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Assessing the Impact of Color Adjustments on Photogrammetry-Based 3D Surface Reconstruction

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***Abstract*—** Photogrammetry has evolved as an important technique for generating point clouds from 2D images especially in the absence of direct 3D sensors for acquiring 3D points. It is seen in several image processing applications that the quality of the result depends on several parameters including luminosity, color saturation, and hue. While the technical workflow of the photogrammetry is well defined but the coloring aspects of the image and its effect on the quality of the point cloud generation has been less explored. This paper studies the impact of color adjustments including contrast, brightness, and gamma variation on 3D point cloud reconstruction capability. The result shows that higher contrast above 40% gradually reduces the reconstruction quality in terms of points on the surface, defining vertex set and faces. Similar observations are also true for brightness values. On negative side beyond -15% tonal adjustments, the results degraded faster. Other interesting results and its potential applications have also been cited in this paper. RMSE observations on resulting dense point cloud, faces and control vertices exhibit substantial loss of quality of reconstructed surface for higher values of brightness and contrast. Several future pointers for improving the reconstruction quality have also been proposed.

***Keywords*—**3D Reconstruction, Photogrammetry, Color Adjustments, Point Cloud

I. INTRODUCTION

Object reconstruction and visualization have wide range of applications today. These applications include 3D printing, virtual reality and immersive interactions, remote tourism, spatial investigations in 3D space and many more. Object reconstruction is important when no or limited real 3D geometrical definition is available. As reconstruction and visualization has gained much attention in recent years, there have been several research aspects under investigation. Some popular approach to 3D visualization includes using raster elevation data like shuttle radar topography mission (SRTM) DEMs and point clouds.

DEM [1] has generally represented a topographic bare-earth surface model and stores raster-based digital elevations of the area/surface of the investigation. DEM-based reconstruction and visualization is mostly used for terrain and large surface modeling. LiDAR [2] generates depth based point data by measuring the distance to a target surface by illuminating them with a pulsed laser and measuring the corresponding returns. LiDAR-based visualization has been very useful with objects of varying sizes including a small monument to a large section of a city street. A high-resolution LiDAR is very effective in surface reconstruction and has better capability for point cloud generation. However, the setup comes at a higher cost.

Much of the efforts have been concentrating on using 3D structural information contained in 3D data formats (such as LiDAR and DEM) for reconstruction purpose. Recently the reconstruction of objects and structures from 2D intensity maps such as in photogrammetry has gained importance. Digital Photogrammetry [3] is a low cost yet effective alternative to LiDAR for the 3D reconstruction and visualization. This motivates investigating the 3D reconstruction capability of photogrammetry on various parameters. In all cases of photogrammetry-based reconstructions, the digital image and information contained in them play the central role. Since photogrammetry relies on digital is among few important key points for consideration in any 3D reconstruction project. With reference to it, the image parameters such as brightness, contrast, hue, saturation, gamma corrections and distance of acquisition not only have an impact on human visual understanding but also digital representations of the scene.

In any photogrammetry-based reconstruction process, the digital image and its quality is a key factor. It must reproduce the structure of objects on earth with the highest accuracy as possible. The natural influences on the acquisition of digital images effects measurements based on them. Additionally, processing these digital images can affect the information contained in them. Since all measurements are done on digitized grey levels or color tones, any variation to it would imply changing measurement based on them. This means it also effects generation of surface point cloud through photogrammetry. Thus, we envisage on color adjustments, consider it more important, and study its impact on 3D reconstruction through photogrammetry in this paper.

II. Related Work

Although the process of photogrammetry is well defined, the aspects and properties of digital images and their impact on 3D reconstruction capability using photogrammetry is less explored. Digital image processing in photogrammtery [4, 5] is a potential area that can influence the reconstruction results. Any small updates to any of the image components can have big visible effect on the reconstruction in photogrammetry. Some researchers have established this in the past.

The effect of image compression has been explored in [6, 7]. It was found that while lower compression ratio of the order of 10 or less has acceptable quality with minimal degradation on the photogrammetric reconstruction, their fast degradation for higher compression ratios. Chromatic aberration of the lens also has an effect on photogrammetric results as shown in [8]. Studies also suggest that improvement in image resolution [9] has a positive impact on photogrammetry by generating high precision measurements and thus 3D models. There has been a little focus study of on tonal adjustments of images used for point cloud generation during object reconstruction through photogrammetry. The studies including transformation from color-to-grey scale [10] and its effect on photogrammetric pipeline suggest that such adjustments do affect the performance of reconstruction. Image histogram equalization and de-colorization showed positive results. Impact of lighting and geometrical measurements from images has been highlighted in [11].

The overview of these studies suggest the need of further investigation to find out the response of tonal adjustments involving brightness and contrast on the accuracy of measurements and thus the surface reconstruction thereupon.

III. The Fundamental Approach

The fundamental approach behind our work is to tweak color tone adjustments over image sets in 2D planar coordinates itself as a preprocessing stage before performing photogrammetry based reconstructions. Some fundamental concepts relating to 2D planar preprocessing used in this work is outlined next.

A. *Color Tone Adjustments*

The color adjustment like brightness, contrast, and hue makes a digital image more or less suitable for the specific application. These adjustments can help to extract features objects contained in the image and thus forms the basis of this research. It is observed that the color adjustments generally have effect on whole image and hence while working with photogrammetry, special care must be taken. Brightness and contrast are some of such important adjustments important in any reconstruction process.

Brightness deals with the aspect of overall lightness or darkness of the given digital image. It can also be seen as an attribute of visual perception in which a specific amount of light radiation or reflection from the object is perceived. It can enable tracking of the object based on the exposure levels. For proper visualization and tracking of objects, setting proper brightness level for the digital image is of prime importance. Note that bright is actually a relative term. The amount of energy emitted by a light source relative to the source of comparison is important. An image that seems to be brighter than one image may be less bright than another. In some cases, this perception may even be difficult to be experienced with naked eye. However, digital processing representations would have significant impact over object reconstruction process.

Contrast refers to the visual property that makes the object distinguishable. In other words, contrast can also be seen as luminance difference that separates objects in the image or video from other objects. An increase in contrast makes light area much light and dark areas much darker. Properly adjusted contrast helps to have discernible objects against the background (or other objects) in the image. During 3D reconstruction process this property can greatly affect identification and tracking of the surface points and hence the reconstruction. Correct contrast levels must be set to discriminate points on one object from another.

B. *Brightness and Contrast Relationship*

A simple relationship between contrast and brightness adjustments can be described by the transformation of the form

$$g(x) = \alpha f(x) + \beta \quad (1)$$

Here x denotes the value of the color component (R, G or B) in the image, α controls the contrast and β is the brightness control. The terms $f(x)$ and $g(x)$represents the source and output image pixels. More conveniently f(x) and g(x) can be written as $f(i,j)$ and $g(i,j)$ corresponding to the pixel located in the $i-th$ row and $j-th$ columns. The terms $\alpha > 0$ and β are also known as gain and bias respectively. It is seen that $0 < \alpha < 1$ generates low contrast and $\alpha > 1$ generates high contrast. These adjustments can be also be understood using arbitrary "curves" $f : [0; 255] \rightarrow [0; 255]$. This exhibits the general relationship between the contrast and brightness adjustments can be understood from Figure 1. Horizontal axis defines the range of contrast adjustments and vertical axis corresponds to brightness values.

Color adjustment behavior have response similar to color perception on paper and can be expressed as "S- curve" as in Figure 1a and "inverted S-curve" as seen in Figure 1c. The S-curve behavior adds contrast at the expense of shadows and tone highlights in the image. The inverted S-curve does its opposite. This curve can allow modelers to better utilize limited dynamic range and thus reconstruction jobs. In high contrast, the textural details are washed away but reflection and extremes are highlighted. This fact may have effect on the reconstruction capabilities in photogrammetry and needs further evaluation. The gain (or loss) of tonal distribution depends on the type of contrast used.

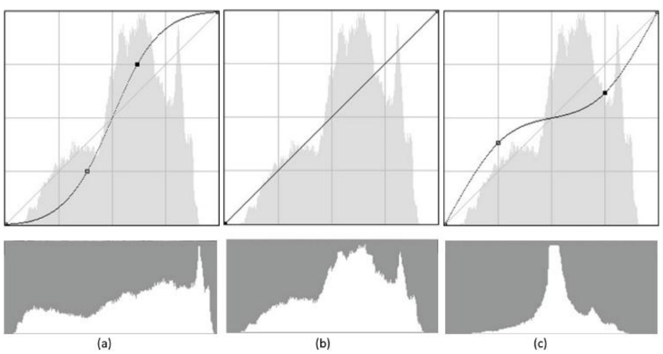


Figure 1. Color Tone Adjustments: (a) High contrast; (b) Standard Input; (c) Low Contrast

Widely used contrast adjustment methods include Weber contrast, Michelson contrast, and RMS contrasts [12]. In most general sense luminance based contrast represent a ratio of luminance difference to luminance average. Hence the effect of small differences under high and low average luminance on point cloud generation and thereby the 3D reconstruction is important.

C. Histogram Based Adjustments

Yet another way to perceive color contribution in 3D reconstruction is by equalizing the tones using histogram equalization. Histogram equalization gives a standard contrast by effectively allowing the spreading of the most frequent intensity values and therefore making the regions with lower local contrast to gain a higher contrast in the image. It will distributes the image gray levels (colors) to reach the maximum allowed gray level (usually white color). The general formula for histogram equalization is given in Equation 2.

$$h(x) = round\left(\frac{cdf(x) - cdf_{min}}{(M \times N) - 1} \times (L - 2)\right) + 1 \qquad (2)$$

Here x is the input image pixel grey level, cdf_{min} gives minimum cumulative distribution function, $M \times N$ defines the image size and L is attributed to maximum allowed grey level. Note that the cdf equals 1, when $0 = r = L - 1$. The effect of contrast adjustments using histogram equalization is shown in Figure 2.

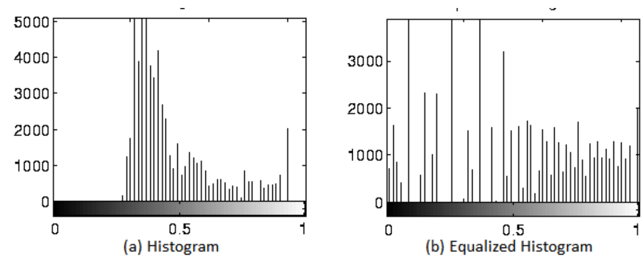


Figure 2. Contrast Adjustment using Histogram Equalization

D. Integrating Image Adjustments with 3D Reconstruction

Theoretically, a properly processed set of images would improve the object reconstruction results. Hence empirically processed images on color tones should precede the 3D reconstruction process.

IV. DATA DESCRIPTION

The data set used for experimental work included originally a set of images obtained from digital Canon EOS 5D camera spanning the portion of the textured building. During preprocessing steps, the data set was populated with 80 sets of tone adjusted set of images. The technical setup of the camera used during image acquisition is given in Table 1. Average disk size of the images was around 5.25 MB each. The physical structure of the building comprises of the concrete smooth textured surface of white and brown colors with interleaved glass windows. The samples of the image in the dataset spans ground view of the front and side views spanning around 170^o horizontally. Note that, these images were terrestrially acquired in sunny day around noon by physically moving around.

Table 1. Image and Camera Properties

	Technical Specifications	
	Property	***Value***
Image	Dimension	4368 x 2912
	Resolution	72 x 72 dpi
	Bit-depth	24
	Color	8RGB
Camera	F-stop	f/10
	Exposure	1/320 sec
	ISO speed	ISO-200
	Focal Length	24mm

A. Image Properties

Images that are used in the photogrammetry process were stored in JPEG 24-bit RGB format. These images are used during preprocessing stage (module 1) of the proposed model to generate custom color adjusted set of images. Both the horizontal and vertical resolutions are set to 72 dpi which is suitable for outdoor imaging especially of polyhedral and manmade objects.

B. Camera Settings

The digital Cannon EOS camera had aperture F-stop value of $f/10$ to control the amount of light into it. The sensitiveness of the camera to incoming light defined by ISO speed was ISO-200 ($1/2$ of a second). Note that, higher value of ISO speed means more sensor sensitiveness to the light and hence more noise. Near base-ISO gives less noise in the acquired image. The camera exposure defined by aperture, ISO and shutter speed was $1/320\ sec$.

V. THE PROPOSED WORKFLOW

The macro level work flow of the proposed 3D reconstruction process is divided into two modules. The first module deals with color tone adjustments while the second module performs the actual steps of photogrammetry (see Figure 3). The first module is more focused on image processing aspects. It is used to perform empirical color tone adjustments for range of values and combinations. Brightness-contrast balance is performed and resulting transformed images are stored to be fed to the photogrammetry module. As a prerequisite, the camera use for acquiring test images are calibrated using set of check-board patterned images. The second module then proceeds with photogrammetry steps.

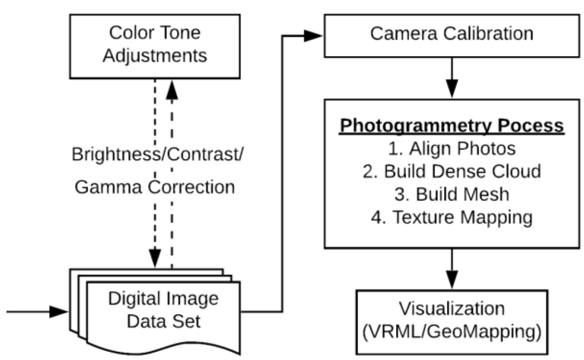


Figure 3. The Proposed Workflow

A brief description of the workflow is describe below.

A. Preprocessing-Color Tone Adjustments

As a preprocessing requirement of the proposed work flow, all digitally acquired images are adjusted for combination of brightness and contrast values. The images are processed for ranges of contrast values keeping constant brightness and new set of test images are generated to populate the data set. Similarly new set of images are obtained by varying the brightness. The adjustments have to be performed on all color channels. Since photogrammetry requires quality photos with quality hence any photo with quality less than 0.5 would be excluded from participating in the process.

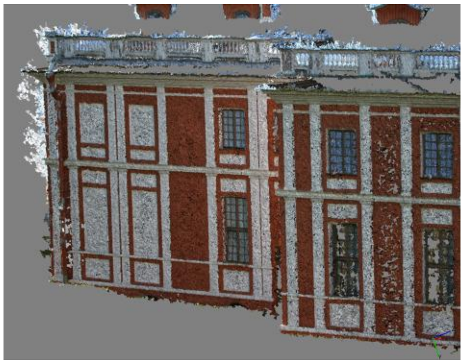
B. The Photogrammetry Process

The output of the photogrammetric process is a 3D model (see Figure 4) composed of dense point cloud and/or textured surface. It is a multistage process. Once the set of test images are loaded for processing, they are analyzed to looks for removing any unnecessary (non-contributing) images from the set. These non-contributing images are the one which do not have necessary minimum overlap among the images of the dataset.

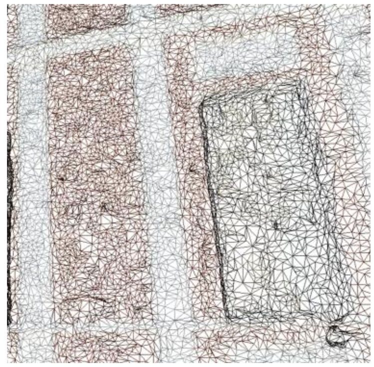
Figure 4. Reconstructed 3D Building Model

The basic purpose of each the steps of photogrammetry is described below.

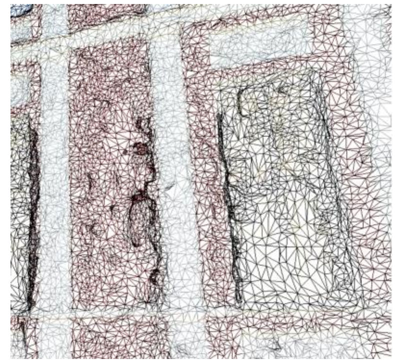
- *Align Images:* The images are aligned using suitable motion model to compute the camera positions and a sparse point cloud. The parameters such as accuracy, pair selection, key and tie point limits are important during alignment process. Downscaling the images by factor of 4 (twice by each side) leads to medium accuracy and a downscale by factor of 16 leads to low accuracy. A highest accuracy can be obtained by upscaling by a factor 4 which will lead to more accurate tie points. Tie points are upper limit of matching points in the image and key points determines the upper limit on feature points to be considered during processing images.
- *Build Dense Cloud*: Using camera positions and the depth information the dense point cloud approximating the 3D surface is generated.



(a) Point Cloud (Brightness=10%)

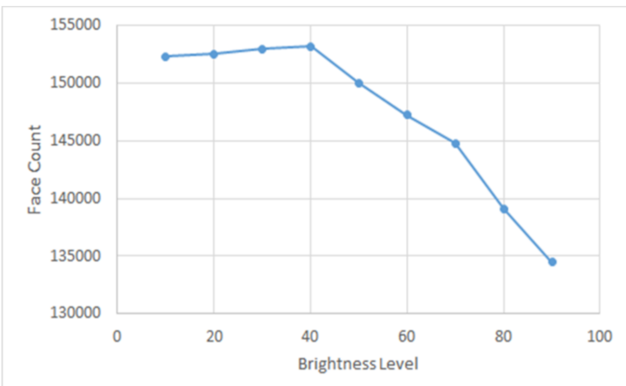


(b) (Brightness=10%)

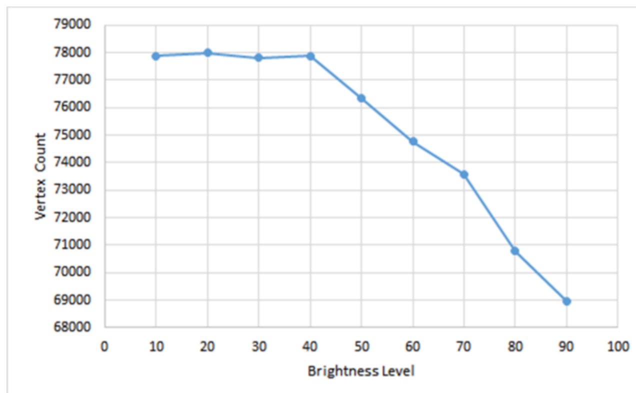


(c) Contrast=70%)

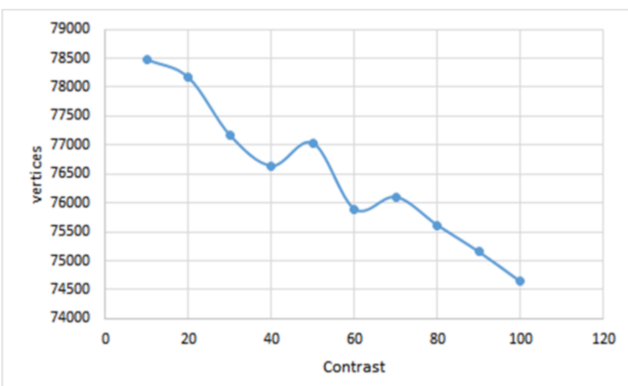
Figure 5. 3-D Reconstructed Outputs



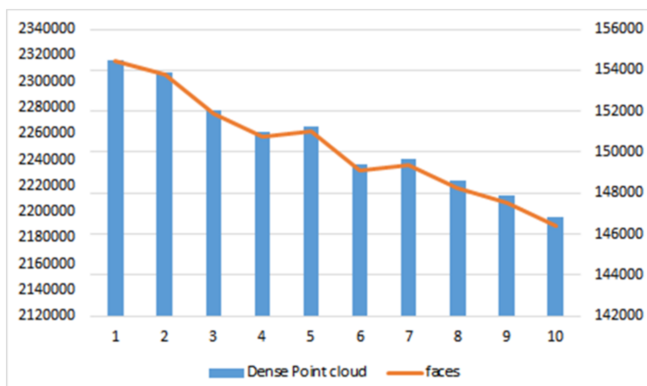
(a) Brightness v/s Face Count Performance



(b) Brightness v/s Vertex Performance



(c) Contrast v/s Vertex Count



(d) Contrast v/s Point Cloud v/s Faces

Figure 6. Reconstruction Performance

- *Build Mesh:* Using the point cloud generated in previous stage, a mesh surface is estimated. Arbitrary mesh surface type can be used for building structures and height field based surface mesh can be used for terrain relief structures. A parameter called polygon count can control the mesh surface detail in the reconstructed surface and can be set in the ratio 1:5 for high, 1:15 for medium, and 1:45 for low detail respectively.
- *Map Texture*: This stage maps textures to the arbitrarily shape determined from the reconstruction process. Texture details can be obtained from single image or a blend of images that is based on either averaging (simple or weighted), maximum or minimum intensities.

- *Export for Visualization*: As a final stage the reconstructed 3D model (point cloud or textured surface) is exported into an independent 3D format like VRML for interactive viewing experiences.

The dense point cloud obtained from the above photogrammetry process gives 3-dimensional spatial occupancy of the object/geospatial structures and can be used to general 3D models. These 3D models can be analyzed for efficiency of the reconstruction and the effect of color tone adjustments on the mesh and textured surfaces visualizations. The various samples of 3D reconstructed models are compared on visual and statistical parameters. The details are finding are discussed in next.

VI. RESULTS

The results of the proposed integration of preprocessing task for color adjustments in brightness and contrast is clearly visible from the visual inspection shown in Figure 5. The statistical observations shown in Figure 6 reveal that while brightness variation has a small impact on the reconstruction up to 40% increase and falls of rapidly thereafter. Contrary to it, for variation in contrast values, the number of reconstructed points had a fast drop immediately from their mean values. It is seen that the small tonal difference is negligible if the average luminance is high, while the same small difference matters if the average luminance is low.

Empirical investigations also confirmed that the higher color depth is would results in less degradation of the reconstruction quality especially when balanced tonal adjustments are applied. However, in some cases for adjustments like histogram equalization produces unrealistic effects when applied to images with low color depth. It was also observed that images with bright but soft lights obtained good results. While working with sharp images the parameter of accuracy must be set high especially the photo-alignment stage of the photogrammetry. This fact is also established by the observed root mean square error (RMSE) values for the dense point cloud, number of faces and the control vertices of the reconstructed surface. The RMSE for generated dense point cloud was 98362 for number of dense points, 6371 for number of faces and 3183 for control points of the resulting surface respectively.

VII. CONCLUSION

In this paper, we have considered the effect of color tone adjustments in photogrammetry based 3D reconstruction of building and demonstrated that both brightness and contrast has an impact on reconstruction capability. It was observed that the reconstructed surface improved for brightness and contrast up to 40% and then gradually degraded. It was concluded that both high contrast and high brightness reduces the reconstruction capacity of the photogrammetry process.

A proper exposure and tonal adjustments are must for acquiring images to be used with photogrammetry. There is strong close cohesion between contrast values of pixels and depth perception of points in the point cloud. An equalized set of images gives the optimal result of 3D reconstruction.

A close inspection of the mesh view of the reconstructed surface proved the presence of deformations and loss of surface details in the reconstructed 3D model. It is suggested that tonal range between -15% to 40% is acceptable for reconstruction purpose. However, for precession based applications this range can be much narrower. The values of RMSE for the reconstructed surface verified the loss of surface quality for higher tonal adjustments on contrast and brightness values. There are further interesting extensions and applications of the color tone adjustments in the surface reconstruction process and can be applied in diversified areas like object depth classification these models, surface deformation study and object fusion.

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