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Elaboration of digital image processing for monitoring environmental impact on Cheops (Khufu) pyramid

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ABSTRACT: The Pharaonic monuments represent the greatest group and express a civilization of a period of more than four thousand years. It is a unique heritage of historical treasures that belongs not only to Egyptians but to all humanity. Stone damage or deterioration of monuments in Egypt due to weathering and environmental impact is sounding. Weathering forms such as soiling, black crusts and whitish crusts are very common in the limestone monuments in Egypt. Considerable color of stone material in combination with intense current detachment of stone material is very characteristic of the lower part of many monuments. The degree of deterioration distribution could be represented using contour lines drawn on sketch of the studied stone blocks of a 4 layers. From this, predictions could be made for each zone according to the degree of deterioration.

1 INTRODUCTION

Egypt located monuments represent one third of all the world's ancient monuments. In addition, they are of outstanding historical and artistic importance ranging from Pharaonic to Greek, Roman, Coptic and Islamic.

The Pharaonic monuments represent the greatest group and express a civilization of a period of more than four thousand years. It is a unique heritage of historical treasures that belongs not only to Egyptians but to all humanity. However, stone damage or deterioration of monuments in Egypt due to weathering and environmental impact is sounding. Weathering forms such as soiling, black crusts and whitish crusts are very common in the limestone monuments in Egypt. Considerable color of stone material in combination with intense current detachment of stone material is very characteristic of the lower part of many monuments.

It seams that the past 70 years of rapid development have worked more damage on the wonders of ancient Egypt than the 4000 years that came before. As the number of people increases, they have spilled out of the cities in search of housing. At Cairo, the Pyramid Plateau, once far from urban sprawl, now lies almost in the shadow of modern apartment buildings. Near by factories and old vehicles send forth noxious clouds of particulate laden exhaust, which becomes corrosive when dissolved by rain. More serious still is the damage caused by water from leaking water supply pipes and aging sewerage system. Also, the extensive irrigation used to make land arable, along with poor drainage, has helped cause the rise in the water table's average level. As the groundwater rises, it dissolves mineral salts from the soil and bedrock. Ancient building made of porous limestone, act like sponges, sucking this salty water from the ground. When the water evaporates, the salts are left behind. when this happens at the stone's surface, these crystallize into destructive white lesions (Hawass, 1993, Heinrichs & Fitzner, 2000 and Fitzner et al. 2002)

The present work is concerned with the most important and most famous monument in Egypt. It is the Great Pyramid of Giza or Cheops Great Pyramid (called Khufa by the Egyptians). The Polluted air of Cairo bathes the Pyramid in nitric and sulfuric acid. Sewage and detergents percolate up through the desert floor. The encrustations of salt, left by the evaporation of brackish ground water have eastern away at the lower part of the Pyramid. Therefore, a comprehensive survey for the condition of monument and elaborate study was done to investigate the case using digital image processing technique. This technique is based on the color of rocks as the change of colors in rocks is the first deserved feature of deterioration.

2 DIGITAL IMAGE PROCESSING

Digital image processing is a very recent technique to analyze the digital photograph, in order to predict the weathering impact on the stone monuments. The degree of weathering can be determined based on the color of rocks because the change in rock color is the first observed feature of weathered rocks. In field observation, weathered rocks can be roughly classified into several degrees of weathering with the aid of color and change of structure observed with the naked eye (Nagano and Nakashima, 1989; Fitzner et al., 2002). Saito et al. (1974) reported as a feature observed with the naked eye that the blue-green- gray tones in fresh rocks changed to brownish ones during weathering. Karmaanov and Rozhkov (1972) pointed out the possibility of quantitative relationships between color characteristics and soil compositions. Therefore, the color of rocks is considered to be one of the few parameters which can determine weak degrees of weathering of rocks due to small changes in their chemical or mineralogical properties.

Chang et al. (2003) developed a computer program “ImagCraft “ to produce the histogram of color change for each color of RGB color system. Evaluation, quantification and rating of stone deterioration by this method is based on colors change or color deteriorated from the original stone to the present (deteriorated stones)

The aim of this paper is to evaluate the impact of the local environmental and weathering on exposed stone surface of the Great Pyramid of Giza and how these parameters affected the stone and caused the decay and change of color system of the stone. The quantification of deterioration degree on the weathered monument stone surface is made using digital image processing.

3 THE GREAT PYRAMID OF GIZA

The Great Pyramid of Giza or Cheops Great Pyramid (called Khufu by the Egyptians) is located in the vicinity of Cairo. It was constructed since more than 4000 years (during the Old Kingdom of Egypt which appeared between 2780 B.C. and 2280 B.C.). It is built of 2300000 blocks of stone, some of which weigh 150 tons each. About 100000 men were employed for twenty years in building it. This great pyramid covers an area of more than 50000 square meters. Time has eroded its sides. It is much smaller in size now that it was. In its present state, the length of each side is 225 meters, the height is 135 meters.

4 MATERIAL OF THE MONUMENT

Limestone from local quarries has been used for construction of monuments in Egypt since Pharaonic times. Eocene limestone outcrops in the boundaries of Cairo providing the material for construction of historical stone monuments in this region. The Great Pyramid of Giza is made of Eocene limestone from the ancient quarries at Giza located west of Cairo.

These Eocene formations show a wide variety of limestone facieses, which are also reflected in the building stones of the monuments studied here. These facieses may be described as a calcarenite formed by detrital phase constituted by grains of calcite, quartz and some fossils and cemented by a micritic matrix that may contain substantial amounts of clay minerals. In some cases the clay content is high enough to be classified as marl (Said, 1990).

In the present work, this ancient quarry was used as source quarry from which source stone was taken.

5 WEATHERING PROCESSES OF MONUMENT

Stone weathering as a natural process can be divided into two groups: (i) physical weathering such as microcraking and disintegration; and (ii) chemical weathering such as discoloration and dissolution of component mineral grains. Both weathering result in certain types of loss in volume of each mineral component (Anon,1980 and Brand, 1990). Any weathering factor normally has negative influence on durability and can be assessed quantitatively by the measurement of change in color system in reference to color of non deteriorated stone (original stone). This can be attained by the use of digital image processing such as the RBG color system. This change can be considered as color deterioration between the original and deteriorated stones.

5 INVESTIGATED PROCEDURES

5.1 Use of "RGB" color space system

Red, Green, Blue are three components of RGB color space system. Any color used in a digital camera is created by blending of R, G, B. Pixel is a unit composed of the image. Every pixel has Red, Green and Blue components. Red, Green, Blue value is defined as an intensity of each components (in range of 0 – 255). Red, Green, Blue values were separately measured in a pixel. So each component intensity can be measured in digital photos by pixel values. Each component can be represented for each color in X- Y chart, in which the X- axis represents the intensity values whereas the Y- axis represent its frequency.

5.2 Use of "ImageCraft" program

For starting of "ImageCraft" program, open the digital image file that you want to analyze. However, there are some difference between the color of the digital image and real color because of the shadow, the location of the light source etc. So, it is needed to calibrate the RGB values of the digital image by using a standard color chart which provides the standard RGB values. By lining with mouse on each color of color chart, the RGB values of each color can be obtained. The relation equation between the RGB value acquired by 'ImageCraft' and the RGB value in the standard color chart - which is attached with it – can be found out for each color (Red, Green and Blue) using the Excel software. The constants of the obtained equation will be applied in the calibration window in 'ImagCraft' program and then the new calibration image can be obtained. Then the whole calibrated image can be cute to several sections which has some homogeneity as far as possible. The histogram with their information and data can be determined for each obtained section using color information menu and RGB statistics in the program.

6 EXPERIMENTAL WORKS

a- Four consecutive horizontal layers of stone were chosen from the Great Pyramid (Khufu or Cheops Pyramid), as shown from the general view of the Pyramid. They are (from below to the top):

First Bed	- P1
Second Bed	- P2
Third Bed	- P3
Fourth Bed	- P4

b- The source stone taken from the ancient source quarry was photographed. This was done after removal surficial layers affected by weathering.

c- For each layer of the four beds, images were taken for seven consecutive blocks (on the horizontal direction). Images were taken using high quausing high quality scientific digital camera (more than 3 mega Pixel). The standard color reference at each stone photographing has been indicated.

d- Computer program for image analysis of digital photos (previously developed by Laboratory for Earth Science at Seoul University under the supervision of Professor Dr. Park) was applied on digital images for all photographed blocks.

c- Cross- sectional scanning was performed for each photographed image after calibrating natural colors with standard colors. Each cross section was taken to collect all possible homogenous features in one section. They are 163 cross-sectional samples for the first stone layer (P1), 197 cross-sectional samples for the second stone layer (P2), 170 cross-sectional samples for the third stone layer (P3) and 170 cross-sectional samples of the third stone layer and 140 cross-sectional samples for the fourth stone layer (P4) as shown in table 1. Thus, the total cross-sectional samples are 670 which were studied and analyzed.

7 RESULTS AND ANALYSIS

- Degree of deterioration according to previously obtained results (from previous stages of research study (Aboushook et al., 2006) was applied by calculating the total points for deterioration of the three standard colors for each of the five deterioration categories namely:
  (very low , low , medium , high , very high)

- Accordingly the percentage of color deterioration could be determined as shown in figure (1) and in tables 1.

- From the above mentioned percentage, detailed description of the state of deterioration for seven stone blocks of each of the four layers could be made. As a result, degree of expected remedy could be predicted as either intensive treatment, simple treatment or medium treatment as given in tables 2.

- General and detailed state of deterioration degree of stone blocks of the 4 layers has been represented by charts as given on figures 1 &2 (as an example)

- Finally, degree of deterioration distribution could be represented using contour lines drawn on sketch of the studied stone blocks of the 4 layers. From this, predictions could be made for each zone according to the degree of deterioration as a cumulating of the 4 layers as shown in figures 3 - 5.

- Other parts of the Pyramid can, therefore be investigated in the same way to predict their degree of deterioration.

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General view of Khufu Pyramid showing the studied four beds of deteriorated stones

Table 1. Effected color points corresponding to different deterioration categories for the studied stones of Khufu Pyramid

Bed No.	Block No.	Sect. Total	Deterioration categories*					Categories Total
			Very Low ΔD% =(0–20)	Low (21-40)	Medium (41-60)	High (61-80)	Very High (81-100)	
P1	P1-1	29	30	21	14	9	5	79
	P1-2	20	8	19	17	10	1	55
	P1-3	20	3	23	19	3	2	50
	P1-4	22	10	20	17	7	0	54
	P1-5	24	2	24	21	13	2	62
	P1-6	26	14	25	17	8	2	66
	P1-7	22	0	11	28	11	1	51
Total		163	67	143	133	61	13	417
P2	P2-1	39	0	18	31	28	18	95
	P2-2	31	8	26	29	13	0	76
	P2-3	29	3	19	27	16	10	75
	P2-4	31	10	22	23	12	8	75
	P2-5	20	13	21	15	4	2	55
	P2-6	25	0	21	21	16	1	59
	P2-7	22	20	24	8	4	0	56
Total		197	54	151	154	93	39	491
P3	P3-1	47	1	16	44	37	12	110
	P3-2	23	0	4	12	16	21	53
	P3-3	25	2	20	20	12	6	60
	P3-4	27	3	19	23	16	9	67
	P3-5	22	0	20	16	17	2	55
	P3-6	15	0	24	13	3	0	40
	P3-7	11	9	13	8	1	0	31
Total		170	15	116	136	102	47	416
P4	P4-1	21	14	25	13	5	0	57
	P4-2	23	17	25	16	5	0	63
	P4-3	28	3	21	30	19	4	77
	P4-4	27	17	16	21	14	4	72
	P4-5	11	0	7	13	10	2	32
	P4-6	18	5	17	16	10	0	48
	P4-7	12	8	18	7	2	0	35
Total		140	64	129	116	65	10	384

* calculated from figures (1- 4)

Table 2. Summary of deterioration state corresponding to percentages of principal categories in the studied stone beds of Khufu Pyramid

Bed No.	Principal Deterioration Categories			General Deterioration State*	Prospecting Degree of treatment
	Low & very Low ΔD% =(0–40)	Medium (41-60)	High & Very High (61-100)		
P1	50	32	18	Low and Medium, Some High	Slightly to Moderate
P2	42	31	27	Low and Medium, Some High	Slightly to Moderate
P3	32	32	36	High and Medium and Low	Intensive to Moderate
P4	50	30	20	Low, Some Medium, some High	Slightly

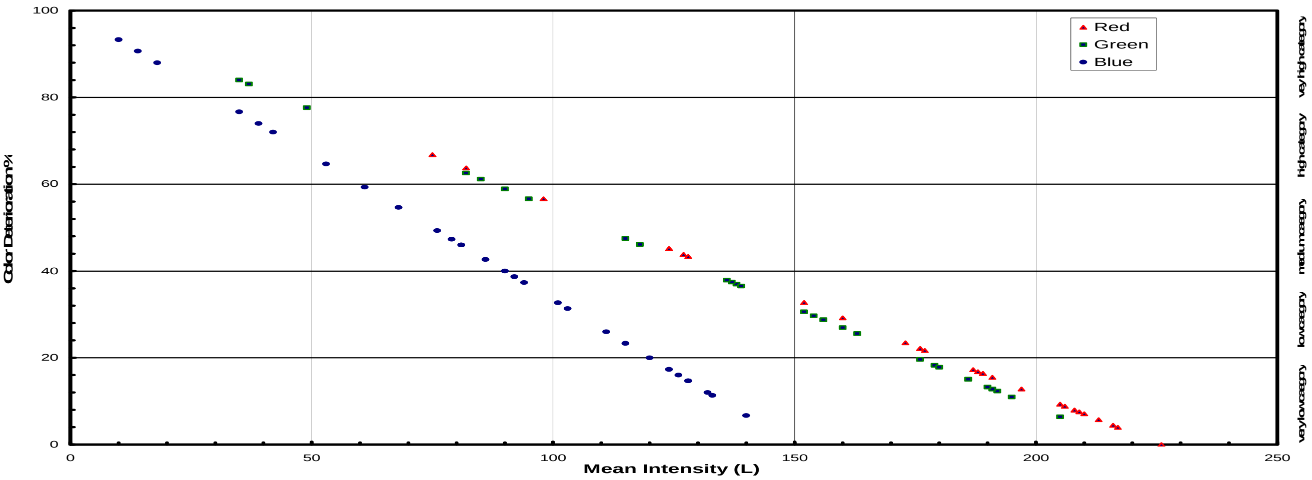

Figure 1. A classified chart to calculate number of effected color points corresponding to each proposed deteriorated category (block P1-1)

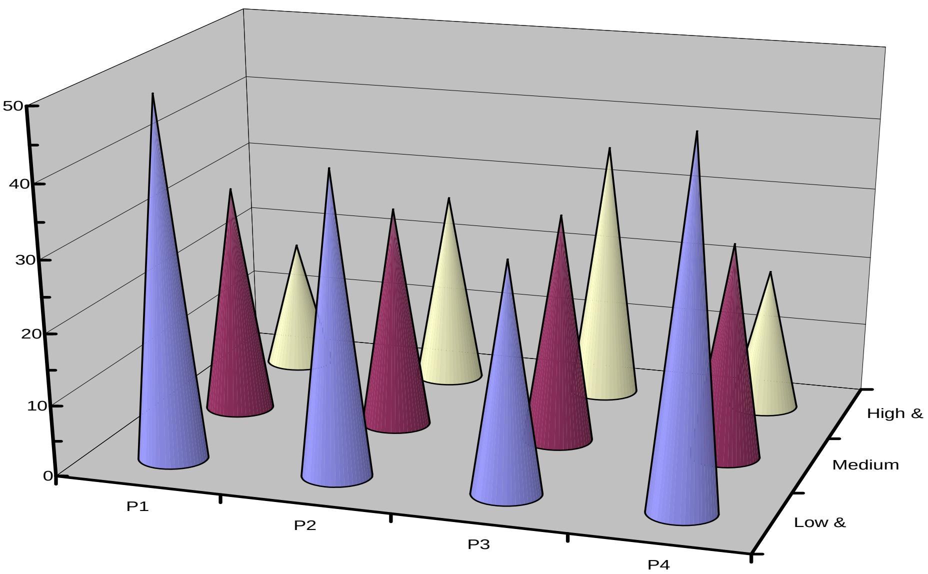

Figure 2. A representative chart cone of principal proposed deterioration categories occuring in the four studied stone bed of Kufu Pyramidd

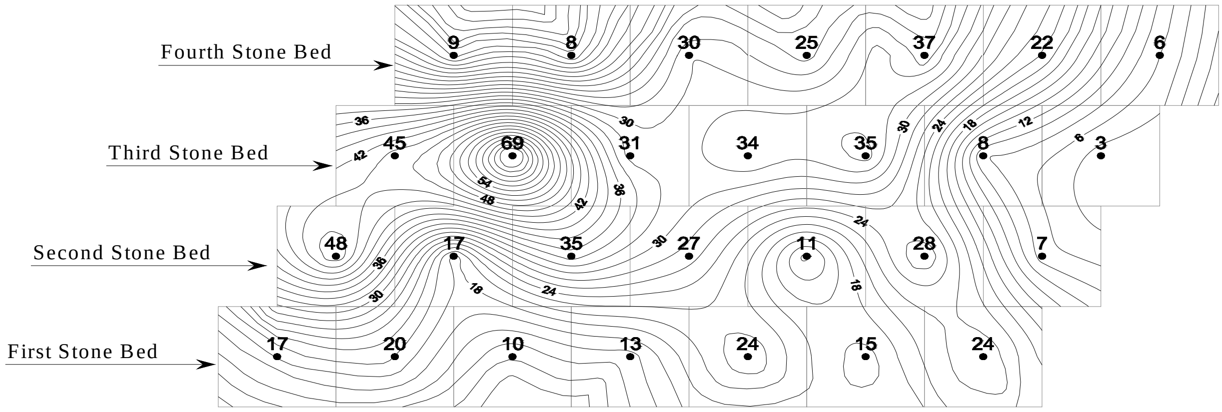

Figure 3. A representative contour map showing high & very high deterioration category in the four studied stone beds of Kufu Pyramid

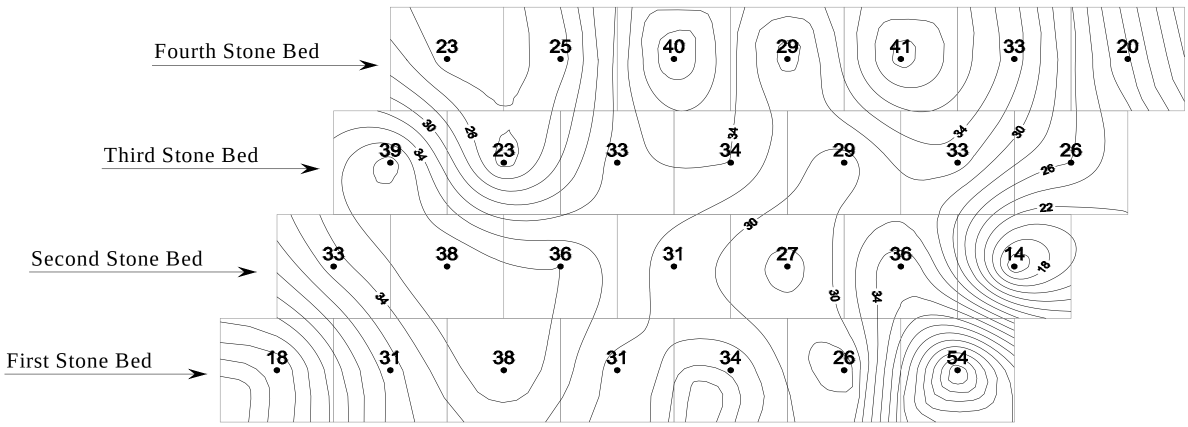

Figure 4. A representative contour map showing medium deterioration category in the four studied stone beds of Khufu Pyramid

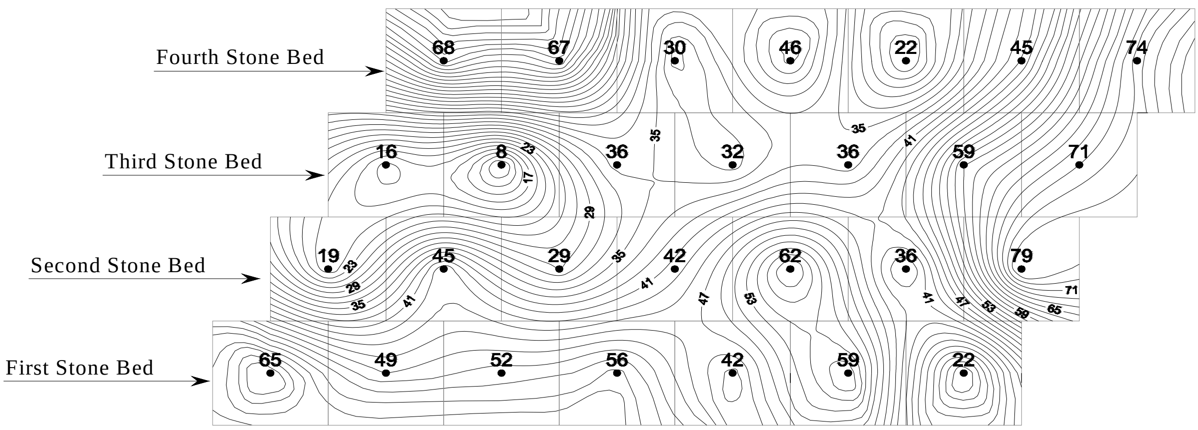

Figure 5**.** A representative contour map showing low & very low deterioration category in the four studied stone beds of Khufu Pyramid