A Comparative Study of Curvature-Based and Differential Versions of Dotter Raster-stereography Techniques

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Abstract

Conventional Line-based Raster-stereography has been a popular technique for 3-D surface topography. However, in its application for human face screening, the problem of line breaking was observed. In order to resolve this problem, there came up a new technique called dotted raster-stereography. The previously reported version of dotted raster-stereography extracted the curvature features of human face. This paper presents a modified version, viz. differential dotted raster-stereography in which instead of curvature, differences in straight line distances between adjacent points are calculated. A comparative picture of the two versions of dotted raster-stereography techniques is presented. Results suggest that this new differential version of dotted raster-stereography algorithm is faster in execution due to its simpler implementation in software, though lower in accuracy, as compared with the previously reported curvature-based version of dotted raster stereography.

Keywords: Raster-stereography, dotted raster grid, differential dotted raster-stereography, face recognition

1 Introduction

Raster-stereography and moiré fringe topography have been popular techniques for the last three decades in the domain of health sciences [1-4]. Both of these techniques are very much similar in terms of 3-D surface screening [5]. Raster-stereography performs grid projection on a surface in order to extract the curvature features of that object. At initial stage of this technique, the grid comprising horizontal and vertical lines normally known as conventional raster grid was used in a number of applications. However, it was observed that lines got broken during line extraction of curved surface because of poor contrast between object's surface and black lines [6]. In order to resolve this problem, the first author of this paper introduced, the concept of dotted raster-stereography in 2013 to extract the curvature features of curved surface, for the face recognition application [7]. The dotted raster-stereography technique produced better results and efficiency in comparison with conventional line raster technique. This paper presents a modified version of dotted raster-stereography technique viz. differential dotted raster-stereography, in which instead of curvatures, differences in straight line distances between adjacent points are calculated. Results and comparative analysis of the two techniques are reported.

2 Literature Review

Raster-stereography and moiré fringe topography techniques have been used in a number of applications by the researchers. For example, the use of conventional line raster grid for

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spinal deformity detection was reported in 2002 [2]. The work on defining the shape of spine using moiré fringe topography was reported in 2014 [8]. In another Study [9], the cogency and consistency of 4-D raster-stereography in dynamic conditions were discussed and it was recommended that raster-stereographic can be used to inspect the spinal posture with an acceptable level of accuracy. Authors in a study [10], presented a non-contact, non-invasive method for imaging and analysis of 3-D surfaces of moving boundaries along with the structure of asymmetrical formed planes. In [11], the author presented a reliable method of raster-stereography to measure the back contour of children body, which also minimized the effect of x-rays.

Human face recognition has been one of the more concerned areas of research for the last few years. Some very common face recognition techniques are Iterative Closest Point [12-17], Hidden Markov Models [18], and Principal Component Analysis [19-21]. Another technique was reported [22] that was based on co-variance-matrix, polynomial-coefficients and algorithm on common eigen-values to recognize among several human faces. In another person[23], authors presented an effective way to identify human faces using Symmetric-Local-Graph-Structure (SLGS), which was based on the concept of Local-Graph-Structure (LGS).

3 Curvature-Based Dotted Raster-stereography

In the concept of curvature-based dotted raster-stereography, a dotted grid as shown in figure 1(a) is projected on the surface of human face to extract and record the curvatures of human face [5]. In this method, human face is converted into certain number of horizontal and vertical pixels (raster image) as mentioned in figure 1(b). The geometry of curvature-based dotted raster-stereography concept is shown in figure 2. By selecting three consecutive points P, Q and R, the arc lengths PR and QR are solved. Same selection of three consecutive points is made from first pixel to last pixel of the image, as given in figure 1(b). This complete calculation of arc lengths provides the curvature feature information of human face. Using the equation of angular displacement ($\sin\frac{\alpha}{2} = \frac{\frac{d}{2}}{L}$), the arc length (s) is calculated, where radius of arc is $L = \frac{1}{K}$. By putting all the values in equation (1), curvatures (K_1 and K_2) are calculated for both horizontal and vertical patterns, based on which, two decision parameters mean (M) and Gaussian (G) are solved.

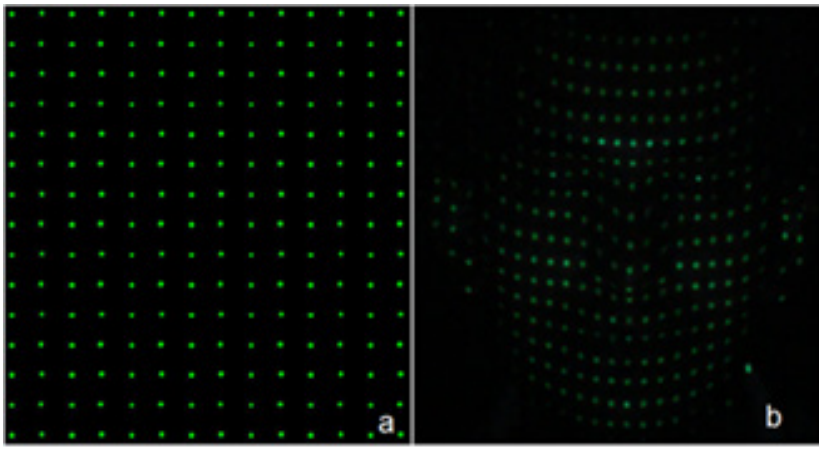


Figure 1: (a) Dotted Raster Grid (b) Curvature-Based Dotted Raster-stereography

Mathematical Formula of curvature-based dotted raster-stereography:

$K\_1=K\_2=\pm\ 1/s\ \sqrt{(24(1-d/s))}$.....(1)

K_1=Horizontal surface curvatures

K_2= Vertical surface curvatures

d = Linear distance PQ or QR

s = Arc length

α= Angle of tangents intersection

L = Perpendicular of triangle

Decision Parameters:

Mean= (K_1+K_2)/2, Gaussian=K_1.K_2

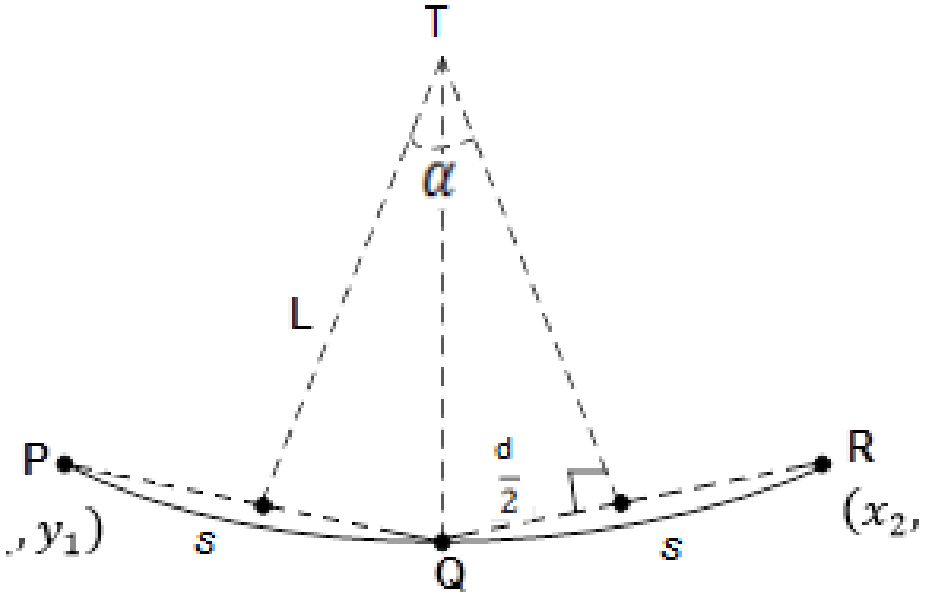


Figure 2: Geometry of Curvature-based Dotted Raster-stereography

4 Differential Dotted Raster-Stereography

This new concept of differential dotted raster-stereography is based on the linear distances between the adjacent points. In this work, '*d*' is the linear distance between two adjacent points 'P' and 'Q', as mentioned in figure 3. In this method, instead of arc lengths, the linear distances between two consecutive points (for both horizontal and vertical directions) are calculated.

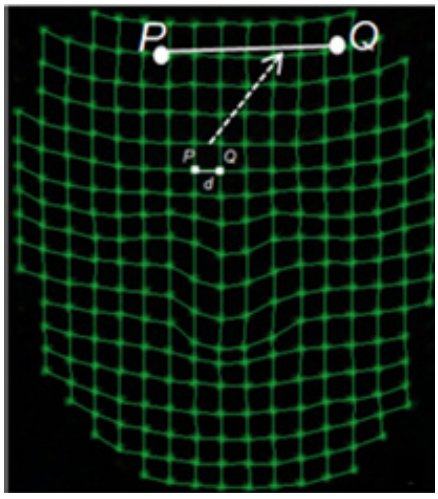


Figure 3: Differential Dotted Raster-stereography

In this proposed model, the facial features of human faces are presented on the basis of linear spacing between two consecutive points. The distance formula $d = \sqrt{(x_{2-}x_{1)}{}^2 + (y_{2-}y_{1)}{}^2}$ is used to calculate distances between two points as illustrated in figure 3, where (x_1, y_1) and (x_2, y_2) are the coordinates of points P and Q respectively. The decision parameter Δd for differential dotted raster-stereography is calculated using the mathematical formula $\Delta d = \sqrt{d_x{}^2 + d_y{}^2}$, where d_x and d_y are the average distances along x- and y-axis respectively, as mentioned in equations (2) and (3).

$$d_x = \frac{(d_{x_2} - d_{x_1}) + (d_{x_3} - d_{x_2}) + \cdots + (d_{x_n} - d_{x_{n-1}})}{n-1} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$d_y = \frac{(d_{y_2} - d_{y_1}) + (d_{y_3} - d_{y_2}) + \cdots + (d_{y_n} - d_{y_{n-1}})}{n-1} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

The complete system of differential dotted raster-stereography comprises eight different phases i.e- capturing human face, extracting distorted grid, cropping image, finding pixel coordinates, mathematical model, calculation of decision parameters, storing in database and face identification. The detailed functional diagram along with the flow of different phases is given in figure 4.

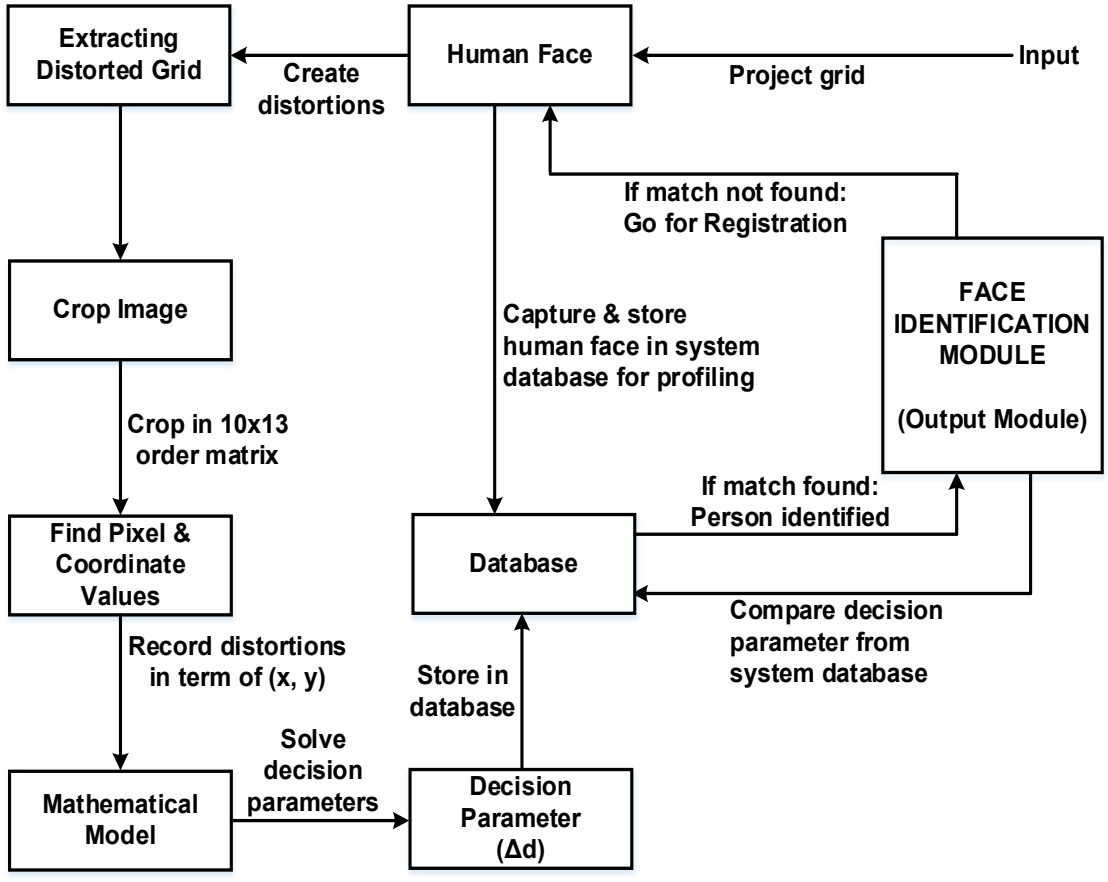


Figure 4: Functional Block Diagram of Differential Dotted Raster-stereography

5 Results and Discussion

A Measured values of curvature and distance parameters

Table 1 presents the horizontal and vertical facial deviations of first four human faces, with the following resulting values of decision-parameter '- Δd' in differential technique:

FID-01: 46.98 *cm*; FID-02: 53.88 *cm* ; FID-03: 67.88 *cm* ; FID-04: 39.80 *cm*

Table 1: Horizontal and Vertical Facial Deviations for Face IDs 01 - 04

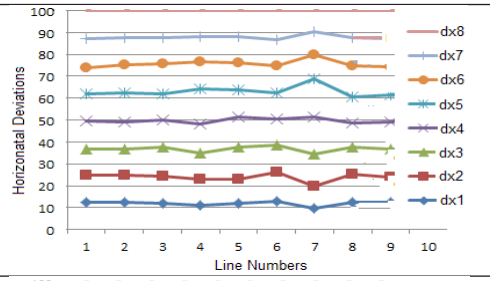
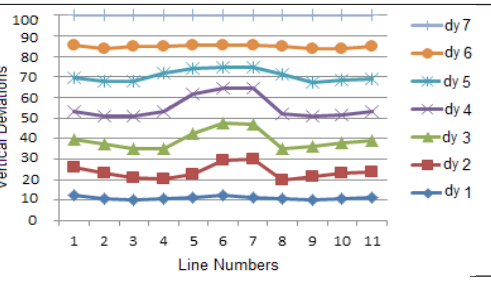
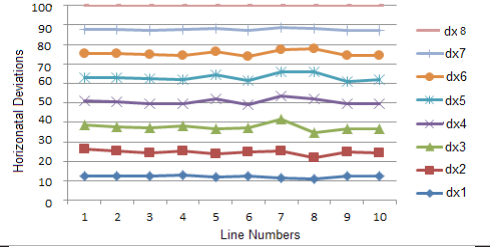
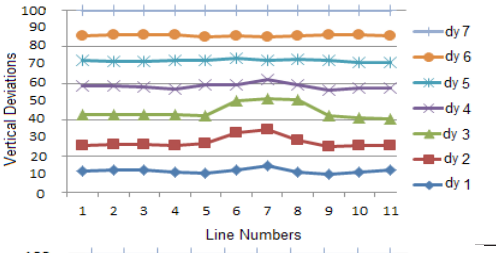
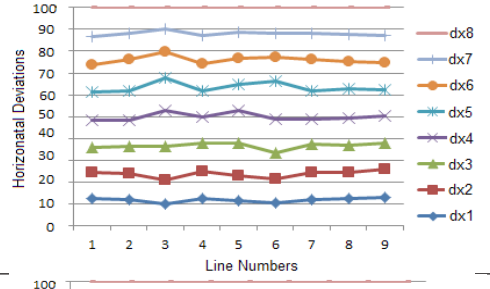
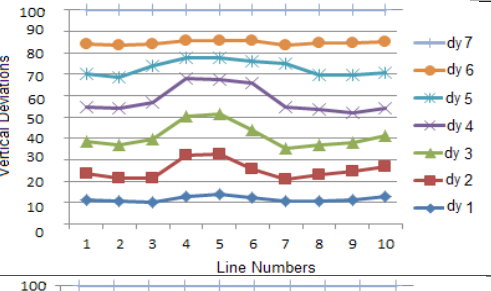
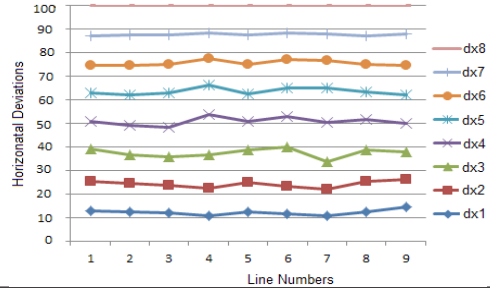
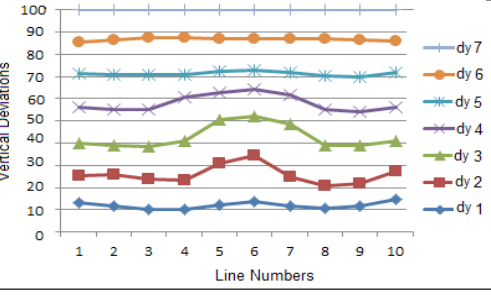
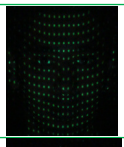
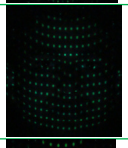
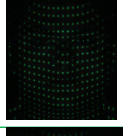
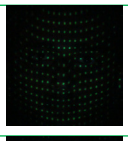
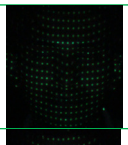
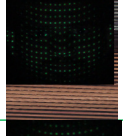
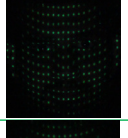
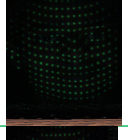
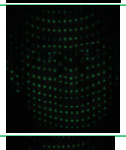
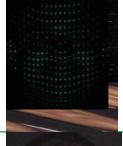
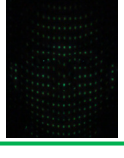
Face IDs	Horizontal Facial Deviations	Vertical Facial Deviations
FID-01		
FID-02		
FID-03		
FID-04		

Table 2 and figure 5 show the final calculated values of decision parameters M & G, and Δd respectively, for curvature-based and differential versions of dotted raster-stereography, for faces FID-01 to FID-10. For test runs of both techniques in IPRL (image processing research lab), same set of sample faces was selected from the system database.

Table 2: Results of decision parameter values for both techniques

			Curvature Based Dotted Raster-stereography				*Differential Dotted Raster-stereography*		
Face IDs	*Sample Human Faces*	*Distorted Grids*	K_1 (cm^{-1})	K_2 (cm^{-1})	*Mean (M)* (cm^{-1})	*Gaussian (G)* (cm^{-1})	d_x (cm)	d_y (cm)	Δd (cm)
FID-01			14.4200	1.7300	8.0800	25.0100	6.66	46.51	46.98
FID-02			4.8541	1.2500	3.0500	6.0600	9.24	53.09	53.88
FID-03			29.3000	1.9000	15.6000	55.6000	7.66	67.45	67.88
FID-04			24.0572	02.0500	13.0500	48.1100	5.79	39.38	39.80
FID-05			22.2000	1.5000	12.0000	33.7500	9.53	49.67	50.57
FID-06			17.2367	2.1230	9.67985	36.59351	12.12	73.14	74.13
FID-07			19.1002	1.8222	10.4612	34.80438	6.31	36.15	36.69
FID-08			27.4513	1.0021	14.2267	27.50895	13.62	77.23	78.42
FID-09			24.0115	1.7698	12.89065	42.49555	11.41	68.19	69.13
FID-10			12.7687	1.8765	7.3226	23.96047	10.98	71.05	71.89

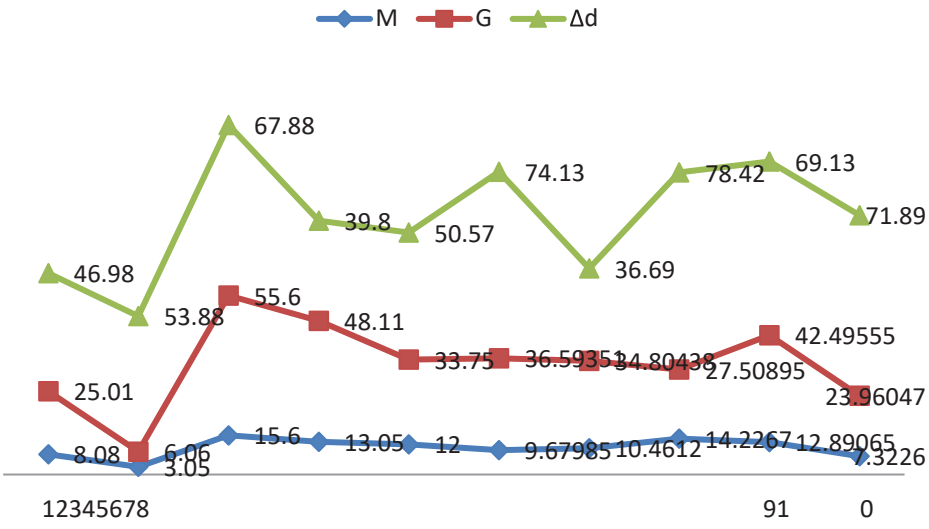


Figure 5: Decision Parameter values for Curvature-Based and Differential Versions of Dotted Raster-stereography

To get the better results in differential version of dotted raster-stereography, each test run was repeated three times. The resulting averages of d_x, d_y and Δd values are mentioned in table 2. It was observed that generally, sufficient difference between the decision parameter (Δd) values for different faces existed that, facilitated easy recognition of different registered human faces from the system database. However, one exception was in the case of facial IDs FID-03 and FID-09, where the two decision parameter values were close i.e. having a difference of only 1.25 cm (= 69.13- 67.88), thus making unique identification of both faces rather difficult.

B Accuracy, Precision and Specificity

The accuracy, precision and specificity values of curvature-based and differential version of dotted raster-stereography techniques for the same sample of 10 faces are summarized in table 3. Each test run in IPRL was repeated three times in order to get consistent results.

Table 3: Accuracy, Precision and Specificity Values

	Curvature Based Dotted Raster-stereography	Differential Dotted Raster-stereography
Accuracy	96.30	80.00
Precision	97.44	87.50
Specificity	33.33	50.00

Out of the sample set of 10 faces, 7 were correctly identified. During test run, it was observed that face ID-09 was wrongly identified as face ID-03 due to close decision parameter values. Details of the study outcomes and the results of parameters for differential dotted raster-stereography are given in figure 6.

		Face Recognition System		
		Condition Positive	Condition Negative	
Differential Dotted Raster-stereography Outcomes	Test Outcomes Positive	**True Positive** TP = 07	**False Positive** FP = 01	Positive predictive value 87.50%
	Test Outcomes Negative	**False Negative** FN = 01	**True Negative** TN = 01	Negative predictive value 50.00%
		Accuracy 80.00%	**Precision** 87.50%	
		Sensitivity 87.50%	**Specificity** 50.00%	

Figure 6: Results of parameters for differential dotted raster-stereography

C Algorithm Execution Time

The curvature based and differential versions of dotted raster-stereography techniques were tested on the same set of 10 human faces from the database in IPRL. It was found that training and testing times for curvature-based technique were 260.5 sec and 2.1 sec respectively. In case of differential technique, training and testing times were found as 180.5 sec and 1.5 sec respectively.

D Discussion of Results

In comparison with the curvature-based version, the newly reported algorithm of differential dotted raster-stereography has lower accuracy but higher specificity. However, it is important that the differential version is faster than curvature-based version. This faster execution of algorithm is very important for saving time, if the application is to be used to recognize a very large number of human faces, such as those of employees in a big organization or of train / airline passengers. Another very important application could be security related, where access is allowed to registered persons only.

6 Conclusion

A new differential version of dotted raster-stereography technique has been reported, that performs simpler calculation as compared with the previously reported curvature-based version

of dotted raster-stereography. Consequently, the differential dotted raster-stereography is faster as compared to its curvature-based version, which is an important factor when performing face recognition operation over a very large-sized database. The accuracy of the new technique is lower, which needs to be worked on for improvement.

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