Glaucoma Screening Using Compensated Cup-to-Disk Ratio Value

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Abstract: This paper proposes a fine tuned methodology to evaluate the compensated Cup-to-Disc Ratio (CDR) of a retinal fundus image to classify it as normal or suspicious for Glaucoma. The CDR value is the foremost feature looked up to check whether the subject is at risk for Glaucoma or not. The methodology proposed applies morphological techniques to extract out the compensated CDR value and ultimately classify the subjects as suspected for Glaucoma or normal. A compensation factor, **α**, is used to normalize the measured CDR value. This method achieves Cup-to-disk ratio detection rate of 80% and classification accuracy of 95% of the detected Cup-to-Disk Ratios.
Keywords: Glaucoma, Optic Disk, Optic Cup, Cup-To-Disc Ratio (CDR), Intraocular Pressure (IOP), Optic Nerve Head (ONH), Retinal Nerve Fiber Layer (RNFL).

Introduction

Of the disorders of eye, the one that relates to the optic nerve damage is known as Glaucoma. This is mostly associated with the increased eye pressure also known as Inter Ocular Pressure (IOP), shown in Figure 1, and is measured using a tonometer [1, 2]. If it exceeds the normal range, i.e. 10-21 mm of Hg, the subject is considered suspicious. This elevated pressure may be due to the clogging of eye's drainage canals over time or may be due to the blockage of these drainage canals. Due to the increase in the pressure, the size of the Optic Cup increases as shown in Figure 2. This affects the Cup-to-Disk Ratio and acts as the contrasting feature in a fundus image to evaluate the subject for Glaucoma screening. The normal CDR value ranges from 0.3 to 0.5 and if this ratio exceeds 0.5, the subject is considered suspicious for Glaucoma.

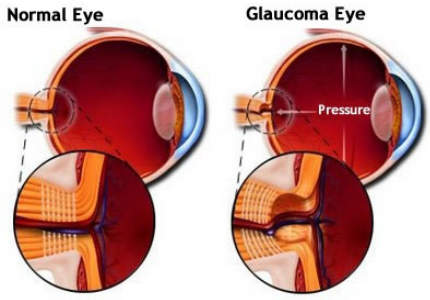

Figure 1: Damage to Optic Nerve due to Increased Eye pressure [3]

The Cup-to-Disk Ratio calculation involves mathematical division of the value of Cup and Disk diameter (taken vertically),

Cup-to-Disk Ratio = (Cup diameter) / (Disk diameter)

There have been so many techniques that have been proposed and used to detect Glaucoma by extracting out the Optic Cup and Disk and then calculating the CDR value from it [5].
For the current research the image database acquired is in JPG format with a resolution of 720x576. The proposed methodology has been applied on a total of 50 retinal fundus images taken from the local physician using an ophthalmoscope acquired at an angle of 45^0 from the posterior pole. The images used are both disc-centric (with optic disk at the centre) and eccentric (with optic disk anywhere in the image but not at the centre). All the image samples were acquired from patients of age between 25 to 60 years.

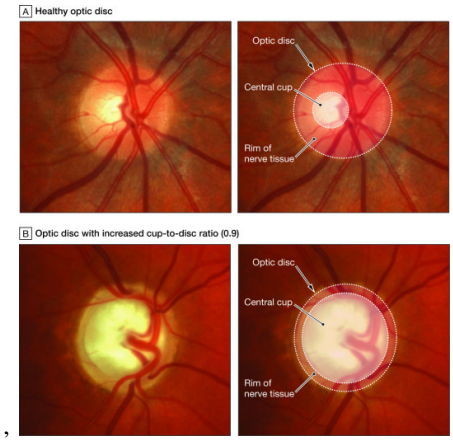

Figure 2: (a) Healthy Optic eye, (b) Eye with increased Cup-to-Disk Ratio [4]

Proposed Methodology

Cup-to-disc Ratio (CDR) is an important parameter after the eye pressure considered for the screening of Glaucoma. It depicts whether the subject is suspicious or not. For the evaluation of the CDR, the Optic disc and the Cup dimensions are extracted out using different image processing techniques [5]. The block representation of the proposed methodology is shown in Figure 3.

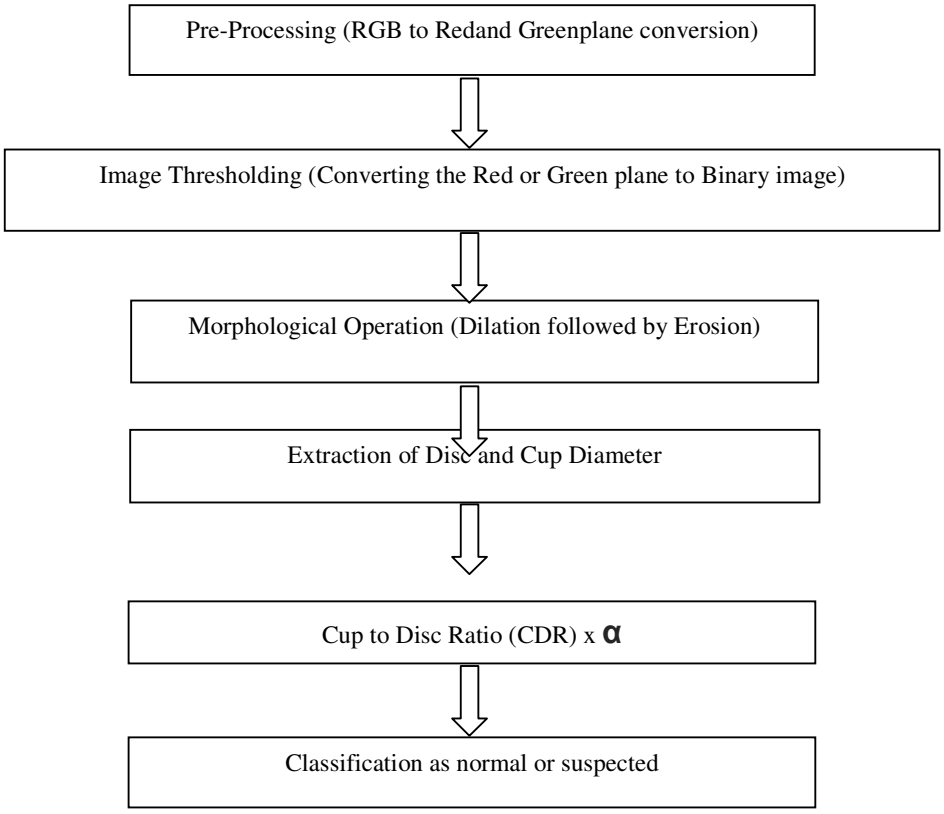

Figure 3: Method for extraction of Cup-to-disc Ratio

Image preprocessing involves the extraction of the Red plane (in case of the optic disc) and the Green plane (in case of optic cup) from the original color retinal fundus image for the extraction of the Disc and the Cup respectively. The Red and Green plane extracted out are then converted into the binary images by thresholding them with a specific level or value of threshold for Disc as well as the Cup.

In the extraction of the Optic Disc, the binary image so obtained has gaps and uneven boundaries in it. To remove these gaps and unsymmetrical boundaries, morphological operations are applied to this binary image. The binary image is applied with the 'CLOSE' operation which smoothes the contour, fuse narrow breaks and long thin gulfs, eliminate small holes, and fill gaps in the contour. It basically involves dilation followed by erosion. Figure 4 shows the results of the morphological operations Erosion, Dilation, Opening and Closing applied to an image (a).

The extraction of cup involves conversion of green plane followed by morphological operations. The morphology is done with the same structuring elements as in case of Disk.

(a) (b) (c) (d) (e)

Figure 4: (a) Original Image, (b) Erosion, (c) Dilation, (d) Opening, (e) Closing

The basic steps of CDR determination method are similar to our work reported earlier [6]. The Cup-to-Disc ratio is denoted as the ratio of the diameter of the cup to that of the disc. The CDR value so obtained is found to be slightly on the higher side. To compensate for that higher value a suitable compensation factor, **α,** is applied. The computed CDRis multiplied with the factor **α**. The value of this factor is taken as 0.98.The subjects are classified as normal or suspected for Glaucoma on the basis of the compensated CDR values. The images with CDR values ranging from 0.3 to 0.5 are classified as the normal ones and those with values greater than 0.5 are screened for Glaucoma or are considered at risk for Glaucoma.

Results

The above mentioned methodology screens the sample images for Glaucoma i.e. whether the subject is normal or suspected. The methodology has been applied on a total of 50 images. The proposed methodology achieved a detection accuracy of 80% and a classification accuracy of 95% by comparing the values obtained from the proposed methodology with the true values provided by the physician as the gold standard for the Disc and Cup diameter. Table 1 given below compares the CDR values obtained from the proposed methodology with the true values.

Table 1: Comparison of True and Measured CDR Values

Sample no.	Disk		Cup		CDR(Measured) = Cup(measured)/ Disk(measured)	CDR(True) = Cup(true)/ Disk(true)	Measured	True
	Measured	True	Measured	True				
1	98	96	40	41	0.40	0.40	Normal	Normal
2	120	123	68	68	0.54	0.55	Glaucomatous	Glaucomatous
3	114	120	55	52	0.49	0.43	Normal	Normal
4	121	119	73	64	0.58	0.54	Glaucomatous	Glaucomatous
5	80	107	66	67	0.78	0.62	Glaucomatous	Glaucomatous
6	120	112	40	45	0.33	0.40	Normal	Normal
7	106	104	50	38	0.46	0.36	Normal	Normal
8	79	108	69	68	0.78	0.63	Glaucomatous	Glaucomatous

9	134	139	98	80	0.71	0.60	Glaucomatous	Glaucomatous
10	103	122	50	55	0.47	0.45	Normal	Normal
11	978	95	39	46	0.40	0.48	Normal	Normal
12	120	121	69	68	0.55	0.56	Glaucomatous	Glaucomatous
13	100	104	-	57	-	0.54	-	Glaucomatous
14	114	120	54	58	0.46	0.48	Normal	Normal
15	80	108	-	59	-	0.54	-	Glaucomatous
16	106	102	50	41	0.46	0.40	Normal	Normal
17	82	107	-	43	-	0.40	-	Normal
18	80	106	66	70	0.78	0.66	Glaucomatous	Glaucomatous
19	130	109	40	44	0.30	0.40	Normal	Normal
20	92	97	-	26	-	0.30	-	Normal
21	101	129	-	50	-	0.38	-	Normal
22	96	107	26	45	0.30	0.42	Normal	Normal
23	93	117	-	30	-	0.30	-	Normal
24	78	110	25	41	0.32	0.37	Normal	Normal
25	74	109	-	43	-	0.39	-	Normal
26	122	121	70	57	0.55	0.47	Glaucomatous	Normal
27	122	144	62	58	0.49	0.40	Normal	Normal
28	120	143	52	63	0.49	0.44	Normal	Normal
29	70	112	62	74	0.78	0.66	Glaucomatous	Glaucomatous
30	82	97	25	36	0.30	0.37	Normal	Normal
31	93	92	26	34	0.30	0.36	Normal	Normal
32	106	95	-	27	-	0.28	-	Normal
33	103	114	43	43	0.39	0.37	Normal	Normal
34	114	92	31	31	0.30	0.34	Normal	Normal
35	134	141	97	88	0.68	0.62	Glaucomatous	Glaucomatous
36	112	132	68	76	0.58	0.57	Glaucomatous	Glaucomatous
37	62	92	31	46	0.51	0.51	Glaucomatous	Glaucomatous
38	105	126	73	59	0.58	0.46	Glaucomatous	Normal
39	100	125	82	85	0.78	0.68	Glaucomatous	Glaucomatous
40	108	107	-	63	-	0.58	-	Normal
41	78	117	53	70	0.58	0.59	Glaucomatous	Glaucomatous

42	97	118	74	89	0.68	0.70	Glaucomatous	Glaucomatous
43	84	114	-	65	-	0.57	-	Glaucomatous
44	96	112	63	64	0.58	0.57	Glaucomatous	Glaucomatous
45	94	115	62	61	0.58	0.53	Glaucomatous	Glaucomatous
46	103	112	53	69	0.51	0.61	Glaucomatous	Glaucomatous
47	114	97	46	41	0.39	0.42	Normal	Normal
48	101	107	52	45	0.49	0.42	Normal	Normal
49	96	107	44	51	0.44	0.47	Normal	Normal
50	97	111	38	50	0.38	0.45	Normal	Normal

The CDR values observed from the proposed methodology were on a slightly higher side. To compensate for these higher values, compensation factors of 0.98 and 0.97 are used and their results are then compared, shown in Table 2 and Table 3.

Table 2: Comparison of Compensated CDR values with **α=** 0.98

S. no.	CDR (True)	CDR (Measured)	CDR (Compensated) = CDR (Measured)*0.98	Uncompensated Error= CDR (True – Measured)	Compensated Error= CDR (True-Compensated)	Uncompensated Error Square	Compensated Error Square
1	0.427	0.408	0.4	0.019	0.027	0.000361	0.000729
2	0.553	0.567	0.555	-0.014	-0.002	0.000196	4E-06
3	0.433	0.482	0.473	-0.049	-0.04	0.002401	0.0016
4	0.538	0.603	0.591	-0.065	-0.053	0.004225	0.002809
5	0.626	0.825	0.809	-0.199	-0.183	0.039601	0.033489
6	0.402	0.333	0.327	0.069	0.075	0.004761	0.005625
7	0.365	0.472	0.462	-0.107	-0.097	0.011449	0.009409
8	0.63	0.873	0.856	-0.243	-0.226	0.059049	0.051076
9	0.576	0.731	0.717	-0.155	-0.141	0.024025	0.019881
10	0.451	0.485	0.476	-0.034	-0.025	0.001156	0.000625
11	0.484	0.398	0.39	0.086	0.094	0.007396	0.008836
12	0.562	0.575	0.564	-0.013	-0.002	0.000169	4E-06
14	0.483	0.474	0.464	0.009	0.019	8.1E-05	0.000361
16	0.402	0.472	0.462	-0.07	-0.06	0.0049	0.0036
18	0.66	0.825	0.809	-0.165	-0.149	0.027225	0.022201
19	0.404	0.308	0.302	0.096	0.102	0.009216	0.010404
22	0.421	0.271	0.265	0.15	0.156	0.0225	0.024336
24	0.373	0.321	0.314	0.052	0.059	0.002704	0.003481
26	0.471	0.574	0.562	-0.103	-0.091	0.010609	0.008281
27	0.403	0.508	0.498	-0.105	-0.095	0.011025	0.009025
28	0.441	0.433	0.425	0.008	0.016	6.4E-05	0.000256
29	0.661	0.886	0.868	-0.225	-0.207	0.050625	0.042849
30	0.371	0.305	0.299	0.066	0.072	0.004356	0.005184
31	0.37	0.28	0.274	0.09	0.096	0.0081	0.009216
33	0.377	0.417	0.409	-0.04	-0.032	0.0016	0.001024
34	0.337	0.272	0.266	0.065	0.071	0.004225	0.005041

35	0.624	0.724	0.709	-0.1	-0.085	0.01	0.007225
36	0.576	0.607	0.595	-0.031	-0.019	0.000961	0.000361
37	0.5	0.5	0.49	0	0.01	0	0.0001
38	0.468	0.695	0.681	-0.227	-0.213	0.051529	0.045369
39	0.68	0.82	0.804	-0.14	-0.124	0.0196	0.015376
41	0.598	0.679	0.666	-0.081	-0.068	0.006561	0.004624
42	0.754	0.763	0.748	-0.009	0.006	8.1E-05	3.6E-05
44	0.571	0.656	0.643	-0.085	-0.072	0.007225	0.005184
45	0.53	0.66	0.646	-0.13	-0.116	0.0169	0.013456
46	0.616	0.515	0.504	0.101	0.112	0.010201	0.012544
47	0.423	0.404	0.395	0.019	0.028	0.000361	0.000784
48	0.421	0.515	0.505	-0.094	-0.084	0.008836	0.007056
49	0.477	0.458	0.449	0.019	0.028	0.000361	0.000784
50	0.45	0.392	0.384	0.058	0.066	0.003364	0.004356
Mean Square Error						0.0112	0.0099

The Mean Square Error of the Uncompensated Cup-to-Disk Ratio is 0.0112, while this error for Cup-to-Disk Ratio compensated by factor of 0.98 is 0.0099. We see a reduction in 13% of mean square error. Moreover there is no change in the diagnostic accuracy.

Table 3: Comparison of Compensated CDR values with **α=** 0.97

S. no.	CDR (True)	CDR (Measured)	CDR (Compensated) = CDR (Measured)*0.97	Uncompensated Error= CDR (True – Measured)	Compensated Error= CDR (True-Compensated)	Uncompensated Error Square	Compensated Error Square
1	0.427	0.408	0.396	0.019	0.031	0.000	0.001
2	0.553	0.567	0.55	-0.014	0.003	0.000	0.000
3	0.433	0.482	0.468	-0.049	-0.035	0.002	0.001
4	0.538	0.603	0.585	-0.065	-0.047	0.004	0.002
5	0.626	0.825	0.8	-0.199	-0.174	0.040	0.030
6	0.402	0.333	0.323	0.069	0.079	0.005	0.006
7	0.365	0.472	0.458	-0.107	-0.093	0.011	0.009
8	0.63	0.873	0.847	-0.243	-0.217	0.059	0.047
9	0.576	0.731	0.709	-0.155	-0.133	0.024	0.018
10	0.451	0.485	0.47	-0.034	-0.019	0.001	0.000
11	0.484	0.398	0.386	0.086	0.098	0.007	0.010
12	0.562	0.575	0.558	-0.013	0.004	0.000	0.000
14	0.483	0.474	0.46	0.009	0.023	0.000	0.001
16	0.402	0.472	0.458	-0.07	-0.056	0.005	0.003
18	0.66	0.825	0.8	-0.165	-0.14	0.027	0.020
19	0.404	0.308	0.299	0.096	0.105	0.009	0.011
22	0.421	0.271	0.263	0.15	0.158	0.023	0.025
24	0.373	0.321	0.311	0.052	0.062	0.003	0.004
26	0.471	0.574	0.557	-0.103	-0.086	0.011	0.007
27	0.403	0.508	0.493	-0.105	-0.09	0.011	0.008
28	0.441	0.433	0.42	0.008	0.021	0.000	0.000
29	0.661	0.886	0.859	-0.225	-0.198	0.051	0.039
30	0.371	0.305	0.296	0.066	0.075	0.004	0.006
31	0.37	0.28	0.272	0.09	0.098	0.008	0.010
33	0.377	0.417	0.404	-0.04	-0.027	0.002	0.001
34	0.337	0.272	0.264	0.065	0.073	0.004	0.005
35	0.624	0.724	0.702	-0.1	-0.078	0.010	0.006
36	0.576	0.607	0.589	-0.031	-0.013	0.001	0.000
37	0.5	0.5	0.485	0	0.015	0.000	0.000
38	0.468	0.695	0.674	-0.227	-0.206	0.052	0.042

39	0.68	0.82	0.795	-0.14	-0.115	0.020	0.013
41	0.598	0.679	0.659	-0.081	-0.061	0.007	0.004
42	0.754	0.763	0.74	-0.009	0.014	0.000	0.000
44	0.571	0.656	0.636	-0.085	-0.065	0.007	0.004
45	0.53	0.66	0.64	-0.13	-0.11	0.017	0.012
46	0.616	0.515	0.5	0.101	0.116	0.010	0.013
47	0.423	0.404	0.392	0.019	0.031	0.000	0.001
48	0.421	0.515	0.5	-0.094	-0.079	0.009	0.006
49	0.477	0.458	0.444	0.019	0.033	0.000	0.001
50	0.45	0.392	0.38	0.058	0.07	0.003	0.005
Mean Square Error						0.0112	0.0093

The Mean Square Error for the Uncompensated Cup-to-Disk Ratio is 0.0112, while this error is 0.0093 for the CDR compensated by factor of 0.97. Here, we see a reduction in 20% of mean square error. However this increases the False Negative in diagnosis and hence is not recommended.
The Figure 5 and Figure 6 show the comparison of true and measured CDR values.

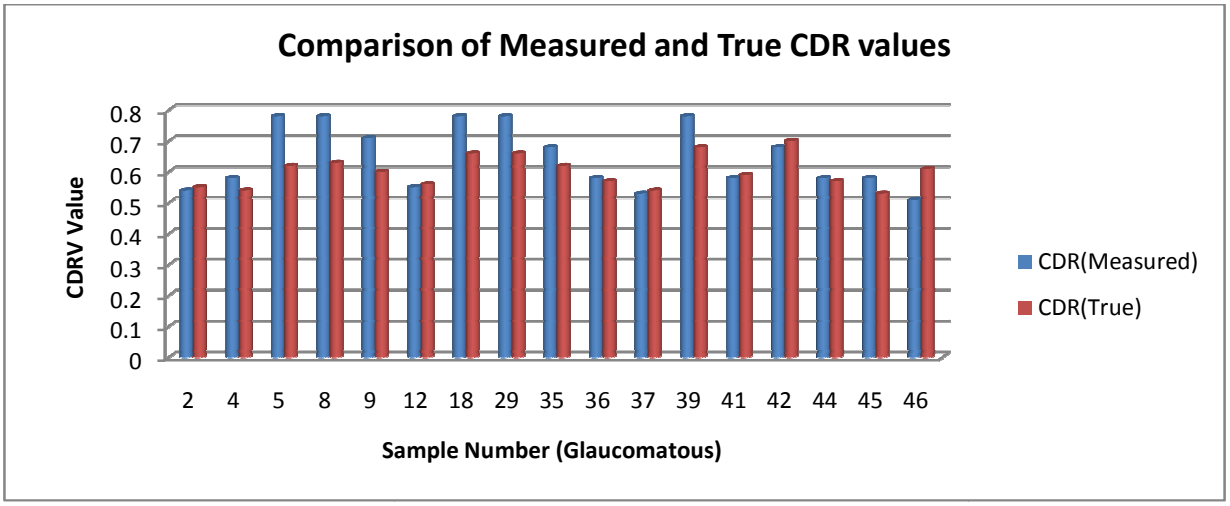

Figure 5: Comparison of true and measured CDR values (Glaucomatous)

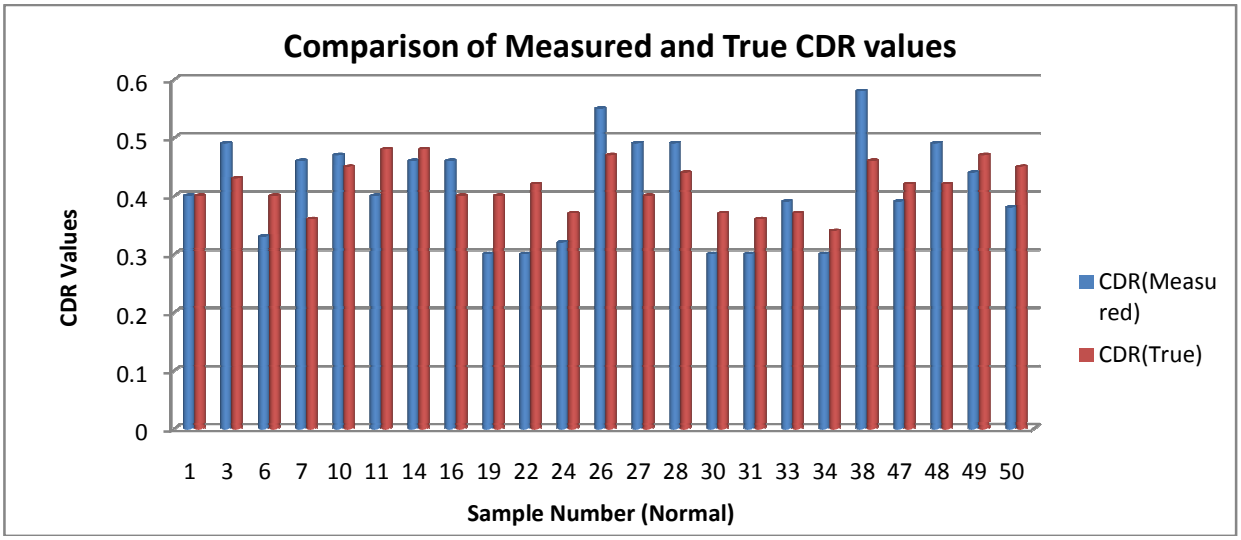

Figure 6: Comparison of true and measured CDR values (Normal)

Conclusion

This paper presents a simple methodology for the screening of Glaucoma. The methodology uses the Morphological operations for the extraction of the Optic Disc and the Cup and ultimately the Cup-to-Disc Ratio. A suitable compensation factor is applied to the measured CDR values for normalizing it. The compensation factor applied is 0.98. The compensated results have also been calculated with compensation factor 0.97. It was observed that with 0.98 the Mean Square Error reduced by 13%. This error was reduced by 20 % when compensation is done by 0.97. However, by using 0.97 there is an increase in the False Negative. Hence, 0.98 is the recommended compensation factor. The results of the classification are given in Table 4 signifying the total samples, correctly classified, incorrectly classified and not classified samples.

Table 4: Results of Classification

Subject	Actual Samples	Correctly Classified Samples	Not Classified	Incorrectly Classified Samples
Normal	30	21	7	2
Glaucomatous	20	17	3	0

As depicted by the confusion matrix, the system achieved a sensitivity and specificity of 100% and 91%. The system acquired an accuracy of 95% with a precision value of 89%. This method achieves Cup-to-disk ratio detection rate of 80% and classification accuracy of 95% of the detected Cup-to-Disk Ratios. In the Confusion Matrix, Figure 8, TP (true positive) depicts the number of samples correctly classified as Glaucomatous. TN (true negative) signifies the number of samples correctly classified as normal samples. FN (false negative) and FP (false positive) signifies the number of samples incorrectly classified as normal and Glaucomatous respectively. The confusion matrix plotted for the proposed methodology is shown in Figure 9. The precision value indicates as in how best the algorithm can detect the Glaucomatous and normal cases. Table 5 and Table 6 show the predictive values and the total test outcomes including Accuracy, Sensitivity and Specificity respectively.

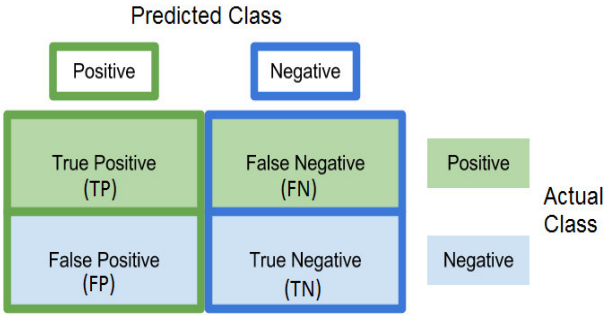

Figure 8: Confusion Matrix

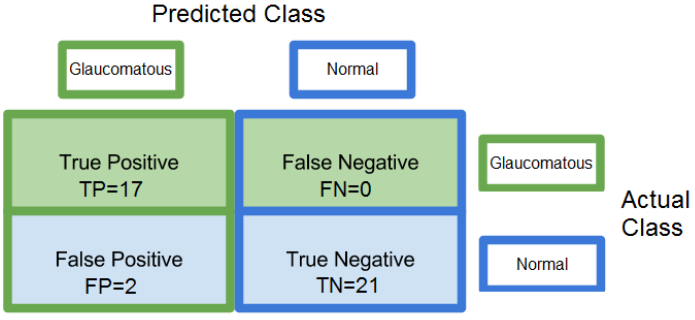

Figure 9: Confusion matrix with proposed methodology's predictive values

Table 5: Predictive values for the system

TP	FP	TN	FN
17	2	21	0

Table 6: Test Outcomes

Parameter	Expression	Value
Accuracy	(TP+TN)/(P+N)	95%
Sensitivity	TP/(TP+FN)	100%
Specificity	TN/(TN+FP)	91%
Precision or Positive Predictive Value (PPV)	TP/(TP+FP)	0.89
Negative Predictive Value(NPV)	TN/(TN+FN)	1
False Positive Rate(FPR)	FP/(FP+TN)	0.086
False Discovery Rate(FDR)	FP/(FP+TP)	0.10
False Negative Rate(FNR)	FN/(FN+TP)	0
F1 Score	2TP/(2TP+FP+FN)	0.94

The mean and standard deviation values of the CDR value are shown in Table 7. It can be seen from the table that the CDR value is higher for Glaucomatous cases as compared to the normal ones. The Student's t-test has been conducted on both the glaucomatous and normal groups and the *P* value came out to be lesser than 0.0001 which indicated that the two groups are extremely statistically significant with 95% confidence interval from -0.3077 to -0.1923.

Table 7: Mean and Standard Deviation values of CDR with *P* value

Feature Name	Normal Mean	Normal Standard Deviation	Glaucomatous Mean	Glaucomatous Standard Deviation	*P* Value
Cup-to-Disk Ratio	0.40	0.08	0.65	0.10	<0.0001

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