Claims:

1. A method of detecting a risk of glaucoma in a subject, the method comprising the steps of:

extracting a plurality of glaucoma indicators from at least one non-stereo fundus image of the subject;

extracting from genome data for the subject genetic marker data indicative of one or more genes or SNPs associated with glaucoma; and

inputting the extracted glaucoma indicators and the genetic marker data into an adaptive model operative to generate an output indicative of a risk of glaucoma in the subject.

2. A method according to claim 1, further comprising the steps of:

examining a medical report of the subject; and

inputting data derived from the medical report examination into the adaptive model.

3. A method according to claim 2, wherein the step of examining the medical report of the subject further comprises the sub-steps of:

structuring the medical report;

deriving patterns within the structured medical report; and

evaluating the derived patterns.

4. A method according to claim 2 or 3, wherein the step of examining the medical report of the subject is performed using one or more of a group of methods comprising pattern matching methods, data modeling methods, features selection methods, classifications methods and correlation methods.

5. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image of the subject further comprises the sub-step of calculating a cup-to-disc ratio from the non-stereo fundus image.

6. A method according to claim 5, wherein the sub-step of calculating the cup-to-disc ratio from the non-stereo fundus image further comprises the sub-steps of:

performing optic disc segmentation in the non-stereo fundus image;

performing optic cup segmentation in the non-stereo fundus image; and

inputting data derived from the optic disc segmentation and data derived from the optic cup segmentation into a CDR adaptive model operative to generate a cup-to-disc ratio.

7. A method according to claim 6, wherein the CDR adaptive model is a neural network.

8. A method according to claim 6 or 7, wherein the optic disc segmentation is performed using a variational level set algorithm.

9. A method according to claim 6 or claim 7, wherein the optic disc segmentation is performed by:

(i) identifying a plurality of edges within the fundus images;

(ii) screening edges to decide whether each of the edge is likely to be due to the boundary of an optic disc, and discarding any edges for which the decision is negative; and

(iii) fitting an elliptical model of the optic disc to the remaining edges.

10. A method according to claim 9 in which in step (i) the edges are identified by finding local intensity maxima or minima of the intensity of the image, and,

said screening step (ii) includes a threshold screening step of discarding edges for which a spatial derivative of image intensity is less than a threshold.

11. A method according to claim 10 in which the threshold is selected locally from a number of pre-determined threshold values, as the threshold value for which the number of edges within a certain locality for which the spatial derivative of image intensity is above the threshold value, is within a desired range.

12. A method according to any of claims 9 to 11, in which the screening step (ii) further includes at least one of:

defining a disc mask based on an estimated position of the optic disc, and excluding ones of the edges which are not within the disc mask; and

defining a cup mark based on an estimated position of the cup, and excluding ones of the edges which are within the cup mask.

13. A method according to any of claims 9 to 12 in which the screening step (ii) further includes removing edges which are within a predetermined distance of each other.

14. A method according to any of claims 9 to 13 in which, in said fitting step (iii), the ellipse is fitted with a constraint that it is longer in the vertical direction than in the horizontal direction.

15. A method according to any of claims 9 to 14 in which, following the fitting step (iii), there is step of defining a plurality of portions of a ring-shaped region encircling the fitted ellipse, performing a texture analysis in each portion of the ring-shaped region, and, if it is determined that any of the portions of the ring-shaped region includes more than a predefined number of edges with a connectivity below a connectivity threshold, the edges within that portion of the ring-shaped region are removed, and step (iii) is repeated.

16. A method according to any of claims 9 to 15 including a refinement step of partitioning the fitted ellipse into portions, and expanding or contracting each portion of the fitted ellipse to increase the number of edges located on the fitted ellipse.

17. A method according to any of claims 6 – 16, wherein the optic cup segmentation is performed using a method comprising:

analyzing a color histogram of the non-stereo fundus image;

applying level-set algorithms to obtain a preliminary estimate of the optic cup boundary;

obtaining a first smoothed optic cup boundary by smoothing the preliminary estimate of the optic cup boundary using ellipse fitting; and

obtaining a second smoothed optic cup boundary by smoothing the preliminary estimate of the optic cup boundary using a maximum inscribed fitted circle.

~~18. A method according to any of claims 6-16, wherein the optic cup segmentations is performed by a method comprising:~~

~~performing a plurality of optic cup identification algorithms to obtain respective preliminary estimates of the position of the optic cup;~~

~~estimating a centre of the optic cup;~~

~~for each of a number of angular positions about the centre of the optic cup combining the estimates of the position of the optic cup to form an improved estimate of the position of the optic cup by a fusion algorithm dependent upon the angular position.~~

~~19. A method according to claim 18 in which the fusion algorithm comprises selecting a respective one of the preliminary estimates of the position of the cup when said angular position is within a corresponding one of a plurality of angular ranges about the centre of the optic cup.~~

~~20. A method according to claim 18 or 19 in which one of the optic cup identification algorithms includes an analysis of blood vessel kinks in the image, and for angular positions at which a kink is detected the fusion algorithm forms the improved estimate of the position of the optic cup based on that kink.~~

~~21. A method according to any of claims 18 to 20 including a step of analyzing the image, and selecting the fusion algorithm based on the result of the analysis,~~

~~22. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-step of detecting disc haemorrhages in the non-stereo fundus image.~~

~~23. A method according to claim 24, wherein the sub-step of detecting disc haemorrhages in the non-stereo fundus image further comprises the sub-steps of:~~

~~identifying a ring-shaped region of interest in the non-stereo fundus image encompassing an optic disc boundary;~~

~~removing blood vessel regions in the identified region of interest;~~

detecting disc haemorrhages from the removed blood vessel regions in the identified region of interest by a color-based analysis, to identify candidate disc haemorrhages; and

screening the candidate disc haemorrhages.

24. A method according to claim 23, wherein the sub-step of removing blood vessel regions in the identified region of interest further comprises the sub-steps of:

forming a first dilated image by applying edge detection on green and grey channels of the non-stereo fundus image to detect and remove blood vessels;

forming a second dilated image by applying edge detection on a red channel of the non-stereo fundus image to obtain an outline of an optic disc region in the non-stereo fundus image;

summing the first and second dilated images to obtain a summed image; and

masking the summed image with the identified region of interest to remove blood vessel regions in the identified region of interest;

25. A method according to claim 23 or 24, wherein the step of screening the candidate disc haemorrhages further comprises the sub-steps of:

comparing the size of each candidate disc haemorrhage with a predefined value; and

removing the candidate disc haemorrhage if the size of the candidate disc haemorrhage falls below the predefined value.

26. A method according to any of the preceding claims, wherein the step of extracting the glaucoma indicators from the non-stereo fundus image further comprises the sub-step of detecting neuroretinal rim loss.

27. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-step of determining whether a neuroretinal rim in the image complies with an ISNT rule, the ISNT rule stating that the neuroretinal rim is broader inferiorly than superiorly, broader superiorly than nasally and broader nasally than temporally.

28. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-step of detecting inter-eye asymmetry of cupping in the non-stereo fundus image.

29. A method according to claim 28, wherein the sub-step of detecting inter-eye asymmetry of cupping further comprises the sub-step of determining that there is inter-eye asymmetry of cupping if the difference in cupping between the non-stereo fundus image and a non-stereo fundus image of the other eye of the subject is greater than or equal to 0.2.

30. A method according to claim 28 or 29, wherein the sub-step of detecting inter-eye asymmetry of cupping is performed using color correction and euclidean geometry transformations.

31. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-step of detecting parapapillary atrophy.

32. A method according to claim 31, wherein the parapapillary atrophy is beta parapapillary atrophy and the sub-step of detecting parapapillary atrophy is performed using one or more of a group of methods comprising level-set methods, histogram-based segmentation methods, edge detection methods and region growing methods.

33. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-step of detecting neuroretinal rim notches.

34. A method according to claim 33, wherein the sub-step of detecting neuroretinal rim notches further comprises the sub-step of applying a red-free filter to the non-stereo fundus image to enhance an optic cup margin and the appearance of a Retinal Nerve Fiber Layer in the non-stereo fundus image.

35. A method according to claim 33 or 34, wherein the sub-step of detecting neuroretinal rim notches is performed using one or more of a group of methods comprising edge detection methods, methods based on shape models and methods based on variation of gradient changes.

36. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-step of analyzing blood vessel patterns in the non-stereo fundus image.

37. A method according to claim 36. wherein the sub-step of analyzing blood vessel patterns in the non-stereo fundus image is performed using wavelet analysis.

38. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-steps of:

making a preliminary estimate of the position of an optic cup boundary on the image;

identifying the edges of blood vessels in a neighborhood of the preliminary estimate of the position of the optic cup boundary;

detecting kinks in the identified blood vessel edges; and

determining the optic cup boundary in the non-stereo fundus image based on the detected kinks.

39. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-steps of:

calculating the size of an optic disc in the image; and

classifying the optic disc in the image according to its size.

40. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-step of calculating a degree of tilting of the optic disc based on the disc contour.

41. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-step of determining the gradeability of the image.

42. A method according to any of the preceding claims, wherein the step of extracting a plurality of glaucoma indicators from the non-stereo fundus image further comprises the sub-step of detecting Retinal Nerve Fiber Layer defects.

43. A method according to claim 42, wherein the sub-step of detecting Retinal Nerve Fiber Layer defects is performed using color and texture-based methods.

44. A method according to any of the preceding claims, comprising a preliminary stage of training said adaptive model using a training set comprising a plurality of non-stereo fundus training images of a plurality of subjects, genetic marker data of the plurality of subjects and clinical data regarding the presence of glaucoma in each subject.

45. A method according to claim 44, wherein the following steps are performed during the preliminary stage of training:

repeatedly extracting a plurality of glaucoma indicators from each non-stereo fundus training image;

repeatedly identifying genetic changes in the genome data of each subject compared to reference genome data;

determining a correlation between the extracted glaucoma indicators, the genetic changes and the clinical data regarding the presence of glaucoma in each subject; and

inputting the correlation into the adaptive model.

46. A method according to claim 45, wherein the step of determining a correlation between the extracted glaucoma indicators, the genetic changes and the data indicating whether glaucoma is present in each subject is performed using statistical analyses.

47. A method according to any of the preceding claims, wherein the plurality of glaucoma indicators extracted from the non-stereo fundus retinal image comprise two or more of a group comprising:

an optic cup-to-disc ratio;

data indicating a presence of disc haemorrhages;

data indicating compliance of a neuroretinal rim with an ISNT rule, the ISNT rule stating that the neuroretinal rim is broader inferiorly than superiorly, broader superiorly than nasally and broader nasally than temporally;

data indicating a presence of inter-eye asymmetry of cupping;

data indicating a presence of a parapapillary atrophy;

data indicating a presence of neuroretinal rim notches;

blood vessel patterns;

a degree of tilting of the optic disc; and

data indicating a presence of Retinal Nerve Fiber Layer defects.

48. A method according to any of the preceding claims, wherein the adaptive model is a multi-layer neural network.

49. A method according to any of the preceding claims, wherein the adaptive model uses one or more of a group of methods comprising Support Vector Machines and Adaboost.

50. A method according to any preceding claim in which the adaptive model is a two-stage model incorporating a first stage in which individual glaucoma indicators are combined with respective sets of said genetic marker data by first adaptive model modules to form respective first outputs, and a second stage in which the first outputs are combined by a second adaptive model.

51. A method according to any preceding claim including, prior to the step of extracting the glaucoma indicators from the at least one non-stereo fundus image, the steps of:

extracting numerical parameters from the fundus image by texture analysis;

determining whether the numerical parameters meet a quality criterion; and

only extracting the plurality of glaucoma indicators if the determination indicates that the numerical parameters meet the quality criterion.

52. A method according to claim 51 wherein the texture analysis step comprises at least one of:

(i) a wavelet decomposition; or

(ii) a step of measuring the degree to which the image contains a plurality of predetermined image features.

53. A method according to claim 51 or claim 52 in which the determination step is performed using an adaptive model trained to perform the determination using training data comprising (i) images which are known to either meet or not meet a quality criterion, and (ii) the corresponding numerical parameters.

54. A method according any preceding claim comprising converting the fundus image into a predefined format if the image is not already in that format.

55. A method according to any preceding claim further comprising, prior to the step of extracting the glaucoma indicators from the at least one non-stereo fundus image, extracting further numerical control parameters from the fundus image, said further numerical control parameters being used as control parameters in the extraction of the glaucoma indicators.

56. A method of processing a non-stereo fundus image to identify whether a plurality of glaucoma indicators are present, the method comprising:

a texture analysis step of extracting numerical parameters from the fundus image;

determining whether the numerical parameters meet a quality criterion; and

only if the determination indicates that the numerical parameters meet the quality criterion, analyzing the fundus image by a plurality of image processing algorithms to determine whether the glaucoma indicators are present.

57. A method according to claim 56 wherein the texture analysis step comprises at least one of:

~~(i) a wavelet decomposition; or~~

~~(ii) a step of measuring the degree to which the image contains a plurality of predetermined image features.~~

~~58. A method according to claim 56 or claim 57 in which the determination step is performed using an adaptive model trained to perform the determination using training data comprising (i) images which are known to either meet or not meet a quality criterion, and (ii) the corresponding numerical parameters.~~

~~59. A method according any of claims 56 to 58, further comprising a step performed before the texture analysis step of converting the fundus image into a predefined format if the image is not already in that format.~~

~~60. A method according to any of claims 56 to 59 further comprising a step of extracting further numerical parameters from the fundus image, said further numerical parameters being used as control parameters in one or more of the image processing algorithms.~~

~~61.~~1. A method of identifying the optic cup in a fundus image, the method comprising:

performing a plurality of optic cup identification algorithms to obtain respective preliminary estimates of the position of the optic cup;

estimating a centre of the optic cup;

for each of a number of angular positions about the centre of the optic cup combining the estimates of the position of the optic cup to form an improved estimate of the position of the optic cup, by a fusion algorithm dependent upon the angular position.

~~62.~~2. A method according to claim ~~61~~ 1 in which the fusion algorithm comprises selecting a respective one of the preliminary estimates of the position of the cup when said angular position is within a corresponding one of a plurality of angular ranges about the centre of the optic cup.

~~63.~~3. A method according to claim ~~61~~ 1 or ~~62~~ 2 in which one of the optic cup identification algorithms includes an analysis of blood vessel kinks in the image, and for

angular positions at which a kink is detected the fusion algorithm forms the improved estimate of the position of the optic cup based on that kink.

64.4. A method according to any of claims 61-1 to 63-3 including a step of analysing the image, and selecting the fusion algorithm based on the result of the analysis.

65. A method of identifying the position of an optic disc in a fundus image, the method comprising:

(i) identifying a plurality of edges within the fundus images;

(ii) screening edges to decide whether each of the edge is likely to be due to the boundary of an optic disc, and discarding any edges for which the decision is negative; and

(iii) fitting an elliptical model of the optic disc to the remaining edges.

66. A method according to claim 65 in which in step (i) the edges are identified by finding local intensity maxima or minima of the intensity of the image, and,

said screening step (ii) includes a threshold screening step of discarding edges for a local spatial derivative of image intensity is less than a threshold.

67. A method according to claim 66 in which the threshold is selected locally from a number of pre-determined threshold values, as the threshold value for which the number of edges within a certain locality for which the spatial derivative of image intensity is above the threshold value, is within a desired range.

68. A method according to any of claims 65 to 67, in which the screening step (ii) further includes at least one of:

defining a disc mask based on an estimated position of an optic disc, and excluding ones of the edges which are not within the disc mask; and

defining a cup mark based on an estimated position of the cup, and excluding ones of the edges which are within the cup mask.

69. A method according to any of claims 65 to 68 in which the screening step (ii) further includes removing edges which are within a predetermined distance of each other.

~~70. A method according to any of claims 65 to 69 in which, in said fitting step (iii), the ellipse is fitted with a constraint that it is longer in the vertical direction than in the horizontal direction.~~

~~71. A method according to any of claims 65 to 70 in which, following the fitting step (iii), there is step of defining a plurality of portions of a ring-shaped region encircling the fitted ellipse, performing a texture analysis in each portion of the ring-shaped region, and, if it is determined that any of the portions of the ring-shaped region includes more than a predefined number of edges with a connectivity below a connectivity threshold, the edges within that portion of the ring-shaped region are removed, and step (iii) is repeated.~~

~~72. A method according to any of claims 65 to 71 including a refinement step of partitioning the fitted ellipse into portions, and expanding or contracting each portion of the fitted ellipse to increase the number of edges located on the fitted ellipse.~~

~~73.~~5. A computer system having a processor arranged to perform a method according to any of the preceding claims.

~~74.~~6. A computer program product such as a tangible data storage device, readable by a computer and containing instructions operable by a processor of a computer system to cause the processor to perform a method according to any of claims 1 to ~~72~~ 4.