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Comparison of Experts and Non-Experts Gaze Pattern for the Target as Optic Disc in the Fundus Retinal Images

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Abstract

The proposed paper presents a significant study done in the field of the medical domain to identify the differences in eye gaze patterns between two groups, the first group is expert optometrists and the second group is non-experts. Eye gaze data is collected through commercial eye tracker during the task of detecting the optic disc in given fundus retinal images. The eye fixations were calculated using dispersion threshold identification (I-DT) algorithm. The heat maps were used for visualization. The set of eye movement features, a number of fixations, duration of fixation in ROI, the number of dwells in ROI, dwell time in the ROI, the number of fixations in the region of interest (ROI) and the energy concentration ratio was estimated to prove the statistically significant difference between the eye gaze patterns.

Keywords: Eye gaze pattern, ROI, Heat map, Fixations

INTRODUCTION

Eye tracking as a research tool becomes popular amongst researchers from different disciplines such as neurophysiologists, cognitive psychologists, electrical engineers, reading researcher, marketing analysts, psycholinguists, and others. Where an individual is looking at is assumed to indicate the thought "on top of the stack" of cognitive processes [1]. This "eye-mind" hypothesis is that an eye-movement recording provides information about where the individual's attention is being directed to the visual display. Eye tracking plays an important role in the visual search task. For example, searching images for retinal structural features and the other abnormal lesion is a common task for optometrists. To find out abnormal lesion, it is necessary to hide normal anatomy (for example optic disc). The procedure of looking for something, whether a pencil or abnormalities, will admit a deliberate process of selecting one location after another for analysis until the object of the lookup is found or the searcher decides the target is not present. Nonetheless, expert optometrists will often describe the sense experience of "knowing" that a particular image contains a known target or region before they are able to find it. The premise is that there is information on the first look at the image and that the "gestalt" impression is a utilitarian function of the expert search process. Where persons are looking and how their eyes are shifted can be estimated using eye tracking. Person's eye movements can help to understand eye gaze pattern of two groups. Applying eye-tracking systems scientists can detect eye movements and study human cognitive processing of visual information for interactive and diagnostic applications [2]. One example is a detection of the optic disc in fundus retinal images. The OD is considered as one of the main features of a retinal image, there are different methods are described in the literature [3], [4], [5] for its automatic detection.

We bring out the difference in gaze pattern of expert optometrists and non-experts group. The eye tracker device is needed to record the eye movement data for analyzing the eye gaze pattern of the expert optometrists and non-experts–whose gaze is attracted by target i.e. optic disc while screening fundus retinal images. The analysis of eye gaze data can be used to discriminate between expert optometrists and with non-experts group. Oculomotor features like (the number of fixations, fixation durations etc. in the region of interest) were estimated from eye gaze data. In order to approximate expert optometrists and non-experts group eye gaze, we have used visual analytics like a heat map. This map is generated by integrating fixations of both groups. The research work proposed having a hypothesis that there exist significant differences in the way optometrists look for the optic disc and that these differences can be objectively measured and tested in Matlab environment. To evaluate the statistical meaning of the results we legitimize our experiment using one-way ANOVA using the SPSS software package (ver. 23.0).

REALTED WORK

A literature survey on the use of eye tracking in the medical domain was carried out. M. Stella Atkins and Adrian Moise

[6] in 2006, designing look-alike radiology workstations for radiology task with artificial stimuli using eye gaze tracking data. In this task, a comparative visual search is carried out for two images placed side by side. For this, two interaction techniques are used. Eye gaze data of four radiologists were recorded while performing the task. Fixation duration on left and right images, on the artificial targets, and on the controls were measured. Here fixations on the left-side images found longer than the right-side images, the left image is used as a reference image by the subjects. There are multiple saccades between left and right side images found. This paper shows that computer interaction techniques and search strategies can be analyzed by using eye gaze data.

Jorge Bernal [7], compares eye gaze pattern of experts and novices. A study conducted to identify visual search pattern differences between physicians of different level of experience. Eye gaze data recorded during the screening of colonoscopy videos for the task of polyp search. Fixations were represented in the form of the heat map. Reaction time, dwelling time and energy concentration ratio were used for comparison. Experimental results demonstrate a significant conflict between two groups. Benjamin Law [8], conducted a study of the surgeon's eye movements. Using eye movements of surgeon his skills can be assessed. The eye movements of 5 experts and 5 novices were collected and compared, for this study. The study is conducted on the task of computer-based laparoscopic surgery simulator. The outcome suggests that experts were more flying and pulled in fewer errors than novices. To complete the task, novices required more visual feedback. While manipulating tool experts manage to gaze on target than novices. Rana S. A. Khan [9], conducted an experiment to study eye gaze pattern of the novice and expert surgeons while watching surgical videos. The gaze of expert surgeons and junior residents were analyzed. The eye gaze data of expert surgeons were recorded when they were performing laparoscopic procedures in the operating room and when watching the operative video. The eye-gaze similarity in self-watching and other watching were calculated from the level of gaze overlay. There was 55% overlap and 43.8% overlap of the gaze reported. There is a notable difference reported between novice and expert surgeons. Hideyuki Matsumoto [10], uses eye gaze to find where neurologists look when viewing brain CT images. Their gaze distribution is compared with the saliency map. Eye gaze data is collected from twelve neurologists and twelve controls. The comparison is carried out on the bases of fixations, dwell time in the ROI. In this paper, we have studied eye gaze pattern of two groups in the target search. The experimental method is described in section 3. The result of the statistical analysis is discussed in section 4 followed by conclusion and discussion in section 5.

THE PRESENT EXPERIMENT

A. Participants

In this study participants are split into two groups. One group is of experts and another one is non-experts. There were 4 expert optometrists (Mean age 29.5) and 10 non-experts (Students with Mean age Mean age 25.75). All Participants had normal or corrected to normal vision. For the expert participants, the eye gaze data is collected at their workplace. For non-experts, the eye gaze data is collected in the university campus. Participants were tested individually. All participants have given their informed consent to participate in the experiment.

B. Experimental setup

The experimental setup is as shown in figure 1.

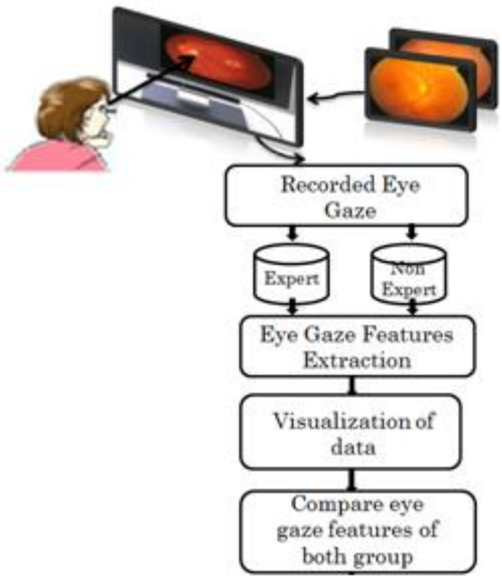

Figure 1. The flow diagram for the comparison of eye gaze patterns of expert and non-expert groups for optic disc detection

The experiment was run on a Dell laptop computer, with screen size 1366 X 768 which was used to display retinal images to participants, as well to collect eye tracking data from participants. The SMI iViewX RED-m (60 Hz) [11] eye tracker is fixed as shown in figure 1, participants faced the center of the screen at a viewing distance of 60 to 66 cm approximately. They are instructed to restrict their head movement. All participants were explained initially that a set of 25 retinal images has to be viewed one by one. They need to find the optic disc (i.e. Target) in each image. The SMI iViewX system was calibrated prior to each recording session using 5 point grid covering the area in which images were presented. The images were displayed for 7 Sec and in sequence. For a non-experts group of participants, a demo is given for information on OD. The main task of the participants is to remain still and look at the monitor. The steps conducted during the experiment are (a) Eye tracking: Here, the participants were instructed to look around the stimulus monitor and their eyes will be traced using SMI iViewX RED-m eye tracker. When a user is sitting in an optimal position in front of the RED-m Eye Tracking Device, the Eye Tracking Monitor will show the user's eyes as two ovals somewhere near the center. This means the user is at an ideal distance from the monitor and the RED-m Eye Tracking Device can track both of the user's eyes. As shown in the following Figure 2 (a). The user is sitting approximately 60 cm from the screen.

Figure 2. (a) Eye tracking and viewing distance adjustment (b) Calibration (c) Validation

(b) Calibration & Validation: Calibration and validation are important steps. In the calibration process, participants will see a small circle on the screen as shown in figure 2 (b). The participants were required to trace the circle. To validate how well the calibration is, immediately after calibration, the same procedure will be repeated for validation. The red circle mark shows the validated points as shown in figure 2 (c). During the experiment, participants were asked to avoid body and head movements. Calibration is good if validated points are closer to original points. Farther Points indicate poor calibration, and in such case, we need to repeat calibration process. (c) Watching images and Recording of Eye gaze data: The stimulus images were shown in full-screen mode. All images will be displayed sequentially one after another. The participants need to watch the images, search for the target (i.e. Optic Disc) and look at the target. The program controls the SMI iView X software and instructs it to record the movement of the subject's eye while watching the images. We have collected total 100 eye gaze samples from experts and total 250 eye gaze samples from non-experts. The stimuli images used in the experiment are a subset of DRIVE [12] (15 images) and STARE [13] (10 images) dataset.

The eye gaze data exhibit a prototypical behavior signifying that an oculomotor event has been recorded. For example, the fixation event is the point where the eye is relatively still. Eye movement is commonly partite into fixations and saccades when the eye gaze pauses in a certain situation is called as fixation. A saccade is a quick, simultaneous movement of both eyes between two phases of fixations. There are two main types of fixation detection algorithm, one is dispersion based and the second is a velocity-based algorithm. Fixations are predominantly detected by a maximum allowed dispersion or velocity criterion. In dispersion based algorithms [14], temporally adjacent samples must be located within a spatially limited region (typically $0.5\text{-}2.0^0$) for a minimum duration. In velocity based algorithms [14], fixations are identified as contiguous portions of the gaze data where gaze velocity does not exceed a predefined threshold (about $10\text{-}5^0$/s). For detection of fixations, we have implemented a dispersion based algorithm based on Salvucci and Goldberg [14]. This algorithm identifies fixations by finding data samples that are close enough to one another for the specified minimal period of time. The dispersion threshold used is1^0 and duration threshold is 150ms. When the data samples within 1^0 of visual angle and at least for 150ms that sequence of data samples considered as fixation as shown in figure 3. Once fixations are detected, then it is counted.

When it is the inside area of interest, the number of fixations often called as Fixation density.

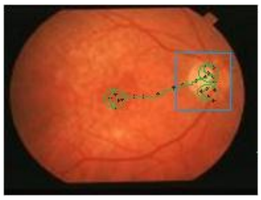

Figure 3. Representation of fixation: Data samples (red dots) must reside in the green circle for a minimum amount of time to consider it as fixation.

Fixation duration gives a period of time in which eyes are relatively stable. A dwell is defined as a single visit in an ROI, from entry to exit, as shown in figure 3, if ROI is represented by blue square then, it contains two fixations and one dwell. Dwell time is often defined as the sum of all fixation duration during a dwell in an ROI. Pupil diameter is a raw data provided as samples by the eye tracker device. The pupil diameter values are typically given in pixels of the eye camera. Some eye trackers can also report pupil diameter in millimeters after a calibration routine. Usually, horizontal pupil diameter is considered as a measure, because the vertical diameter is too sensitive to eyelid closure. This measure can be used to study a variety of cognitive and emotional states. The normal pupil size in adults varies from 2 to 4 mm in diameter in bright light to 4 to 8 mm in the dark [15]. We have calculated the number of fixations, duration of fixation in the ROI, the number of dwells in the ROI, dwell time in the ROI, the number of fixations in ROI for experts and non-expert group, and for 25 stimulus images. Figure 4 shows an example for fixations of expert and non-expert.

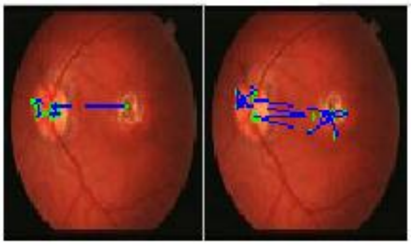

Figure 4. One expert fixation (left) and one non-expert fixation (right) for retinal image

C. Visualization of eye gazes fixations in Heat map

Heat maps provide quick, very intuitive, and in some cases objective representation of eye tracking data that naive users and even children can immediately grasp a meaning from. Their intuitiveness has made heat map visualizations very popular in parts of applied and scientific eye tracking community. Their major advantage is that they very quickly give an easily digestible overview of the total data from a large number of participants. In the eye tracking for web usability field, heat map visualization is very commonly used to describe the general outcome of an eye tracking study [15]. For example, Nielsen refers to the well quoted F-pattern [16] “Eye tracking visualization shows that users often read web pages in an F-shaped pattern: two horizontal strips followed by vertical strips.” Wulff [17] uses heat maps to investigate how viewers explore web pages and conclude that only the very first links are looked at and the user does not read much on the page. Similarly, Bojko [18] compares two-page designs, using the heat map only to show that in the one case the gaze of the participants was focused only on the task-relevant target, while in the other web page design, the gaze was spread out. In the proposed work, a heat map was developed to visualize in fundus retinal images where the experts and non-experts look [7]. We were interested to know the eye movement behavior of two groups. The heat map is calculated from a set of different fixation points (X_k, Y_k), k Ɛ [1, N] where N is the total number of fixation points found in an image and (X_k, Y_k) is the location of the k-th fixation point. Those fixation points are interpolated by a Gaussian function to generate a fixation density map $S(x,y)$ [7]:

$$S(x,y) = \frac{1}{N}\sum_{k=1}^{N}\frac{1}{2\pi\sigma_s^2}\exp\left(-\frac{(x-x_k)^2+(y-y_k)^2}{2\sigma_s^2}\right) \quad (1)$$

Where x and y denote, respectively, the horizontal and vertical positions of a pixel and σ_s is the standard deviation of the Gaussian function. In this manner, each fixation share to the heat map in a local neighborhood centered on the fixation location and with an area of influence defined by σ_s . Thus, a pixel in a region heavily populated by fixations has a brighter value than a pixel in a more dispersed area. The σ_s is calculated by (2) as suggested by [7].

$$\sigma_s = D*\tan(0.5\pi/180) \quad (2)$$

Where D is the viewing distance between participant and display. The calculated heat map results are shown in Figure 5. The hot spots in the heat map point outs the region that attracts participants gaze.

D. Concentration Ratio (CR)

Concentration ratio is the percentage of the energy that falls under the optic disc. Here we have calculated energy as the sum of heat map values. The formal definition of CR is:

$$CR = 100\times (E_{od} / E_t) \quad (3)$$

where E_{od} corresponds to the total energy under the optic disc, and E_t corresponds to the total energy of the map for the whole image. A high CR value will indicate a heat map is concentrated on the optic disc, whereas a low CR value will indicate a more diffuse energy map [7] (shown in figure 6). The first row of figure 5 (b), shows the heat map calculated from Avg. Experts fixations focused fully on the optic disc region, whereas heat map calculated from Avg. non-experts fixations are comparatively scattered as shown in figure 5 (c) first row.

STATISTICAL ANALYSIS

The statistical analysis is carried out for expert optometrists group and non-experts group based on the number of fixations, pupil diameter, the number of fixations in the ROI, the number of Dwells and Dwell time in the ROI. Graphs are shown in figure 7.

One way ANOVA was used to analyze the results. The mean and standard Deviation for each feature were summarized in table 1 below. The groups were analyzed based on the mean and variance. The null hypothesis was mean and variance of the two classes is equal. The two groups revealed differences in the mean test: t critical two tail value is 2.0638. Number of Fixations having t stat value -6.16. The number of fixations in the ROI having t stat value 8.48. The duration of fixations in ROI with t stat value 6.22. Number of Dwells in ROI with t stat value -6.24. The dwells time in ROI with t stat value 7.65 and Pupil diameter with t stat value -2.85. For all above features, t stat value lies in the critical region. So we have rejected the null hypothesis and accept the alternative hypothesis. The mean of the two classes is not equal.

The two groups revealed differences in no. of fixations $[F(1,48)=11.992, p < 0.05]$, the number of fixations in ROI [F

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(1,48)=70.996, p < 0.05], duration of fixation in ROI [F (1,48)=39.839, p < 0.05], pupil diameter [F (1,48)=8.607, p < 0.05], No. of dwells in ROI [F (1,48)=39.176, p < 0.05] and dwell time in ROI [F (1,48)=67.515, p < 0.05]. The F values above indicate that variance of two classes are not equal. We found a significant difference between two groups for all features.

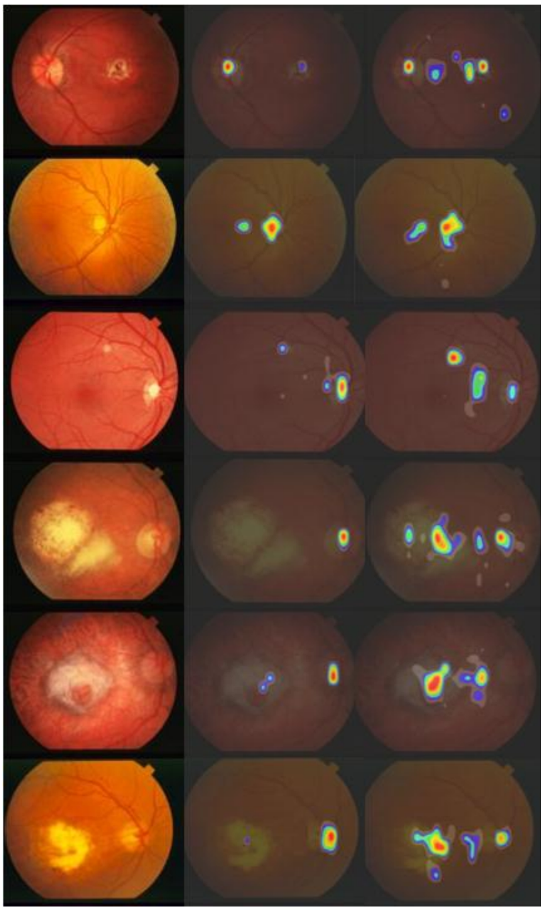

Figure 5. (a) Retinal image (b) Heat map of Avg. Experts fixations (c) Heat map of Avg. Non-Experts fixations

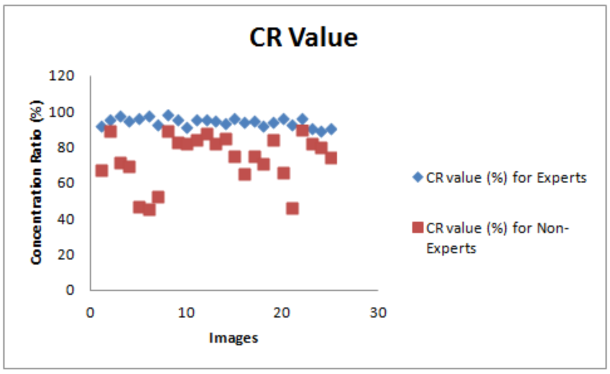

Figure 6. Scatter plot for concentration ratio of Avg. Experts and Avg. Non-Experts

The conclusions derived from the correlation between eye gaze features for expert and non-expert are as follows: we found a positive correlation between no. of fixations in ROI and duration of fixation in ROI for experts $[r = 0.605, p = 0.001]$. A positive correlation is observed between no. of fixations in ROI and dwell time in the ROI for experts with $[r = 0.416, p = 0.039]$. There is no correlation between the number of fixations and number of fixations in ROI, dwell time in the ROI and number of dwells in ROI for the experts with $[r = 0.304 \text{ and } r = -0.138, p > 0.05]$ respectively.

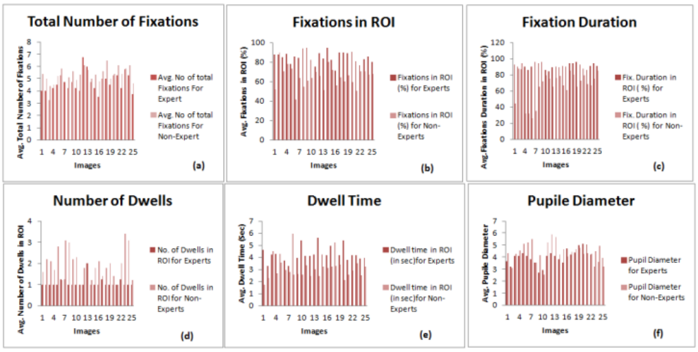

Figure 7. (a) Total number of fixations in ROI (b) Fixations in the ROI (c) Fixation Duration in the ROI (d) Number of Dwells in the ROI (d) Dwell time in the ROI (e) Pupil Diameter

Similarly, the number of fixations and no. of fixations in ROI found independent for non-experts with $[r = -0.394, p > 0.05]$. The no. of fixations in ROI and fixation duration in ROI for non experts were not correlated with $[r = 0.241, p > 0.05]$. The no. of fixations in ROI and dwell time in ROI, and dwell time in the ROI and no. of dwells in ROI were found independent with $[r = 0.139 \text{ and } r = 0.118, p > 0.05]$ respectively. The scatter plots for all features for both groups are shown in figure 8.

The inference from the analysis is as follows: Experts able to find target soon and fixate their gaze on the target, maximum experts gaze were concentrated on the target. Whereas non-experts fixations were scattered throughout the image. After target identification, non-experts found less effective to fixate gaze on it. Expert's maximum fixations were in the optic disc region. The two groups also revealed differences in the concentration ratio [F (1,48) =55.139, p < 0.05].

CONCLUSION AND DISCUSSION

In the survey given in [19], the number of fixations measure was found to be most common. Here results indicate that the experts have comparatively less total numbers of fixations in their domain of experts. This fewer fixation because they may omit fixations on irrelevant parts of the image. This finding agrees with the literature. Rotting [20] concludes that a low number of fixations could mean either that the task goal has been reached, that the participant is experienced, or search task is simple. We found from the result that out of a total number of fixations by experts the maximum fixations fall in the optic disc region i.e. the ROI as shown in figure 4. Similarly, a high number of fixations for non-experts groups may indicate difficulty in interpreting the fixated information same as reported in [21].

Table 1. Mean and Standard Deviation for both groups

Features	Experts		Non-Experts	
	Mean	Std. Deviation	Mean	Std. Deviation
No. of Fixations	4.66	0.80	5.02	0.50
No. of Fixations in ROI (%)	85.11	6.05	61.08	16.09
Duration of fixation in ROI (%)	90.70	3.40	66.68	18.72
No. of Dwells in ROI	1.08	0.21	1.97	0.68
Dwell time in ROI (Sec)	4.37	0.68	2.9	0.56
Pupil Diameter	3.98	0.61	4.45	0.79

We also found from the results that, duration of the fixation in ROI is more of an expert. Longer fixation of the experts indicates, with increasing skill, more information is extracted around the point of fixation making eye movements overall more efficient. A longer fixation duration is much connected with richer and more effortful cognitive processing [22]. The more fixation, lower the duration and vice versa. Given task has an impact on fixation duration. For the proposed experiment here, the task was to search for a target and look at it until next image displayed. This may be one of the reasons that result shown for experts, fixation duration in the region of interest is high compared with the non-expert.

All these findings indicate that functional link between what is fixate and cognitive processing of that item- the longer the fixation the deeper it's processing. The higher dwell time indicates interest in an object or higher informativeness of an object [23]. This indicates a strong relationship between consecutive fixations on an item and how much you need to mine information from it. Dwell time in ROI was also compared between the two groups. It was observed that dwell time for an expert in OD region was longer. In the present experiment number of dwells in ROI made by experts, are comparatively less than the non-experts OD region was longer.

Results shows, there is no major difference in pupil diameter between expert and non-experts. But, the observation is that set of images for which OD is easy to locate the targets, pupil diameter for both groups is closer. Whereas, a set of images for which OD is not a popup target, the pupil diameter of non-expert group is slightly larger. This may agree with the findings, mental workload increases the pupil diameter [24].

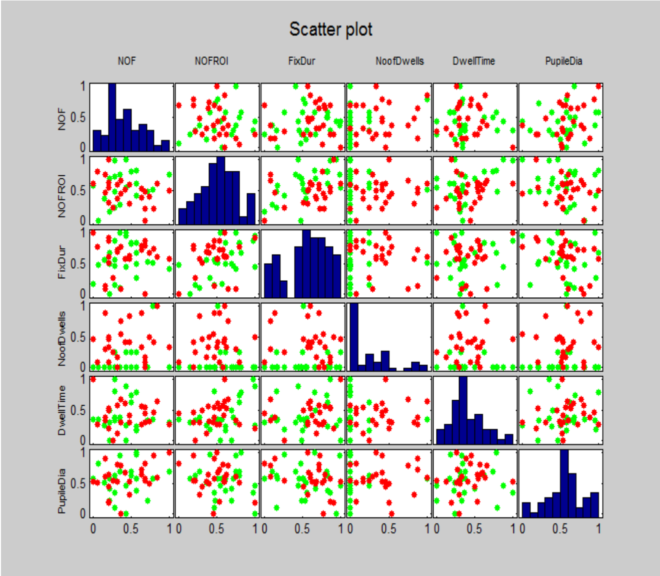

Figure 8. Scatter plot by Experts (represented by green color) and non-experts group (represented by red color)

Concentration ratio (CR) is applied to estimate whether heat maps are concentrated on to optic disc or spread throughout the image. The comparability of the CR values on to optic disc shows that (figure6) there is a statistically important difference between experts and non-experts. This indicates experts gazing on the optic disc when the image appears on the display. Collectively the results show that experts and non-experts group behaves differently in the task of optic disc detection.

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