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INVESTIGATION OF NOVEL HEXAGONAL IMAGE GRID PROCESSING FOR DIFFERENT COMPUTER VISION APPLICATIONS

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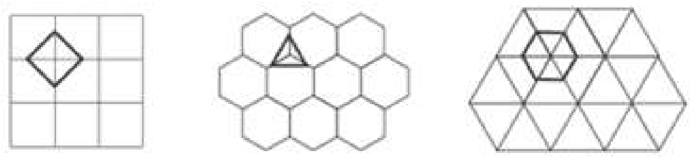
ABSTRACT: Acquisition, processing, and visualization using a human visual system (HVS) is a natural real-time process. This process should be electronically integrated into the computer vision system. The initial stage of collecting image information from nature is done using the acquisition phase. A camera or scanner or some other hardware is used for this purpose. But, in the present scenario, almost all cameras available function on square pixel-based images. Photoreceptors of our eyes exactly resemble hexagonal grids. Therefore, if it is possible to develop cameras having hexagonal pixels, it will be a grant innovation. Keeping this in mind, several software approaches are built in this paper to demonstrate hexagonal grid image processing for different applications such as denoising, edge detection, and compression. The image processing phase will include specific mathematical algorithms to extract the structural features present in an image. The integration of computer vision systems with the human visual system in terms of the grid is a significant point of interest in this paper concerning various applications using hexagonal image processing.

Keywords: Hexagonal pixel, Edge detection, Denoising, Image compression, Gabor filter, Wavelet, Alternate pixel suppression, Peak signal-to-noise ratio (PSNR), Mean squared error (MSE).

1. INTRODUCTION

Hexagonal images represented using hexagonal pixel is an alternate grid of image processing in the area of computer vision processing. The hexagonal domain is well structured for creating a human visual system, as the alignment of photoreceptors in the human retina resembles a hexagonal grid form. To tile an image, there are three potential established approaches for covering a whole image without overlapping the samples and space between them.



(a) (b) (c)

Figure 1: Three image tessellations (a) Square, (b) Hexagonal, and (c) Triangular tessellations [1]

The three different approaches are shown below in Fig.1. Fig.1(a) is a similar and commonly used square tessellation because it is compatible with the traditional Cartesian coordinate scheme. Fig.1(b) is the hexagonal tessellation that is similar to our human visual system and has the advantages such as greater angular resolution, equidistant connectivity, lesser quantization defect, etc. Fig.1(c) is the triangular tessellation with a decent dense packing compared with the square tessellation. The human retina resembles a hexagonal decoration strategy. The rods and cones cells that are responsible for vision are arranged approximately in a hexagonal grid pattern known as a retinal mosaic [1].

This is another motivation for relying on hexagonal image processing. The rods and cone cells also have hexagonal decoration plans in the animal's vision. Therefore, by capturing and creating images of hexagonal tessellation, one can get a good understanding of computer vision recognition. The major restriction of handling hexagonal image grid processing is the unavailability of capturing devices to outsource hexagonal images. Therefore, conversion of square tessellation to hexagonal tessellation before moving to hexagonal image processing is mandatory. For the conversion of a rectangular grid to a hexagonal grid, the resampling method is preferred.

1.1.Research Objectives

The goal of this work is to analyze existing hexagonal image processing performance analysis on various image processing algorithms and applications. Precisely, we want to investigate the advantage of using hexagonal sampling grid planes to process various applications for image processing. This study addresses the following issues concerning hexagonal image processing: (1) Hexagonal image processing (Re-sampling method), (2) Edge Detection in a hexagonal grid structure, (3) Hexagonal domain image compression using DCT, Wavelet, and Gabor filter.

A review of hexagonal sampling is summarized in Section 2 followed by the performance analysis of hexagonal image processing using various algorithms being elaborated in Sections 3, 4, and 5. Finally, in section 6, the conclusions drawn from this research work are elaborated.

1.2 MOTIVATION FOR HEXAGON STRUCTURE

Hexagon is the geometrical structure that best fills a plane with units of equal size and leaves no space lost. Because of its 120-degree angles, hexagonal packaging minimizes the perimeter of a given area. Patterns and geometry are present everywhere, however, nature seems to have a special thing to do in number 6. Beehives, Graphite crystalline structure, raft of bubbles and dragon fly eyes are the very few examples that can be found in the hexagon form in nature. The detailed structure evaluation are mentioned below:

Beehives in nature is a marvellous engineering that they store nectar in perfect hexagonal cells as shown in Fig.2. According to William Kirby in 1852, bees are "Heaven-instructed mathematicians." Honeycombs are made from beeswax, a substance created by worker bees. When the temperature is right, worker bees secrete wax scales from special glands in their body. Then they chew the wax with a bit of honey and pollen to produce the beeswax. The hexagonal cells serve as storage vessels for honey, as well as homes to raise young bees [9].

Figure 2: Bees making perfect hexagonal cells

The insect eye, on the other hand, is a compound eye as shown in Fig.3, consisting of thousands of tiny hexagonal tubes called ommatidia. Each has its own lens at the front and its own cluster of light sensing cells at the back. The tubes form an interlocking carpet that wraps around the insect's head. The image formed is a mosaic, and each tube contributes one piece. Wrap around vision helps aerial hunters like dragonflies spot their prey [10].

Figure 3: Insects compound eye

During the exploration and study of unknown phase phase of 2D materials, Graphene Antimony, Bismuth and Phosphorous which is known as pnictogen which belongs to nitrogen family (V-A) have honeycomb lattice structure [11] as shown in Fig. 4.

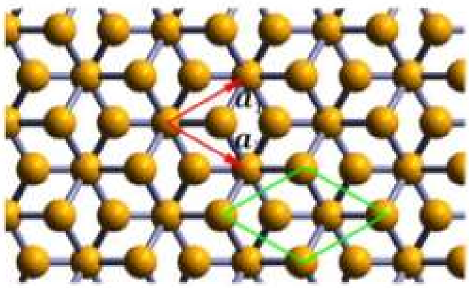


Figure 4: Top view of three-dimensional layered structure of V-A elements

A bubble is a small amount of gas, captured in a thin film of liquid. The bubbles shrink in thin films until the friction pulling is balanced by the air pressure that forces the bubbles out as the sphere is the most compact form, with the maximum volume being enclosed in fewer surface areas. The surface tension pull is always also backward, to minimal the surface shape, (In bubble raft we can see that when bubbles join together its shape deforms to hexagon). If the aim is to reduce the perimeter in that area, it turns out that hexagonal packaging beats triangles and squares as shown in Fig.5. [12].

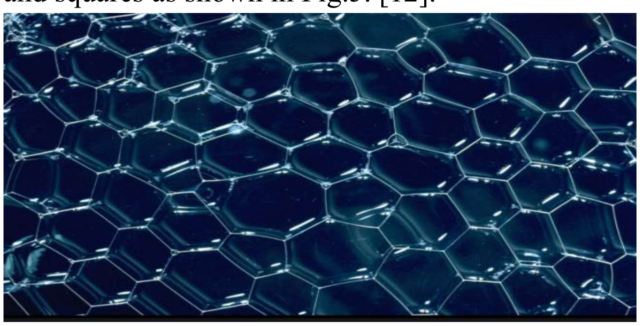


Figure 5: Bubble rafts form hexagonal pattern

The Belgium physicist joseph plateau determined in the late 19th century that joints of 120° are the most mechanically stable configuration where the strength of film is all in balance, so bubble rafts form hexagonal pattern not only minimizes the pull of surface tension, but is also most mechanically stable. However, a power of surface tension is present which wishes to reduce the perimeter and when bubbles come together, mechanical stability in hexagonal packing is the best balance between fewer shapes.

From the above analysis on hexagon structure, it can be concluded that if we are packing cells in in a plane, only there are three options: square, equilateral triangle and hexagons. Of these, hexagon structure will have high packing density as shown in Fig 6.

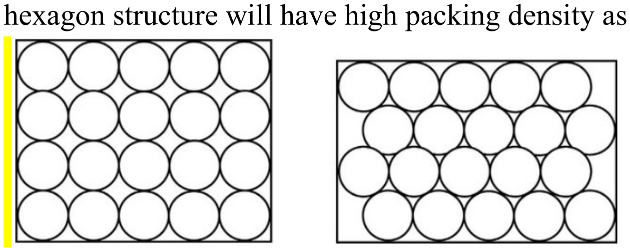


Figure.6 : Square packing and hexagonal packing

Moreover, in digital image processing, hexagon structure provides dozens of powerful computation features like greater angular resolution, uniform connectivity reduced storage area and higher packing density [13]. But in spite of these advantages, hexagonal grid structure is not used in computer graphics and vision field. This is due to the lack of suitable capturing and display devices. Fortunately, this difficulty is now overcome by different software schemes which reproduces hexagonal pixels or grid from square pixels. The different powerful conversion techniques have been discussed in this paper. This conversion technique allows computer vision researchers to work on these hexagonal lattices. In the next section, we describe the details of various tessellation schemes.

2. ANALYSIS OF HEXAGONAL IMAGE PROCESSING

To resample a rectangular grid to a hexagonal grid, the possible software simulation methods including the Alternate row and column suppressal method and Half-pixel shift method are discussed below [2].

2.1.Alternative Suppression of Rows and Columns

Deploying the Alternate pixel suppresser method, the hexagonal domain can be mimicked on the rectangular grid as shown in Fig.7. The procedure for sub-sampling shall be as follows by the rule [3]:

Hex_pixel_val(x,y) = val_pixel (2*x, 2*y) , if x is even
= val_pixel (2*x , 2*y + 1) , if x is odd (1)

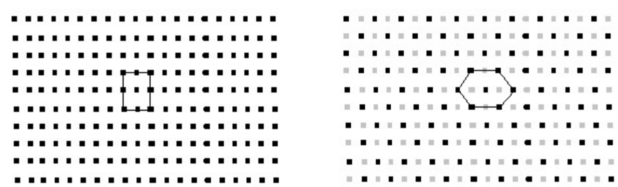


Figure 7: Rectangular grid and hexagonal grid reproduced using alternate pixel suppression method

The suppressed pixels in the hexagonal grid have no association with those in their rectangular counterparts. Deletion of pixel values stipulates pixel values to zero. These suppressed pixels are not considered in the mathematical calculation when processing this sub-sampled image. The hexagonal images mimicked using this method have only one-fourth of the total pixel count in the rectangular domain.

2.2.Half-pixel Method

Half-pixel method for obtaining a hexagonal lattice from the normal rectangular lattice is outlined below in Fig.8. Initially, find the midpoint between two adjacent pixels for each odd line by simply linear interpolation mid= (left + right)/2). Dispose of left and right, holding the mid values.

$P^{new}(i, 2j) = P^{old}(i, 2j)$
$P^{new}(i, 2j + 1) = (P^{old}(i, 2j + 1) + P^{old}(i + 1, 2j + 1)) / 2$ (2)

This formula gives a hexagonal mapping from a regular square or rectangular lattice:

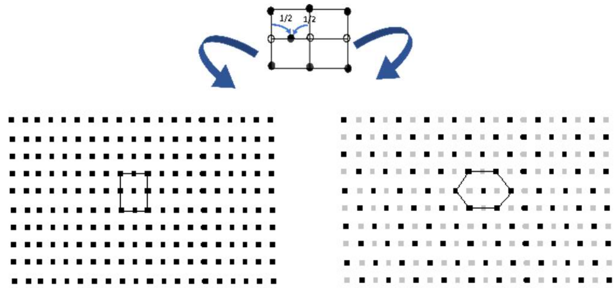


Figure 8: Transformation of the regular square domain into the hexagonal domain

2.3 pseudo hexagonal pixel

The visual influence of the hexagon and square pixel was calculated by Yabushita [9] in his approach. In order to make the density identical to that of the hexagonal grid, a simulated hexagonal pixel (hyperpel) is simulated through a set of many square pels. Fig.9. displays the resulting hyperpels. The resulting hyperpels were seen with 60 X 60 pels in resolution.

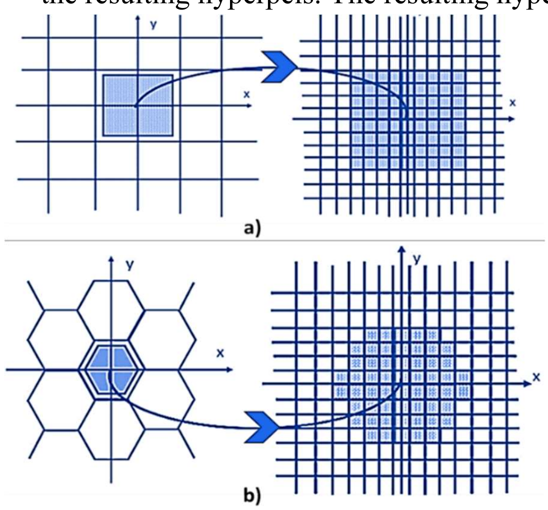


Figure 9: Hyper pixel design (a) square, and (b) Hexagon

2.3 Virtual hexagonal structure

The Wu and T. Qiang. Hintz [15] showed an architecture of the virtual spiral that prevails during the hexagonal image processing mechanism as shown in Fig 10. The resulting results can be mapped using this virtual grid hexagonal structure and transformed back into a square grid structure. Lastly, results can also be returned to the rectangular grid from the spiral architecture.

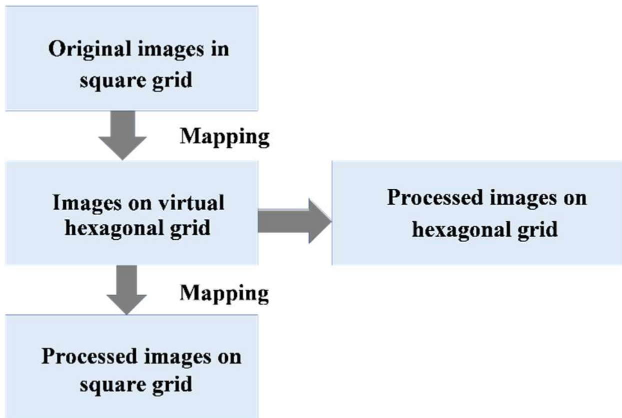


Figure 10: Virtual hexagonal structure

3. HEXAGONAL IMAGE COMPRESSION BY DCT, WAVELET, AND GABOR FILTER

Image compression is a mapping from a higher dimensional space to a lower dimensional space. It plays a vital role in multimedia applications [4]. The methodology for hexagonal image compression is shown in Fig.11. The procedure followed for hexagonal image compression based on wavelet and Gabor filter is as follows [5]:

(a) Using an Alternate pixel suppressing approach to resample the square image to the hexagonal image.
(b) Gabor filter interpolation is used to enhance the quality of the hexagonal image. The interpolation methods followed are:
(i) Hexagonal structure shows directional symmetry in orientations of 00, 600, and 1200.
(ii) Select the direction of filtering along 00, 600, and 1200 and do filtering.
(iii) Using the correct wavelet for decomposing the interpolated image.
(iv) Perform the compression using the function ‘wdencmp’.

The procedure followed for DCT-based hexagonal image compression is as follows [6]:
(a) The sample image is broken down into small blocks of size 8 x 8 blocks of pixels.
(b) Starting from left to right, DCT is applied to each block from the top to bottom.
(c) Compression of each block through quantization.
(d) The compressed array blocks that form the image are stored in a small amount of space.
(e) Reconstruction of the original image using IDCT.

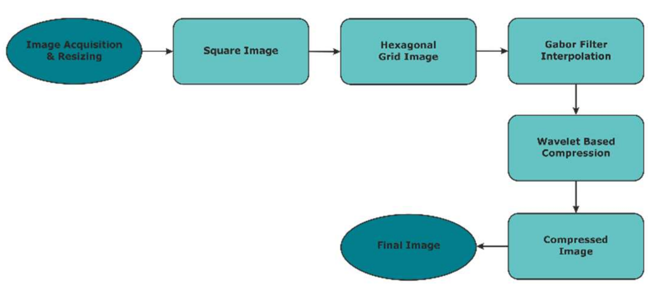


Figure 11: Block diagram of hexagonal compression

3.1 Results and Discussions of Image Compression in the Hexagonal Framework

A comparison of hexagonal image compression using a Gabor filter and a conventional rectangular grid is made in terms of Peak signal-to-noise ratio (PSNR), Mean squared error (MSE), and Compressed image size. Table 1 shows better results for the hexagonal representation. In hexagonal image compression, pixel requirement is less compared to conventional representation.

Table 1: Comparison of image compression in a rectangular grid and hexagonal grid [1]

Test Images	**Sampling**	**MSE**	**PSNR**	**Compressed image size**
Threshold value = 10				
water.jpg (61.7 KB)	Rectangular	2.3034	92.6378	60.9 KB
	Hexagonal	6.5335	88.1101	40.0 KB
Threshold value = 20				
water.jpg (61.7 KB)	Rectangular	5.3637	88.967	60.7 KB
	Hexagonal	6.6094	88.06	40.4 KB
Threshold value = 30				
water.jpg (61.7 KB)	Rectangular	7.9532	87.2562	60.7 KB
	Hexagonal	6.616	88.0556	40.4 KB
Threshold value = 40				
water.jpg (61.7 KB)	Rectangular	9.3936	86.5333	60.3 KB
	Hexagonal	6.616	88.0556	40.4 KB

4. HEXAGONAL IMAGE DENOISING USING WAVELET TRANSFORM

Due to the limitation of the hardware device in the hexagonal domain, resampling is used to convert square images to hexagonal images. After re-sampling, the hexagonal images are interpolated using a Gabor filter. Fig.12. shows the methodology of image de-noising using the hexagonal grid.

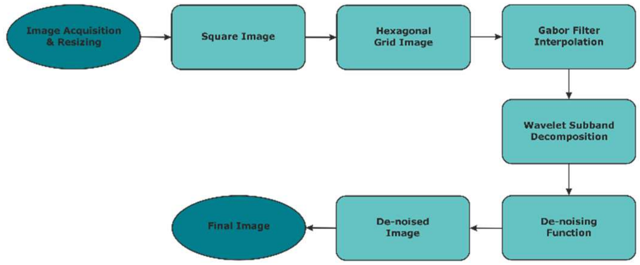


Figure 12: Denoising of an image in the hexagonal grid

4.1.Results and Discussion of Image De-Noising

De-noising of images is done on both the rectangular domain and hexagonal domain using MATLAB software with the inbuilt functions. The PSNR values for different compressed images with different noise levels are shown in Table 2. The PSNR value is found to be high for hexagonal grid images.

Table 2: Denoising of images on hexagonal grid

Noise Level	Input Image	Python Function	
		Rectangular Grid Image	Hexagonal Grid Image
15	lena.jpg	25.48	45.37
	gull.jpg	23.36	42.1
	goldhill.jpg	22.14	40.13
	flower.jpg	24.19	43.89
30	lena.jpg	21.33	38.67
	gull.jpg	20.67	37.56
	goldhill.jpg	20.78	37.89
	flower.jpg	19.45	33.45

5. EDGE DETECTION USING HEXAGONAL GRID

Edge detection plays a major role in determining the discontinuities in image applications. An edge is associated with a coordinated set of connected pixels that shows some variations in the intensity levels of pixels [7-8]. Hexagonal structured edge detection is performed by resampling the image to a hexagonal grid. The block diagram of edge detection using a hexagonal grid is shown in Fig.13 Different operators involved in edge detection are Sobel, Prewitt, Canny, and Laplacian of Gaussian.

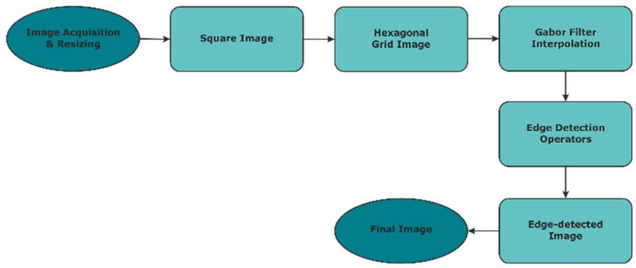


Figure 13: Block diagram of hexagonal grid edge detection

5.1.Results and Discussions using Edge detection

The comparison of edge detection operators is done on the factors like PSNR and MSE. From Table 3, it is clearly seen that the hexagonal image has higher PSNR and lower MSE. Fig.14. and Fig.15. shows the MSE and PSNR comparisons of square pixel and hexagonal pixel images.

Table 3: Denoising of images on hexagonal grid

Operator	Square Pixel Image		Hexagonal Pixel Image	
	MSE	PSNR	MSE	PSNR
Sobel	0.3591	52.5761	0.3330	52.9008
Prewitt	0.3589	52.5870	0.3331	52.9064
Roberts	0.3518	52.6479	0.3317	52.9231
Gaussian	0.3461	52.5411	0.3309	52.8912
Canny	0.3518	52.6781	0.3301	52.9205

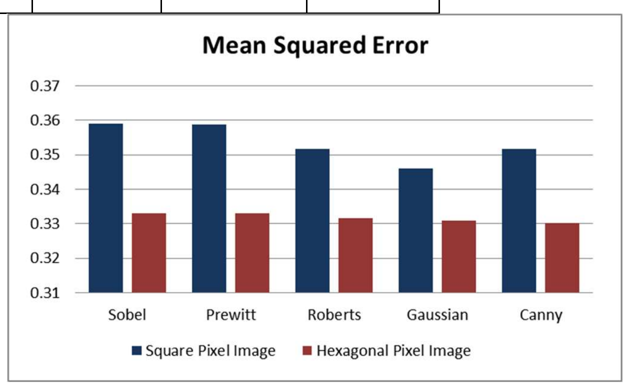


Figure 14: MSE Comparison of Square Pixel and Hexagonal Pixel Images

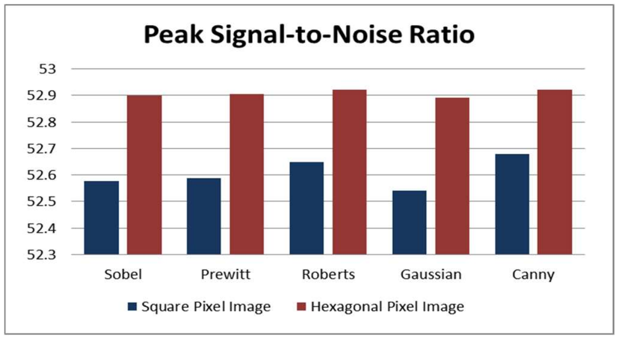


Figure 15: PSNR Assessment of Square Pixel and Hexagonal Pixel Images

6. CONCLUSIONS

The objective of this study is to prove whether using an alternative approach, the hexagonal grid will improve the performance of different image processing algorithms. Here, the performance analysis of image de-noising and image compression algorithms have been discussed. In conclusion, it can be noticed that the hexagonal images rather than square images have proved advantageous due to equidistant connectivity and the HIP framework possessing higher computational savings. Due to the unavailability of hardware to capture the hexagonal images, usually, software simulation-based approaches are used for converting square images to hexagonal images which is the major limitation of this study. Using a hexagonal representation of the image, computer vision can be made similar to human vision. For capturing hexagonal images, image-capturing hardware with hexagonal grid sensors is needed. This will lead to a creative world that has computer vision close to human vision. In the future, it will be largely needed to build a hexagonal grid sensor for better real-time visualizations.

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