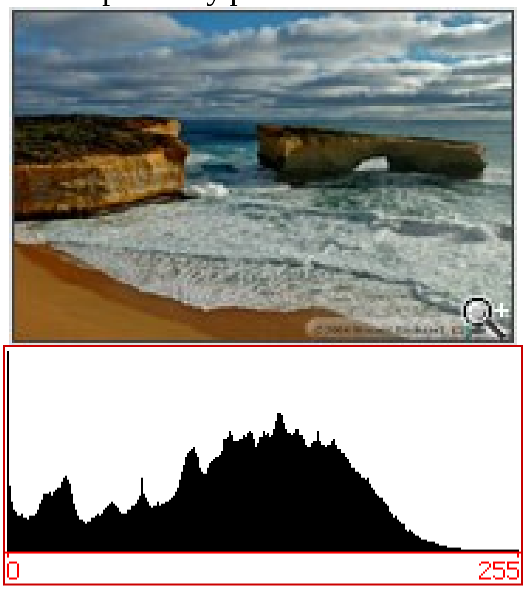


Figure (3-D)

The limited dynamic range of this camera Figure (3-E) was used to capture shadow detail at the expense of highlight detail. The long exposure needed by the shadow buckets to collect sufficient photons resulted in overflowing of some of the highlight buckets.

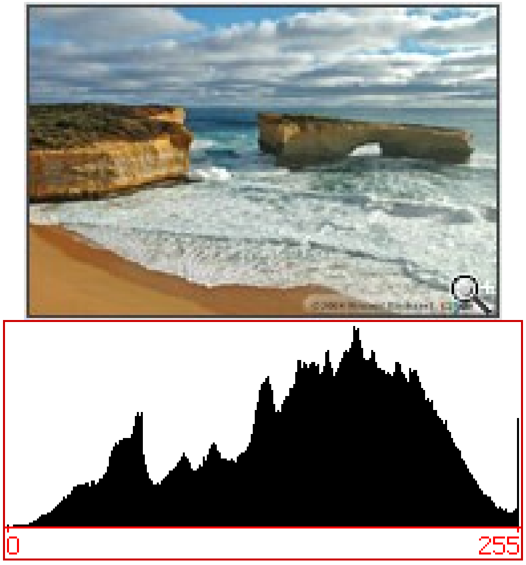


Figure (3-E)

In figure (3-F) the dynamic range of the scene is smaller than the dynamic range of the camera, typical when shooting images from an airplane. The histogram can be stretched to cover the whole tonal range with a more contrast image as a result, but posterization can occur.

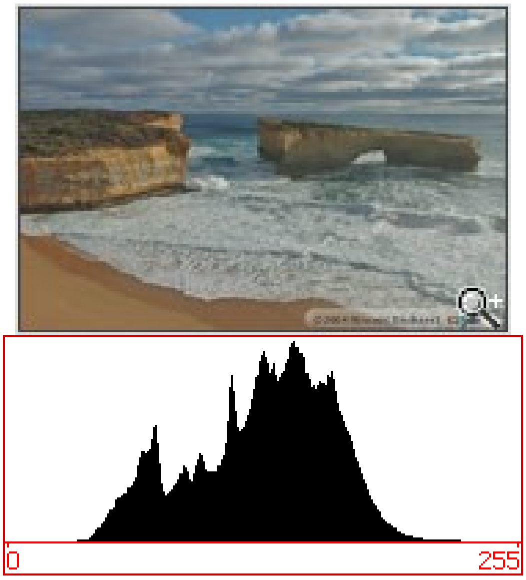


Figure 3-F

Assuming that the darkest useable zone has 8 levels (considered, the eye can distinguish fewer levels in shadows), the charts figure 3 expresses that a 12 bit A-to-D converter has a potential dynamic (exposure) range of 9 zones and a 14-bit A-to-D has a potential range of 11 zones. Both these numbers are far in excess of the range ordinarily achieved with digital cameras.

Some insight could be gained by looking at a simple imaging system-- a camera/printer combination that reproduces images with no editing or manipulation. The two gamma equations mentioned on RAW conversion.[Adair2010] are applied exactly. The contrast of the print would be identical to the scene contrast-- a nice idea in theory, but one that rarely produces "fine" prints because a print can only reproduce a tonal range of about 100:1-- 6.6 f-stops. In this case the system dynamic range would also be 6.6 f-stops-- well under the camera's potential dynamic range.

Considering that the amount of noise depends on the exposure and ISO speed, and it has a spectral distribution-- it's not a simple number (noise ratio). But it has a few important properties affecting it like ISO speed & exposure time so to take maximum advantage of digital camera's hidden dynamic range it should be set to its lowest ISO speed. High ISO speeds increase noise and make it difficult to expand dynamic range through the use of curves.

Exposure

The optimum approach for setting exposure depends on the format used for storing the image; it's slightly different for RAW than for standard image formats such as JPEG or TIFF. The storage format is selected- by intent or by default- before making the exposure. [Derrick 2004]

If a standard file format is used for saving images, the exposure should be set for tones that look good-- as close as possible to the tones wanted in the final print. This works best if the scene dynamic range is close to the dynamic range available in a print- about 5 to 7 f-stops.

If saving images in RAW format is chosen, exposure is set to capture maximum information to maintain as much highlight and shadow detail as possible, even if the middle tones aren't what will be shown in the final print. It should be aimed to capture all highlights except for bright light sources and specular reflections. Enough exposure

should be carried out to capture detail in large shadow areas. The right exposure, which recommends setting the exposure to the maximum value that doesn't burn out highlights. (This applies only to images saved in RAW format.) However a little margin will be better way there are plenty of levels in 12-bit A-to-D converters. In extreme situations, two or more exposures can be done and combined later in software. [Sinclair 2007]
Shadow and highlight details are extremely important in fine full-toned prints. To the eyes, a print with dead shadows or burnt out highlights looks amateurish. One of the things that distinguished the glorious prints of Paul Strand, Edward Weston, and Ansell Adams is the tonal detail in shadows and highlights, as well as middle tones considered that prints of these great artists, are references
In either case, a histogram should be used the chart that shows the distribution of tonal levels (figure 4). A histogram should be displayed in the camera's LCD monitor immediately after each exposure. The camera's default settings may need to be changed: In the Nikon D90 menu The Review can be set to On (Info) and Review time to 8 sec. test exposures is preferable to be done for each shot and check the histogram to be sure that the picture is exposed correctly. If not, exposure compensation can be set or BKT mode. Then test exposures should be deleted.
Although the importance of saving files in RAW format is clear, there are instances where high quality images can be achieved using JPEGs. Claude Jodoin of Michigan (famous photographer) uses JPEGs for weddings and other high volume events. RAW conversion is too slow for the workflow. This photographers use high quality lighting, an ExpoDisc to set the White Point, and know how to expose properly, so images look good straight out of the camera. The bottom line is satisfied clients. This doesn't work well for landscape photography, where lighting is uncontrolled and scene contrast varies all over the place.

Measuring digital camera tonal response and dynamic range
With the new Imatest program, digital camera tonal response and dynamic range are measured easily and accurately using a transmission step wedge-- a piece of film with zones of increasing density. The details of the measurement are in the Imatest [Derrick 2004] Q-13 tour.
Figure 4 shows the results for measuring tonal response and dynamic range at ISO 400 in digital camera canon EOS 10D , converted from RAW format with Capture One EX. The upper left plot is the density response curve. The lower left plot is noise measured in f-stops-- a relative measure that corresponds to the eye's response. Each step represents 1/2 f-stop (a density step of 0.15).

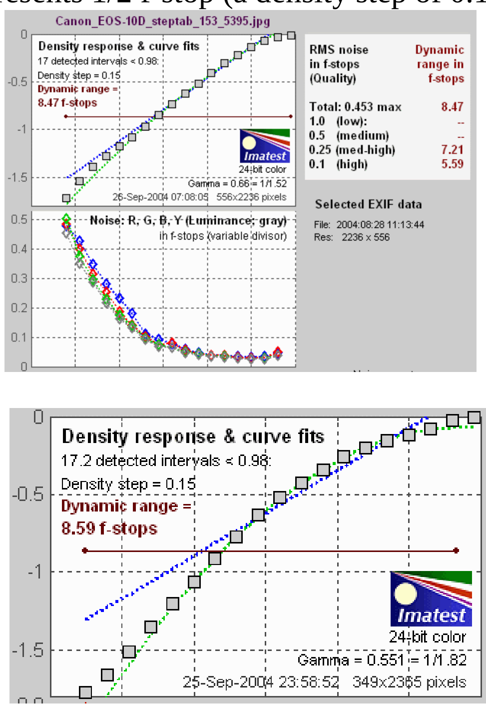


Figure 4
Measuring digital camera tonal response and dynamic range

The total dynamic range of the EOS-10D is 8.5 f-stops. Dynamic range improves slightly (but less than expected) for 48-bit TIFF conversion and ISO 100. Noise is significantly lower for 48-bit TIFF conversion. The shape of the response curve is a strong function of the conversion software settings. The curve on the right for Canon Zoom Browser with Contrast set to Low is very different from Capture One LE (though both are half an "S" curve), but the dynamic range hardly changes.[Busch 2005]

Experimental work

This study utilizes an experiment to achieve significant tonal quality for a series of images taken for the same scene using digital camera. A detailed experiment design is summarized in table [Adair2010], the procedure is shown in table [Bandoh 2010]

Table [Adair2010] Experimental settings

Item	Details
Devices used	Nikon D90 camera .Tripod. HP computer
Programs used	Photoshop CS5
Camera settings	AV camera mode was set to fix D.O.F ,F stop 8,BKT mode was set to shoot 3 different exposures, 0,+2,_2 recording in raw format.

Procedure:

Table Experimental procedure [Bandoh 2010]

Fixing the camera on a tripod ,shooting the same scene (pyramids) in three different exposures,

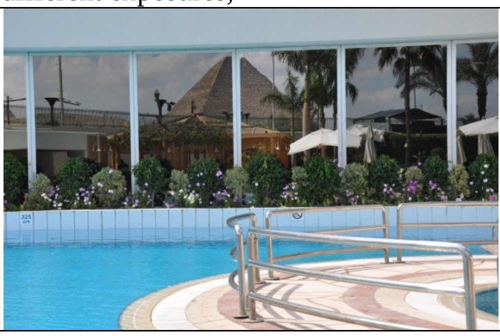


Figure (5A) 0 level normal exposed image.
Exposure was set at f.8 s.1/125

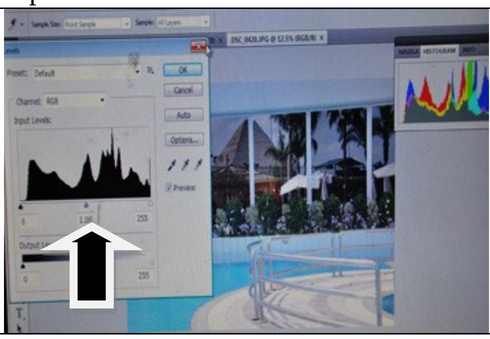
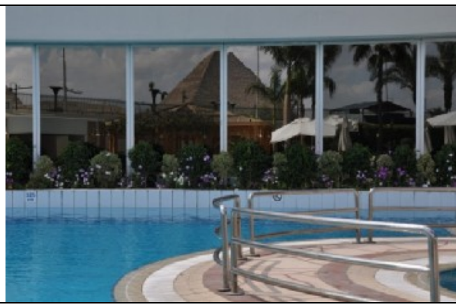
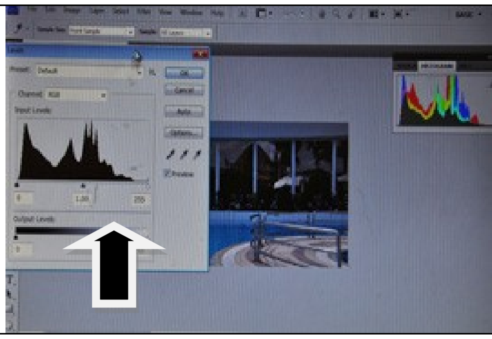


Figure (5A) 0 level curves
As we can observe details loss in the left side representing dark areas of the scene, and the curve is concentrated on specific areas of brightness meaning details loss in some areas of the scene.

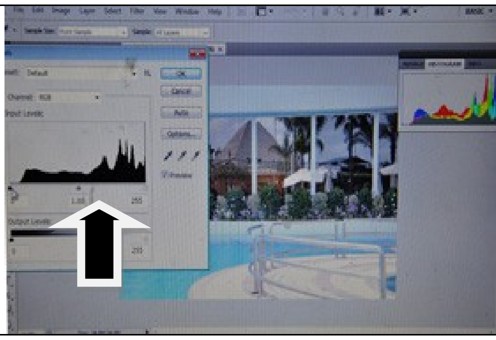


-2 exposure (5-B)
Exposure was set at f.8 s.1/640



-2 exposure(5-B) level curve as we can observe details loss in the right side representing bright areas in the scene, and overlapping brightness levels in both sides.

+2 exposure (5-C)
Exposure was set at f.8 s.1/50



+2 exposure (5-C)
Level curves as we can note that the representing brightness curve is concentrated on the side of bright values and the curve does not end on the darkest point.

Figure 6 the final result
An HDR image with high tonal quality. Resulting from merging 3 different exposure photos

Results

- HDR technique used in this work faithfully reproduces most of the visible and invisible contrast in the scene working with Nikon digital D90 camera considering that other models and camera types were not tested in this research.
- A highly lost details was observed in both high light areas represented in the sky in the original scene and in the front reflecting area& dark areas represented in the green area, and in mid-tone areas represented in the pyramids that can be treated with HDR technique with more color enhancement and details in all image brightness levels represented in the final treated HDR image figure 6 and working in RAW format is recommended in this type of shooting (HDR)
- A high dynamic range (HDR) images has been proven to provide superior picture quality by allowing a larger range of brightness levels to be captured and reproduced than traditional low dynamic range (LDR) images.

Discussion

The Researcher believes that HDR photography is one of the best working techniques to work with when capturing images with digital camera in scenes containing variable brightness levels than the digital camera sensor ability to record ,But it must be clear that working with HDR technique is based on;

- Extensive knowledge of digital camera metering system and its dynamic range in capturing images
- Respectable background of working with image enhancement programs such as Photoshop
- An experience in working with raw image format and its benefits

And the conclusion is that Digital cameras can produce images with outstanding tonal quality if we use the proper techniques for capture, storage, and editing, a Curves control is particularly desirable.
It would be suggested that a further work should be carried out on more enhancements in digital camera tonal range response using sophisticated camera sensors.

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