Assessment of the ISNT rule on publicly available datasets.

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Abstract. The ISNT rule is a technique that has been used to detect glaucoma from fundus images. The rule states that for a healthy fundus image, the segmented optic disc can be divided into four neuro-retina rim quadrants namely; the Inferior, Superior, Nasal and Temporal neuro-retina rims. The Inferior is the widest followed by the Superior then the Nasal. The Temporal quadrant is the least. However, since the advent of the rule there have been several experiments that prove the inefficiency of the rule to diagnose glaucoma while other experiments argue that the rule is efficient. Experiments carried out by individuals were done using dataset sourced by the individuals not on publicly available fundus datasets. This makes the experiments not easily reproducible. This work assesses the ISNT rule using the RIM-ONE v3 dataset and the DRISHTI-GS dataset which are both publicly available datasets. The performance of the ISNT rule on the datasets is compared with the performance of a trained Extreme Gradient Boost classifier (XGB). The results show that the XGB classifier outperforms the ISNT rule and its' variant. The ISNT rule demonstrated a random performance on the databases used.

Keywords: Retinal Fundus Image, Glaucoma, Blood Vessel Segmentation, ISNT, Image Segmentation.

1 Introduction

Glaucoma is an ocular diseases characterized by progressive degeneration of the optic disc and the retinal ganglion cells [1, 2]. It is a leading cause of blindness and usually comes with no obvious symptom at its early stages. Diagnosis of glaucoma is usually carried out by evaluating structural changes in the optic disc [3, 4]. The ISNT rule was first proposed by Jonas et al. in the year 1988 and has since been used for the diagnosis of glaucoma [5, 6]. The ISNT rule states that for a healthy fundus image, the segmented optic disc can be divided into four neuro-retina rim quadrants namely; the Inferior (I), Superior (S), Nasal (N) and Temporal (T) neuro- retina rims. The Inferior is the widest followed by the Superior then the Nasal and the Temporal quadrant being the least i.e I > S > N > T [5-9].

Several studies in research have been carried out to verify the ability of the ISNT rule to effectively detect glaucoma [10-13]. From the conducted studies it cannot be established that the ISNT rule can effectively detect glaucoma. Authors like Harizman et al. [10] and Chan et al. [14] concluded that the ISNT rule is effective in detecting glaucoma while Morgan et al. [12], Pogrebniak et al. [13] and Qui et al. [2] concluded that the ISNT rule has limited potential in detecting glaucoma. Sihota et al. [11] was inconclusive about the use of ISNT rule to detect glaucoma. Furthermore, most of the studies were conducted on privately sourced dataset and fundus images. This makes the results not reproducible and as a result, cannot be easily verified.

This work uses publicly available fundus images to assess the ISNT rule. This makes the work reproducible and the results verifiable. This work uses the RIM-ONE v3 and the DRISHTI-GS database to assess the extent to which ISNT rule can be used to detect glaucoma. Moreover, a classifier is trained using the extracted I, S, N and T values and its performance in detecting glaucoma is tested on both databases. This is done using the cross validation method. Finally, the performance of the ISNT rule is then compared with that of the classifier.

The contributions made by this work include an assessment of the ISNT rule on two publicly available dataset and an alternative use of the I, S, N, and T values is proposed.

The rest of this paper is organized as follows: section II discusses the related work, section III discusses the proposed approach of the experiment, section IV presents the results of the experiment and section V discusses the limitations of the study. Section VI presents the conclusion and the last section explains the future work.

2 Related Work

The analysis of the neuro-retina rim in optic discs has been a subject of great interest. The Inferior (I), Superior (S), Nasal (N) and Temporal (T) features are obtained from such analysis. The ISNT rule as already stated explains that these features follow a known pattern in healthy optic discs and has been reported to detect glaucoma in some cases.

Hariz et al. [11] tested the ISNT rule on 66 non-glaucomatous eyes and 43 open-angle glaucoma. Their objective was to determine whether the ISNT rule can differentiate non- glaucomatous eyes from glaucomatous eyes. This was done by subjecting all subjects to rigorous eye examination. The examination included perimetry, laser ophthalmoscopy and disc photography. After the examination, an eye was randomly selected from each subject (i.e the selected eye could be the left or right eye). The ISNT rule was then assessed after extracting the ISNT features from the optic disc photographs. They found out that the ISNT rule was consistent in 52 of the 66 non-glaucomatous eyes and 12 of 43 glaucomatous eyes. They concluded that the ISNT rule can be used to differentiate non-glaucomatous eyes from glaucomatous eyes and is not affected by differences in race.

Sihota et al. [11] evaluated the effectiveness of the ISNT rule in discriminating between non-glaucomatous eyes and early glaucoma. In the experiment, 136 subjects with non-glaucomatous eyes and 63 subjects with primary open-angle glaucoma were subjected to Heilderberg Retina Tomograph (HRT) and achromatic automated perimetry. It was discovered that the ISNT rule was applicable in 71% of the subjects with non-glaucomatous eyes and 68% of the early glaucoma subjects. However, in their report, Sihota et al. were not conclusive about the effectiveness of the use of ISNT rule in differentiating non-glaucomatous eyes from early glaucoma.

Morgan et al. [12] determined how good an optic disc can be classified as glaucomatous or non-glaucomatous using the ISNT rule. A total of 129 subjects were used in the experiment: 78 subjects with open-angle glaucoma and 51 with closed-angle glaucoma. The initial classification categorized as non-glaucomatous or glaucomatous eyes was done by two experts based on the shape of the optic disc and the subjects' visual field. The ISNT rule was broken down into three separate Boolean comparisons which are I>S, S>N, N>T. The result was published based on the positive likelihood that the ISNT rule was observed by the 129 subjects. The evaluation was carried out by three expert observers and their positive likelihood ratio was reported as 1.11 (at 95% Confidence Interval (CI)), 1.07 (at 95% CI) and 1.06 (at 95% CI) respectively. Morgan et al. concluded that the ISNT rule is not a very good technique for detecting open –angle glaucoma.

Pogrebniak et al. [13] carried out an experiment to find out if non-glaucomatous optic disc does not follow the ISNT rule in children. The experiment was done on a total of 131 children. This was done by obtaining fundus images of children with large non- glaucomatous optic disc. The width of the neuro-retinal rims was then extracted for further analysis. The results showed that only 16% of non-glaucomatous non-premature children followed the ISNT rule and 21% of non-glaucomatous eyes but with a history of prematurity. The results also showed that 73% of children with normal optic disc followed the ISNT rule. Their experiment concluded that ISNT rule is more applicable in children with normal optic disc and also that the inherent shape of the optic disc greatly affects the applicability of the ISNT rule.

Chan et al. [14] evaluated the accuracy of the ISNT rule and some of its variant using subjects that are Asian adults. The subjects went through standard eye examinations and glaucoma subjects were defined using the International Society Geographical & Epidemiological Ophthalmology (ISGEO) standards. The extensive experiment was carried out using 6,112 subjects and 11,840 eyes were used. There were 249 eyes with glaucoma and 11, 591 eyes without glaucoma. The results showed that 232 (93.2%) out of 249 eyes with glaucoma violated the ISNT rule as expected but only 1,823 (15.7%) out of 11,591 eyes followed the ISNT rule. Chan et al. concluded that the ISNT rule may be useful when combined with other techniques such as the HRT algorithms for glaucoma detection.

Qiu et al. [2] evaluated the performance of the ISNT rule on the Retinal Nerve Fiber Layer (RNFL) thickness and further assessed the ISNT rule on 138 non-glaucomatous but myopic eyes (myopia is an eye condition that causes light rays to be focused in front of the retina thereby making the subject to see near objects clearly but far objects are not clearly seen). The results showed that 88.4% and 37% of the eyes did not follow the ISNT rule on the RNFL thickness and the rim area respectively. Qiu et al. concluded that ISNT rule and its variants are not very good options in differentiating glaucoma from non-glaucomatous eyes especially in myopic eyes.

It should be noted that all the research-work discussed were carried out on privately sourced subjects and datasets and each research-work has its own peculiar result even though the same ISNT rule was being evaluated.

3 Proposed Experimental Approach.

RIMONE v3 [15, 16] and DRISHTI-GS [17, 18] databases are used for this experiment. The two databases are used because they both have the optic discs and the optic cups segmentation provided as ground-truth and thus eliminating any error that can arise as a result of improper segmentation. The segmentations provided in the databases (shown in Fig.1 and Fig.2) were carried out by trained experts. Furthermore, the segmented optic discs and optic cups are properly labelled. The RIMONE v3 dataset is labelled as 'glaucoma', 'suspect' and 'normal'. DRISHTI-GS dataset contains only 'glaucoma' labelled segmentations.

The ground-truths (these are segmented optic discs and segmented optic cups) and the dataset labels are extracted from the database. The segmented optic discs and cups are then masked along their sectors to obtain the Inferior, Superior, Nasal and Temporal quadrants as shown in Fig. 3. This is done using the ogrid library of the numpy package. The masking is done along the 3, 6, 9 and 12 o'clock positions. The I, S, N and T values are then extracted from the prior created quadrants. Some of the values extracted are shown in Table 1. The extracted values are then re-arranged based on the eye to which the segmented optic disc belongs to (The segmented optic disc belongs to either the left eye or the right eye). This is done because the Nasal and Temporal quadrants differ according to which eye it is. This is shown in Fig. 3.

Subsequently, the analysis of the I, S, N and T values is performed. This step assesses the ISNT rule. An Extreme Gradient Boost (XGB) classifier is then trained with the I, S, N and T values and its performance in discriminating between glaucoma and non-glaucoma is obtained.

The proposed approach is further described by the following algorithm.

Step 1: Extraction of ground-truth segmentation and labels

Step 2: Masking of optic cup and optic disc segmentations to obtain the ISNT quadrants.

Step 3: Obtaining the I, S, N and T values for each pair of optic disc and optic cup

Step 4: Analysing the obtained values to check for consistency with the ISNT rule

Step 5: Training an XGB classifier with the ISNT values and using 5- fold cross validation method to test the accuracy in discriminating between glaucoma and non-glaucoma.

4 Experiment Results and Analysis

The ISNT rule is tested on the RIM-ONE v3 database and the DRISHTI-GS database. The RIM-ONE v3 database has 158 segmented optic discs and cups, in which 39 of them are labelled as ‘glaucoma’, 84 are labelled ‘normal’ and 35 are labelled as ‘glaucoma-suspect’. The DRISHTI-GS has 50 segmented optic discs and cups. All segmented optic discs and cups in DRISHTI-GS database are labelled ‘glaucoma’. In our analysis, we focus only on ‘glaucoma’ and ‘normal’ labelled segmented optic discs and cups. We leave out the optic discs and cups that are labelled as ‘suspect’. This is done so as to have a clearer estimation of the ISNT rule’s performance because an item labelled ‘suspect’ could either be normal or glaucomatous. The experiment was carried out using Kaggle’s 2 CPU cores, 14 GB RAM.

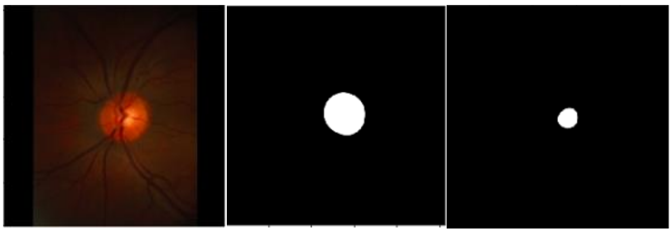
It is expected that all segmented optic discs labelled ‘normal’ should follow both the ISNT rule and its variant. Also, it is expected that none of the optic discs labelled ‘glaucoma’ should follow neither the ISNT rule nor its variant.

In the RIM-ONE v3 dataset, five out of 84 segmented optic discs labelled ‘normal’ follow the ISNT rule and 26 follow a variant of the ISNT rule (i.e. $I \geq S \geq N$). The ISNT rule variant does not include the Temporal (T) values in its computation.

Also in the dataset, two out of 39 segmented optic discs labelled ‘glaucoma’ follow the ISNT rule and six follow the ISNT variant (i.e. $I \geq S \geq N$).

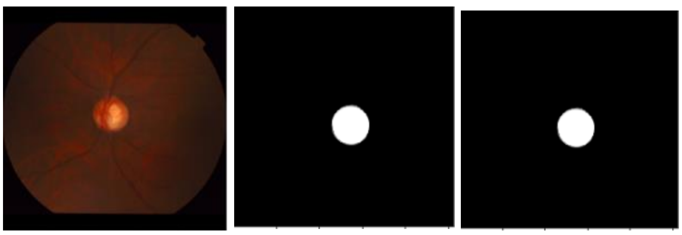
In the DRISHTI-GI dataset, three out of 50 segmented optic discs follow the ISNT rule and eleven follow the ISNT variant (i.e. $I \geq S \geq N$). It should be noted that DRISHTI-GS dataset contains only ‘glaucoma’ labelled segmented optic discs.

Table 2 shows the outcome of the ISNT rule for both the RIM-ONE v3 and the DRISHTI-GI databases.



(a) (b) (c)

Fig. 1. (a) Fundus image showing the optic disc and cup RIMONE v3 (b) Optic disc segmentation of a Left eye from RIMONE v3 (c) Optic cup segmentation of a Left eye from RIMONE v3



(a) (b) (c)

Fig. 2. (a) Fundus image showing the optic disc and cup from DRISHTI-GS database (b) Optic disc segmentation from DRISHTI-GS database(c) Optic cup segmentation from DRISHTI-GS database

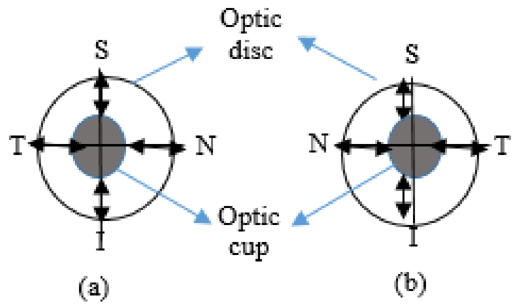


Fig. 3. (a) ISNT evaluation for a right eye (b) ISNT evaluation for a left eye.

Table 1. I, S, N and T values extracted from their quadrants for the RIM-ONE V3 and DRISHTI-GS databases

Database	Serial number in database	I	S	N	T	Label('glaucoma or 'normal')
RIM-ONE v3	1	30	26	30	32	normal
	2	38	16	32	24	normal
	3	27	26	16	34	normal
	4	24	25	35	17	normal
	1	17	17	26	12	glaucoma
	2	6	5	7	12	glaucoma
DRISHTI-GS	1	5	14	11	9	glaucoma
	2	5	8	8	3	glaucoma
	3	12	17	10	13	glaucoma
	4	2	7	7	5	glaucoma
	5	6	6	6	4	glaucoma

Table 1 shows some I, S, N and T values from both the RIM-ONE v3 database and the DRISHTI-GS database. The table also includes the serial number and label of the optic disc and cup as it is in the databases. In table 1, it can be seen that none of the fundus image labelled normal follows the ISNT rule and so are the images labelled 'glaucoma'. However, it can be seen that fundus images labelled 'normal' have higher I, S, N and T values than the 'glaucoma' labelled images.

Table 2. ISNT rule performance on the RIM-ONE V3 and DRISHTI-GS databases

	RIM-ONE v3		DRISHTI-GS
	Percentage of non-glaucomatous optic discs that follow the rule (%)	Percentage of glaucomatous optic discs that follow the rule (%)	Percentage of glaucomatous optic discs that follow the rule (%)
ISNT rule (I ≥S≥N≥T).	5.95	5.13	6
ISNT variant rule (I ≥S≥N).	30.95	15.38	22

Table 2 shows the percentages of RIM-ONE v3 and DRISHTI-GS datasets that follow the ISNT rule. The table shows a very little conformity to the ISNT rule especially by the RIM-ONE v3 dataset. Only about 6 % follow the ISNT rule and 31% follow the ISNT variant. It can also be seen that about 5 % of the 'glaucoma' labelled optic discs and cups in both databases follow the ISNT rule.

For an optimum performance, it is expected that all the 'normal' labelled optic disc should follow the ISNT rule (and its' variant) and none of the 'glaucoma' labelled optic discs should follow the rule. Hence, we should expect close to 100% conformity (not 5.95 and 30.95) from the 'normal' labelled optic discs and about 0% conformity (not 5.13, 15.98, 6 and 22) from the 'glaucoma' labelled optic discs.

We further trained an Extreme Gradient Boost classifier (XGB) using the I, S, N and T values. An XGB classifier was used because of its flexibility and proven performance in regression and classification tasks [19]. The XGB classifier was first tested only on the RIM-ONE v3 dataset using five cross validation. It was then tested on both the RIM-ONE v3 and DRISHTI-GS datasets combined. The obtained results are shown in Table 3. The metrics used for testing are precision, recall, ROC-AUC and accuracy.

Table 3. XGB classifier performance on both the the RIM-ONE V3 and DRISHTI-GS databases

	RIM-ONE v3	RIM-ONE V3 + DRISHTI-GS
Precision	0.74	0.87
Recall	0.81	0.88
ROC-AUC	0.83	0.90
Accuracy	0.81	0.87

Table 3 shows that the classifier does better in classifying segmented optic discs into glaucoma and normal. The performance of the classifier becomes optimum when more data from the DRISHTI-GS dataset is added. This is expected as a classifier performs better when trained with more instances. In order to make a comparison between the performance of the ISNT rule and the XGB classifier, we represent the performance of the ISNT rule using the same metrics used for the XGB classifier. This is shown in Table 4.

Table 4. Comparison between ISNT rule and XGB classifier

	ISNT rule (I ≥S≥N≥T)	ISNT variant rule (I ≥S≥N).	XGB classifier
Precision	0.50	0.60	**0.87**
Recall	0.06	0.31	**0.88**
Accuracy	0.51	0.57	**0.87**

Table IV shows that the performance of the ISNT rule and its variant is erratic and close to random. Although the ISNT variant performs better, the XGB classifier however, has the best performance. The ISNT rule may not have a good performance on the databases used in this experiment, however the I, S, N and T values have proven to be of great relevance especially when they are used to train a classifier.

5 Limitation of Study

The study is carried out using the ground-truths available in the databases chosen. Hence, the study assumes the provided ground-truths are very accurate segmentations of the optic discs and cups. Furthermore, 'normal' labelled optic discs and cups may be affected by other ocular diseases other than glaucoma. The effect of which is not quantified in this study.

6 Conclusion

The ISNT rule and its variant are not able to discriminate excellently between normal segmented optic discs and glaucoma segmented optic disc using the RIM-ONE v3 and the DRISHTI-GI databases. The ISNT rule could be useful in detecting deep glaucoma as reflected in the result from the DRISHTI-GS but may not be used for detecting early and moderate glaucoma. Though the ISNT rule may not prove very useful in discriminating normal from glaucoma optic discs, the I, S, N and T values are very useful and should be used to train a classifier. The XGB classifier out-performed both the ISNT rule and its variant.

7 Future Work

The study will be carried out using more publicly available databases. This will give a wider overview of the ISNT rule's performance. Also, a study that compares the performance of ISNT rule with other methods of glaucoma detection will be conducted.

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