



(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
29.11.2006 Bulletin 2006/48

(21) Application number: **03758324.2**

(22) Date of filing: **20.10.2003**

(51) Int Cl.:
G06T 7/00 (2006.01)

(86) International application number:
PCT/GB2003/004527

(87) International publication number:
WO 2004/038633 (06.05.2004 Gazette 2004/19)

(54) **AUTOMATED HISTOLOGICAL GRADING OF TUBULES**

AUTOMATISIERTE HISTOLOGISCHE GRADUIERUNG VON TUBULI

CLASSEMENT HISTOLOGIQUE AUTOMATISE DE TUBULES

(84) Designated Contracting States:
**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IT LI LU MC NL PT RO SE SI SK TR**

(30) Priority: **23.10.2002 GB 0224626**

(43) Date of publication of application:
20.07.2005 Bulletin 2005/29

(73) Proprietor: **Qinetiq Limited**
London, SW1E 6PD (GB)

(72) Inventors:
• **GUITTET, Christelle Marie,**
Malvern Technology Ctr
Malvern,
Worcestershire WR14 3PS (GB)
• **VARGA, Margaret Jai,**
Malvern Technology Centre
Malvern,
Worcestershire WR14 3PS (GB)

• **DUCKSBURY, Paul Gerard,**
Malvern Technology Ctr.
Malvern,
Worcestershire WR14 3PS (GB)

(74) Representative: **Williams, Arthur Wyn Spencer**
QinetiQ Limited
Intellectual Property,
Cody Technology Park,
Ively Road
Farnborough, Hants GU14 0LX (GB)

(56) References cited:
US-A- 6 031 930

• **CHENG H D ET AL: "A parallel approach to tubule
grading in breast cancer lesions and its VLSI
implementation" COMPUTER-BASED MEDICAL
SYSTEMS, 1991. PROCEEDINGS OF THE
FOURTH ANNUAL IEEE SYMPOSIUM
BALTIMORE, MD, USA 12-14 MAY 1991, LOS
ALAMITOS, CA, USA, IEEE COMPUT. SOC, US, 12
May 1991 (1991-05-12), pages 322-329,
XP010024202 ISBN: 0-8186-2164-8**

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Description

[0001] This invention relates to a method, an apparatus and a computer program for grading tubules: it is particularly (although not exclusively) relevant to assessment of histological slides to provide clinical information on potentially cancerous tissue such as breast cancer tissue.

[0002] Breast cancer is a common form of female cancer: Once a lesion indicative of breast cancer has been detected, tissue samples are taken and examined by a histopathologist to establish a diagnosis, prognosis and treatment plan. However, pathological analysis of tissue samples is a time consuming and inaccurate process. It entails interpretation of images by human eye, which is highly subjective: it is characterised by considerable inaccuracies in observations of the same samples by different observers and even by the same observer at different times. For example, two different observers assessing the same ten tissue samples may easily give different opinions for three of the slides - 30% error. The problem is exacerbated by heterogeneity, i.e. complexity of some tissue sample features.

[0003] CHENG H D ET AL: "A parallel approach to tubule grading in breast cancer lesions and its VLSI implementation" COMPUTER-BASED MEDICAL SYSTEMS, 1991. PROCEEDINGS OF THE FOURTH ANNUAL IEEE SYMPOSIUM BALTIMORE, MD, USA 12-14 MAY 1991, LOS ALAMITOS, CA, USA, IEEE COMPUT. SOC, US, 12 May 1991 (1991-05-12), pages 322-329, XP010024202 ISBN: 0-8186-2164-8 teaches an automated system for tubule grading which detects tubules in a manner ensuring that each detected tubule is a homogeneous area enclosed by a circular dark boundary. The only feature computed is the total area of the detected tubules.

[0004] There is a need to provide an objective measurement of tubules grading to support a pathologist's diagnosis and patients' treatment.

[0005] The present invention provides a method of grading tubules in a first image of a histological slide characterised in that it has the steps of:

- a) providing a second image of first objects in the first image which are sufficiently large and of appropriate pixel value characteristics at boundaries to potentially be tubules,
- b) providing a third image of second objects in the first image having pixel value characteristics of holes within tubules and fat,
- c) combining data from the second and third images to identify selected second objects which are within first objects,
- d) performing one or more of the following:

- i) counting first objects in the first image which may potentially be tubules to provide a parameter *NOB*,
- ii) counting the first objects having selected second objects within them and likely to be tubules to provide a parameter *N*,
- iii) determining the relative areas of selected second objects as proportions of respective first objects within which they are located to provide parameters *RATIO*,
- iv) determining the total area of selected second objects as a proportion of total area of first objects within which they are located to provide a parameter *SURF*,
- v) determining a parameter *PERCENT* = N/NOB , and
- vi) counting the number of first objects containing at least medium sized holes to provide a parameter *T*, and

- e) grading the first image's tubules on the basis of the one or more parameters as aforesaid with reference to parameter threshold values.

[0006] The invention provides the advantage that it is an objective method of grading tubules in a histological slide.

[0007] The step of providing a second image may incorporate:

- a) thresholding the first image to provide a fourth image retaining relatively darker image pixels and rejecting relatively lighter image pixels,
- b) processing the fourth image by applying the following steps in succession, the first being applied to the fourth image and each after the first being applied to the outcome of the respective immediately preceding step: inversion, morphological dilation, median filtering, hole filling and morphological opening.

[0008] The step of providing a third image may comprise thresholding the first image to provide a binary fourth image in which relatively lighter image pixels have a different binary value to that of relatively darker image pixels. The step of combining data from the second and third images comprises multiplying pixels in the second image by or ANDing them with respective corresponding pixels located in like positions the third image. The step of grading the first image's tubules employs parameter threshold values set to obtain a grading comparable with that obtainable by an appropriate medical expert.

[0009] In a preferred embodiment, the present invention provides a method of grading tubules in a first image of a histological slide having the steps of:

- a) providing a second image of first objects in the first image which are sufficiently large and of appropriate pixel value characteristics at boundaries to potentially be tubules and counting them to provide a parameter *NOB*,
- b) providing a third image of second objects in the first image having pixel value characteristics of fat and holes within tubules,
- c) combining data from the second and third images to identify selected second objects which are within first objects,
- d) counting the first objects having selected second objects within them and likely to be tubules to provide a parameter *N*,
- e) determining the relative areas of selected second objects as proportions of respective first objects within which they are located to provide parameters *RATIO*,
- f) determining the total area of selected second objects as a proportion of total area of first objects within which they are located to provide a parameter *SURF*,
- g) determining a parameter $PERCENT = N/NOB$,
- h) counting the number of first objects containing at least medium sized holes to provide a parameter *T*, and
- i) grading the first image's tubules on the basis of the first image's parameters as aforesaid with reference to parameter threshold values.

[0010] In this embodiment, the invention provides the advantage that it is an objective method which grades tubules from a variety of parameters yielding multiple grading from which a median can be derived.

[0011] In another aspect, the present invention provides a computer apparatus for grading tubules in a first image of a histological slide programmed to:

- a) compute a second image of first objects in the first image which are sufficiently large and of appropriate pixel value characteristics at boundaries to potentially be tubules,
- b) compute a third image of second objects in the first image having pixel value characteristics of holes within tubules and fat,
- c) combine data from the second and third images to identify selected second objects which are within first objects,
- d) implement one or more of the following:
 - i) counting first objects in the first image which may potentially be tubules to provide a parameter *NOB*,
 - ii) counting the first objects having selected second objects within them and likely to be tubules to provide a parameter *N*,
 - iii) determining the relative areas of selected second objects as proportions of respective first objects within which they are located to provide parameters *RATIO*,
 - iv) determining the total area of selected second objects as a proportion of total area of first objects within which they are located to provide a parameter *SURF*,
 - v) determining a parameter $PERCENT = N/NOB$, and
 - vi) counting the number of first objects containing at least medium sized holes to provide a parameter *T*, and
- e) grade the first image's tubules on the basis of the one or more parameters as aforesaid with reference to parameter threshold values.

[0012] In a preferred embodiment of this aspect, the present invention provides a computer apparatus for grading tubules in a first image of a histological slide programmed to:

- a) provide a second image of first objects in the first image which are sufficiently large and of appropriate pixel value characteristics at boundaries to potentially be tubules and counting them to provide a parameter *NOB*,
- b) provide a third image of second objects in the first image having pixel value characteristics of fat and holes within tubules,
- c) combine data from the second and third images to identify selected second objects which are within first objects,
- d) count the first objects having selected second objects within them and likely to be tubules to provide a parameter *N*,
- e) determine the relative areas of selected second objects as proportions of respective first objects within which they are located to provide parameters *RATIO*,
- f) determine the total area of selected second objects as a proportion of total area of first objects within which they are located to provide a parameter *SURF*,
- g) determine a parameter $PERCENT = N/NOB$,

- h) count the number of first objects containing at least medium sized holes to provide a parameter T , and
- i) grade the first image's tubules on the basis of the first image's parameters as aforesaid with reference to parameter threshold values.

[0013] In a further aspect, the present invention provides a computer program for use in grading tubules in a first image of a histological slide containing instructions for controlling a computer apparatus to:

- a) compute a second image of first objects in the first image which are sufficiently large and of appropriate pixel value characteristics at boundaries to potentially be tubules,
- b) compute a third image of second objects in the first image having pixel value characteristics of fat and holes within tubules,
- c) combine data from the second and third images to identify selected second objects which are within first objects,
- d) implement one or more of the following:
 - i) counting first objects in the first image which may potentially be tubules to provide a parameter NOB ,
 - ii) counting the first objects having selected second objects within them and likely to be tubules to provide a parameter N ,
 - iii) determining the relative areas of selected second objects as proportions of respective first objects within which they are located to provide parameters $RATIO$,
 - iv) determining the total area of selected second objects as a proportion of total area of first objects within which they are located to provide a parameter $SURF$,
 - v) determining a parameter $PERCENT = N/NOB$, and
 - vi) counting the number of first objects containing at least medium sized holes to provide a parameter T , and
- e) grade the first image's tubules on the basis of the one or more parameters as aforesaid with reference to parameter threshold values.

[0014] In a preferred embodiment of this aspect, the present invention provides a computer program for grading tubules in a first image of a histological slide containing instructions for controlling a computer apparatus to:

- a) provide a second image of first objects in the first image which are sufficiently large and of appropriate pixel value characteristics at boundaries to potentially be tubules and counting them to provide a parameter NOB ,
- b) provide a third image of second objects in the first image having pixel value characteristics of fat and holes within tubules,
- c) combine data from the second and third images to identify selected second objects which are within first objects,
- d) count the first objects having selected second objects within them and likely to be tubules to provide a parameter N ,
- e) determine the relative areas of selected second objects as proportions of respective first objects within which they are located to provide parameters $RATIO$,
- f) determine the total area of selected second objects as a proportion of total area of first objects within which they are located to provide a parameter $SURF$,
- g) determine a parameter $PERCENT = N/NOB$,
- h) count the number of first objects containing at least medium sized holes to provide a parameter T , and
- i) grade the first image's tubules on the basis of the first image's parameters as aforesaid with reference to parameter threshold values.

[0015] The computer program and apparatus aspects of the invention may have preferred features corresponding to those of respective method aspects.

[0016] In order that the invention might be more fully understood, embodiments thereof will now be described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a block diagram of a procedure of the invention for measuring tubule activity;

Figure 2 is a block diagram showing part of the procedure of Figure 1 in more detail, and

Figures 3 to 7 are simplified versions of images obtained during the Figure 2 procedure.

[0017] Referring to Figure 1, there is illustrated a procedure 10 of the invention for assessment of tubule activity in tissue samples presented as histopathological slides of potential carcinomas of the breast. The procedure 10 requires

data from histological slides in a suitable form. Sections are taken (cut) from breast tissue samples (biopsies) and placed on respective slides. Slides are stained using the staining agent Haemotoxylin & Eosin (H&E), which is the standard stain for delineating tissue and cellular structure. Tissue specimens stained with H&E are used to assess tubule activity. In the present example, image data were obtained by a pathologist using Zeiss Axioskop microscope with a Jenoptiks Progres 3012 digital camera. Image data from a slide is a set of digital images obtained at a linear magnification of 10 (i.e. 10X).

[0018] To select images, a pathologist scans the microscope over a slide, and at 10X magnification selects two regions (referred to as tiles) of the slide which appear to be most promising in terms of an analysis to be performed. Both these regions are then photographed using the microscope and digital camera referred to above. The digital camera produces for each region a respective digitised image in three colours, i.e. red, green and blue (R, G & B) eight bit values for each pixel and therefore in the range 0 to 255: each image is an electronic equivalent of a tile. Three intensity values are obtained for each pixel in a pixel array to provide an image as a combination of R, G and B image planes. The image data from the two tiles are stored in a database 12 for later use. Tubule activity is determined using a tubule feature detection process 14: this provides a tubule score 18 for input to a diagnostic report at 20.

[0019] The objective of the procedure 10 is to perform an extraction and a count of the tubules present in an image. A tubule is an image of a section through a mammary duct produced in the slide production process: it can appear round, oval, cylindrical or irregular depending on the angle of the section to the duct axis and the shape of the duct after sectioning. It appears as a white area surrounded by a dark epithelial layer (or boundary). A tubule score is 1, 2 or 3 according to whether the condition is least, moderately or most serious respectively. Tubules may be less in number or absent in images scored 2 or 3 because cancerous cells are invading them. The procedure 10 seeks to identify those white areas in an image that are surrounded by a dark epithelial layer: This should exclude fat, which also appears white but tends not to be surrounded by a darker epithelial layer.

[0020] In a prior art manual procedure, a clinician places a slide under a microscope and examines a region of it at magnification of x10 for indications of tubule activity. The prior art manual procedure for scoring tubule activity involves a pathologist subjectively estimating the amount of tubules present in a tissue sample, taking care to ignore those areas considered to be fat cells. The process described below in this example replaces the prior art manual procedure with an objective procedure.

[0021] Referring now to Figure 2, the process 14 is shown in more detail: it is carried out for each of the two digitised images mentioned above, but will be described for one. At 30 an input colour image is used to calculate a greyscale equivalent: i.e. for each pixel the respective red, green and blue pixel values are averaged to produce a single greyscale pixel value. This is repeated for all pixels in the image to provide for further processing a greyscale initial image 50 as shown in Figure 3 in simplified form. Figure 3 illustrates various kinds of initial image feature, tubules 51 with pronounced dark boundaries containing one or more holes such as 52, large dark objects 53, fat cells 55 with only very narrow faint boundaries and small dark objects 56 of no interest.

[0022] Step 32 is shown in more detail as a number of constituent steps a) to e) within chain lines 33. At a), the objective is to select from the greyscale image 50 only relatively darker pixels and omit relatively lighter pixels. An image is obtained from a) which contains relatively darker objects of varying size: the larger of these objects are likely to contain tubules, but others smaller in size are unlikely to do so. To implement step a), initially all pixels in the greyscale image 50 are compared with one another to obtain their maximum (Maxg) and minimum (Ming) values: these values are used to compute a parameter P given by:

$$P = 12(\text{Maxg} - \text{Ming})/100 \quad (1)$$

[0023] Each pixel in the greyscale image 50 is then divided by 255 so that it lies in the range 0 to 1. The value P is then used to transform the greyscale image 50 into an output image as shown in Table 1 below:

Table 1

Input image pixel value	Output image pixel value
$< 1/255$	0
$\geq 1/255 \text{ AND } \leq (\text{Maxg} - P)/255$	Mapped to the range [0,1]
$> (\text{Maxg} - P)/255$	1

[0024] This means $1/255$ becomes 0, $(\text{Maxg} - P)/255$ becomes 1 and $x \geq 1/255 \text{ AND } \leq (\text{Maxg} - P)/255$ becomes (x-

$1/255)/(\{\text{Maxg-P}\}/255 - 1/255)$. The resulting output image values are now thresholded to produce a binary image: all output image pixel values less than a threshold value of 0.85 are set to zero, and all other pixel values are set to 1. The threshold of 0.85 was arrived at experimentally using trial images.

[0025] At b) the image output from step a) is inverted so that epithelial layers now appear white and background and holes appear black. A morphological dilation is applied to the inverted image which thickens and closes small gaps in the white epithelial layers but leaving background and tubule holes unaffected. The objective of b) is to close boundaries likely to contain tubules that might have been left open by step a). Morphological operations are often used to fuse narrow gaps and eliminate small holes in individual groups of contiguous pixels appearing as blobs in an image. They can be thought of as removal of irregularities or spatial "noise", and they are standard image processing procedures published in Umbaugh S.C., 'Colour vision and image processing', Prentice Hall, 1998. In this instance the morphological dilation is represented by a disc-shaped structuring element with 5 rows and 5 columns and corresponding (by convention) to a radius R of two pixels:

$$\text{Structuring element} = \begin{array}{ccccc} & & 0 & 0 & 1 & 0 & 0 \\ & & 0 & 1 & 1 & 1 & 0 \\ & 1 & 1 & 1 & 1 & 1 & \\ & 0 & 1 & 1 & 1 & 0 & \\ & 0 & 0 & 1 & 0 & 0 & \end{array} \quad \begin{array}{c} \updownarrow \\ R \end{array} \quad (2)$$

here the expression "disc-shaped" arises from the distribution of 1 s in the element which appear as a rudimentary disc.

[0026] Morphological dilation is an expansion operation: for an original binary image (i.e. having pixel values 1 and 0 only), the expansion operation comprises locating each pixel with value 1 and setting pixels nearby to it also to 1. The structuring element defined by Equation (2) above illustrates this: the central 1 indicates a pixel under consideration and 1 s above, below, on either side of it and diagonally near to it indicate pixels in the binary image set to 1; 0s in the structuring element indicate relative positions of pixels that remain unchanged.

[0027] At c) a median filter is applied to the output of step b): the median filter operation selects each pixel in the output of step b) in succession and takes a 3 x 3 array of those pixels centred on the selected pixel; the 3 x 3 array of pixels is then sorted into ascending order of pixel value, i.e. 0s followed by 1s. The median pixel value (fifth of nine) is then taken as the filter output to replace the value of the selected pixel. The filter output will be 0 or 1 according to whether or not the 3 x 3 array has more 0s than 1 s. This is repeated across the image. Pixels in or separated by one pixel from edge rows and columns do not have the requisite 3 x 3 array, and for these the original pixel values are retained in the median filtered image. Median filtering is desirable to remove small isolated groups of pixels generated during thresholding at a). Step c) is desirable (but not essential) - it has the effect of smoothing blobs in the median filtered binary image produced at b).

[0028] The output image from step c) contains image regions or blobs which are white outlines around tubule structures, and the next process at d) is to fill these blobs to make them solid for further processing - the objective is to fill in holes which ideally lie within tubules. To achieve this, all pixels contained within each boundary of white pixels are set to the same value as the boundary. Here a hole is a set of background pixels that cannot be reached by filling in the background from the edge of the image: the technique of hole-filling is based on morphological reconstruction as published in Piere Soille, 'Morphological image analysis: Principals and Applications', Springer-Verlag, 1999, pp 173-174. At e), a binary image resulting from d) is then subjected to morphological opening using the 9x9 disc shaped structuring element, defined below in Equation (3).

$$\begin{array}{cccccccc}
 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\
 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\
 5 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
 \text{Structuring element} = & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
 10 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\
 15 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0
 \end{array} \quad (3)$$

[0029] Step e) removes small groups of dark pixels such as 56 that are not part of larger objects or boundaries around tubules.

[0030] Steps a) to e) identify blobs in the greyscale image 50 (corresponding either to dark areas with holes inside or to wholly dark objects) that are more likely to be the boundaries of tubules. In Figure 4, a binary image 60 is shown which is the output of step e): identified blobs are now represented as closed blobs 61 (i.e. containing no holes) of varying sizes of pixel value 1 in a background 62 of 0s.

[0031] Step 34 is a procedure undertaken to extract white regions of the initial greyscale image 50, these regions appearing as relatively high value pixel groups. This step is shown in more detail at f), g) and h) within chain lines 35. At f), each pixel value in the initial image 50 is divided by 255 so that it lies in the range 0 to 1, and then the pixel values x in the resulting image (input image in the table below) are remapped to an output image for the selection of light regions in accordance with the following table:

Input image value	Output image value
$< (\text{maximum} - Q) / 255$	0
$\geq (\text{maximum} - Q)/255 \text{ AND } \leq 1.0$	Mapped to the range [0,1]

Where $Q = 40(\text{Max}_g - \text{Min}_g)/100$

[0032] In the above table, the expression "Mapped to the range [0,1]" means that: a pixel value x which is $\text{BOTH } \geq (\text{maximum} - Q)/255 \text{ AND } \leq 1.0$ becomes:

$$(x - (\text{maximum} - Q)/255) / (1 - (\text{maximum} - Q)/255).$$

[0033] The resulting output image values are thresholded at g) to produce a binary image: all output image pixel values less than a threshold value of 0.35 are set to zero, and all other pixel values are set to 1. The threshold of 0.35 was arrived at experimentally using trial images. An image 70 resulting from g) is shown in Figure 5: it is equivalent to the image 50 with "white island" areas 72 shown cross-hatched.

[0034] Referring to Figure 4 once more, the image 60 resulting from step e) contains black objects 61 among which there are dark tubule boundaries with respective filled (darkened) inner regions (originally white), all marked as a single object of pixel 1 values and in a background of 0s. The image 70 resulting from step g) contains regions 72 of pixel value 1 which corresponding to lighter regions 52/55 of the greyscales image 50. The image 70 also contains 0s in positions corresponding to darker regions 51/53 of the image 50. At h), a logical AND operation is now carried out between each pixel in the image 60 with the respective corresponding pixel in the same position in the other image 70. The AND operation is equivalent in this instance to multiplication because a one-bit AND operation gives the product of two input bits. The output of the AND operation is 1 in each case where both ANDed pixels are 1, and is 0 otherwise. Also at h), the result of the AND operation is smoothed.

[0035] Figure 6 shows a binary image 80 resulting from the AND operation between the images 60 and 70 and subsequent smoothing at h). The image 80 has 1 s only at locations 81 (shown cross-hatched) corresponding (see

image 50) to central holes such as 52 in potential tubules 51. This has the effect of removing objects which correspond in the original greyscales image 50 to isolated white islands (usually fat cells) which are not surrounded by a dark boundary.

[0036] At 36 a respective connected component labelling (CCL) operation is applied to each of the images 60 and 80 resulting from e) and h): CCL is a known image processing technique (sometimes referred to as 'blob colouring') published by Klette R., Zamperoni P., 'Handbook of Image Processing Operators', John Wiley & Sons, 1996, and Rosenfeld A., Kak A.C., 'Digital Picture Processing', vols. 1 & 2, Academic Press, New York, 1982. It gives different numerical labels to objects (blobs) in a binary image containing 0s and 1s only, objects being groups of contiguous or connected pixels of 1: each object is assigned a number (label) different to others to enable it to be distinguished. CCL labels objects with numbers beginning with 1, so the numbers of the highest numbered objects in the images 60 and 80 are respectively the number of objects which might potentially be tubules and the number of holes previously within dark areas.

[0037] A tubule may contain one or more holes, and this is required to be detected to avoid an incorrect tubule count. At 38, each pixel in the h) image 80 is multiplied by the corresponding pixel in the same location in the CCL of image 60, which is a colour image when displayed on a colour monitor because CCL gives different colours to different objects. Figure 7 shows an image 90 resulting from multiplication at 38: the image 90 does not have an image feature corresponding to the lower left hand blob in Figure 4, because it has been eliminated by multiplication by 0s in corresponding locations in the image 80. The image 90 retains features 91, 92 and 93a to 93c corresponding to tubule holes such as 52 in the initial image 50. In this example images were processed using computer software referred to as "Matlab®" produced by Mathworks Inc., an American corporation. A Matlab function "ismember" is used to identify holes 91 and 92 associated with respective single tubules that have different labels, and holes 93a to 93c all associated with the same tubule that have the same label albeit different to those of holes 91 and 92. Differences in labelling and colouring is indicated in Figure 7 by differing shading, i.e. hole 91 is unshaded, hole 92 is dotted and like-labelled holes 93a to 93c are all cross-hatched. The number of different shadings in Figure 9 reflects the number of tubules corrected for multiple holes in any tubule.

[0038] The areas of the objects and holes labelled are also obtained using a Matlab function "find" in order to compute the number of pixels per coloured object or hole. This gives the total object area in each case for the four objects 61 in Figure 4 (of which the lower left object 61 is later discarded), and the hole area for each of the holes 91 to 93 in Figure 7.

[0039] The following parameters are now derived:

N = Number of objects containing one or more holes (in image 90, $N = 3$)

NOB = Number of objects with and without holes ($NOB = 4$ in image 60)

ratio of total surface area of holes to total surface area of objects including their holes.

$$SURF = \frac{\text{total-holes area}}{\text{total-objects total area}} = \text{ratio of total surface area of holes to total surface area of objects including their holes.}$$

$PERCENT = N/NOB$ = ratio of number of objects with holes to total number of objects with and without holes

$$RATIO = \frac{\text{hole area}}{\text{object total area}}$$

for each object, the ratio of the area of its hole(s) to its area including its hole(s): $RATIO$ is large for objects (tubules) with relatively large holes and small for objects with relatively small holes compared to object size.

T = Number of objects containing significantly large holes, i.e. objects having $RATIO > 0.09$

The threshold used to determine T discriminates against small holes unlikely to correspond to tubules.

[0040] At 42 the parameters obtained above are used to grade tubules detected in an image, and to derive a score with a value of 1, 2 or 3: the score is derived with reference to prearranged thresholds obtained by analysing a set of images which a pathologist has graded. The thresholding operation is performed using independent tests: the results of these tests are subsequently combined to yield a composite tubule score. Since the tests are all independent, any

one on its own or combination of two or more can be used to provide a tubule score, but use of all five tests to provide a composite score produces better results.

Test1: *PERCENT* is compared to 12 and 20. A high *PERCENT* >20 has been observed to characterise score 1 images, while a low *PERCENT* <12 characterises score 3 images; otherwise, i.e. if $12 \leq \text{PERCENT} \leq 20$, an image score of 2 is indicated.

Test2: *T* = Number of objects containing medium to large holes, i.e. for which *RATIO* > 0.09, is compared to threshold values of 2 and 5: $T < 2$, i.e. $T = 1$ or 0, indicates an image score of 3, whereas $T = 5$ or greater indicates score 1; otherwise, i.e. if $T = 2, 3$ or 4, the score is more likely to be 2.

Test3: *RATIO* is large for objects (tubules) with relatively large holes and small for objects with relatively small holes compared to object size. *RATIO* is compared to threshold values of 0.07 and 0.03. When holes are large corresponding to image score 1, *RATIO* is likely to be higher than 0.07; when holes are small corresponding to image score 3, *RATIO* is likely to be below 0.03. Otherwise, i.e. if $0.03 \leq \text{RATIO} \leq 0.07$, the indicated image score is 2.

Test4: *N* = Number of objects containing one or more holes (in image 90, $N = 3$) corresponding to tubules. *N* is compared to 20 and 11: $N > 20$ indicates a score 1 image and $N < 11$ a score 3 image; otherwise i.e. if $11 \leq N \leq 20$, the indicated image score is 2.

Test5: *SURF*: If *SURF* is greater than 0.001, the total area of holes is large indicating an image score of 1; if *SURF* is less than or equal to 0.0002, the total area of holes is small indicating an image score of 3; otherwise, i.e. if *SURF* is greater than 0.0002 but not greater than 0.001, an image score of 2 is indicated.

[0041] The final tubule score for an image is taken as the median value of five scores obtained respectively from the above five tests. When two images are used, two results for each test are obtained: the mean of these two results is computed and used with corresponding mean values from the other tests to derive a median value over the test results.

[0042] The invention was tested on a set of 206 images acquired at low magnification X10: the results were 44 images at score 1, 24 images at score 2, 138 images at score 3 were gathered. The thresholds thereafter were set after a thorough observation of the image data obtained (grouping, clustering...) and reaching a compromise. It is important to note that those thresholds may not be appropriate to another set of data because of staining differences. Furthermore those thresholds might be biased due to the fact that the image dataset contained a disproportionately large number of score 3 images.

[0043] The percentage and numbers of images graded by the classifier process of the invention in agreement with a pathologist's score was computed as well as the percentage and numbers of images where agreement was lacking. The results are tabulated below.

Pathologist →	Score 1	Score 2	Score 3
Classifier ↓			
Score 1	70.4 %	4.2 %	5.1 %
Score 2	18.2 %	70.8 %	21.7 %
Score 3	11.4 %	25 %	73.2 %

Pathologist →	Score 1	Score 2	Score 3
Classifier ↓			
Score 1	31	1	7
Score 2	8	17	30
Score 3	5	6	101

[0044] Tubule gradings were calculated over 206 available images and compared with a pathologist's scores with the following results:

- 72.3 % (149) images were graded by the classifier process of the invention with a score in agreement with a pathologist's score;
- 21.8 % (45) images were graded by the classifier process of the invention with a score differing by 1 from a pathologist's score; and
- 5.8 % (12) images were graded by the classifier process of the invention with a score differing by 2 from a pathologist's score.

[0045] The image dataset contained more than three times as many score 3 images (138) compared to score 1 images (44) and more than five times as many compared to score 2 images (24). Best results were obtained for images scored 3 by pathologists with an 73.2% correct classification: this might be attributable to the high number of images available enabling thresholds to be more optimised for score 3 images. A classification which is at least 70% correct was achieved for images of all three scores 1, 2 and 3. Since pathologists themselves are not necessarily more than 70% correct, this means that so far as it is possible to do so the invention is verified as regards all three scores. The average time to compute results for an image was estimated to be in the range 20 to 40 seconds.

[0046] The processing of digital image data in the tubules process of the invention can clearly be implemented by an appropriate computer program recorded on a carrier medium and running on a conventional computer system. Such a program is straightforward for a skilled programmer to implement without requiring invention, because a number of the processing functions are commercially available as indicated, and others are well known computational procedures. Such a program and computer system will therefore not be described further.

[0047] The scope of the invention is defined by the appended claims.

Claims

1. A computer-implemented automated method of grading tubules in a first image (50) of a histological slide having the steps of:
 - a) providing a second image (60) of first objects (61) in the first image (50) which are sufficiently large and of appropriate pixel value characteristics at boundaries to potentially be tubules,
 - b) providing a third image (70) of second objects (72) in the first image (50) having pixel value characteristics of fat and holes within tubules,
 - c) combining data from the second and third images (60, 70) to identify selected second objects (81) which are within first objects (61),
 - d) performing one or more of the following:
 - i) counting first objects (61) in the first image (50) which may potentially be tubules to provide a parameter *NOB*,
 - ii) counting the first objects (51) having selected second objects (81) within them and likely to be tubules to provide a parameter *N*,
 - iii) determining the relative areas of selected second objects (81) as proportions of respective first objects (51) within which they are located to provide parameters *RATIO*,
 - iv) determining the total area of selected second objects (81) as a proportion of total area of first objects (51) within which they are located to provide a parameter *SURF*,
 - v) determining a parameter $PERCENT = N/NOB$, and
 - vi) counting the number of first objects (51) containing at least medium sized holes (52) to provide a parameter *T*, and
 - e) grading the first image's tubules (51) on the basis of the one or more parameters as aforesaid with reference to parameter threshold values.
2. A method according to Claim 1 **characterised in that** the step of providing the second image (60) includes filling holes (52) in first image objects (51) to provide second image first objects (61) without holes.
3. A method according to Claim 1 or 2 **characterised in that** a hole (52) is defined as a set of background pixels that cannot be reached by filling in background from an edge of the first image (51).

4. A method according to Claim 1, 2 or 3 **characterised in that** it includes the step of processing the third image (70) to distinguish between first objects (51) containing single selected second objects (92) from first objects (51) containing multiple selected second objects (93a, 93b, 93c).

5. A method according to Claim 1 **characterised in that** the step of providing a second image (60) incorporates:

- a) thresholding the first image (50) to provide a fourth image retaining relatively darker image pixels and rejecting relatively lighter image pixels,
- b) processing the fourth image by applying the following steps in succession, the first being applied to the fourth image and each after the first being applied to the outcome of the respective immediately preceding step: inversion, morphological dilation, median filtering, hole filling and morphological opening.

6. A method according to Claim 1 **characterised in that** the step of providing a third image (70) comprises thresholding the first image (50) to provide a binary fourth image in which relatively lighter image pixels have a different binary value to that of relatively darker image pixels.

7. A method according to Claim 1 **characterised in that** the step of combining data from the second and third images (60, 70) comprises multiplying pixels in the second image (60) by or ANDing them with respective corresponding pixels located in like positions the third image (70).

8. A method according to Claim 1 **characterised in that** the step of grading the first image's tubules (51) employs parameter threshold values set to obtain a grading comparable with that obtainable by an appropriate medical expert.

9. A method according to Claim 1 **characterised in that** in step d) all the parameters *NOB*, *N*, *RATIO*, *SURF*, *PERCENT* and *T* are obtained, and in step e) these parameters are used to grade the first image's tubules (51).

10. Computer apparatus for grading tubules in a first image (50) of a histological slide, said computer apparatus being programmed to:

- a) compute a second image (60) of first objects (61) in the first image (50) which are sufficiently large and of appropriate pixel value characteristics at boundaries to potentially be tubules,
- b) compute a third image (70) of second objects (72) in the first image (50) having pixel value characteristics of fat and holes within tubules,
- c) combine data from the second and third images (60, 70) to identify selected second objects (81) which are within first objects (61),
- d) implement one or more of the following:

- i) counting first objects (61) in the first image (50) which may potentially be tubules to provide a parameter *NOB*,
- ii) counting the first objects (51) having selected second objects (81) within them and likely to be tubules to provide a parameter *N*,
- iii) determining the relative areas of selected second objects (81) as proportions of respective first objects (51) within which they are located to provide parameters *RATIO*,
- iv) determining the total area of selected second objects (81) as a proportion of total area of first objects (51) within which they are located to provide a parameter *SURF*,
- v) determining a parameter $PERCENT = N/NOB$, and
- vi) counting the number of first objects (51) containing at least medium sized holes (52) to provide a parameter *T*, and

- e) grade the first image's tubules (51) on the basis of the one or more parameters as aforesaid with reference to parameter threshold values.

11. Computer apparatus according to Claim 10 **characterised in that** it is programmed to provide the second image (60) by filling holes (52) in first image objects (51) to provide second image first objects (61) without holes.

12. Computer apparatus according to Claim 10 or 11 **characterised in that** it is programmed to define a hole (52) as a set of background pixels that cannot be reached by filling in background from an edge of the first image (51).

13. Computer apparatus according to Claim 10, 11 or 12 **characterised in that** it is programmed to process the third image (70) to distinguish between first objects (51) containing single selected second objects (92) from first objects (51) containing multiple selected second objects (93a, 93b, 93c).

14. Computer apparatus according to Claim 10 **characterised in that** it is programmed to provide a second image (60) by:

- a) thresholding the first image (50) to provide a fourth image retaining relatively darker image pixels and rejecting relatively lighter image pixels,
- b) processing the fourth image by applying the following steps in succession, the first being applied to the fourth image and each after the first being applied to the outcome of the respective immediately preceding step: inversion, morphological dilation, median filtering, hole filling and morphological opening.

15. Computer apparatus according to Claim 10 **characterised in that** it is programmed to provide a third image (70) by thresholding the first image (50) to provide a binary fourth image in which relatively lighter image pixels have a different binary value to that of relatively darker image pixels.

16. Computer apparatus according to Claim 10 **characterised in that** it is programmed to combine data from the second and third images (60, 70) by multiplying pixels in the second image (60) by or ANDing them with respective corresponding pixels located in like positions the third image (70).

17. Computer apparatus according to Claim 10 **characterised in that** it is programmed to grade the first image's tubules (51) with parameter threshold values set to obtain a grading comparable with that obtainable by an appropriate medical expert.

18. Computer apparatus according to Claim 10 **characterised in that** it is programmed to obtain all the parameters *NOB*, *N*, *RATIO*, *SURF*, *PERCENT* and *T*, and to use these parameters to grade the first image's tubules (51).

19. A computer program for grading tubules in a first image (50) of a histological slide, said computer program containing a instructions to control a computer apparatus to:

- a) compute a second image (60) of first objects (61) in the first image (50) which are sufficiently large and of appropriate pixel value characteristics at boundaries to potentially be tubules,
- b) compute a third image (70) of second objects (72) in the first image (50) having pixel value characteristics of fat and holes within tubules,
- c) combine data from the second and third images (60, 70) to identify selected second objects (81) which are within first objects (61),
- d) implement one or more of the following:

- i) counting first objects (61) in the first image (50) which may potentially be tubules to provide a parameter *NOB*,
- ii) counting the first objects (51) having selected second objects (81) within them and likely to be tubules to provide a parameter *N*,
- iii) determining the relative areas of selected second objects (81) as proportions of respective first objects (51) within which they are located to provide parameters *RATIO*,
- iv) determining the total area of selected second objects (81) as a proportion of total area of first objects (51) within which they are located to provide a parameter *SURF*,
- v) determining a parameter $PERCENT = N/NOB$, and
- vi) counting the number of first objects (51) containing at least medium sized holes (52) to provide a parameter *T*, and

- e) grade the first image's tubules (51) on the basis of the one or more parameters as aforesaid with reference to parameter threshold values.

20. A computer program according to Claim 19 **characterised in that** it contains instructions for providing the second image (60) by filling holes (52) in first image objects (51) to provide second image first objects (61) without holes.

21. A computer program according to Claim 19 or 20 **characterised in that** it contains instructions for defining a hole (52) as a set of background pixels that cannot be reached by filling in background from an edge of the first image (51).

22. A computer program according to Claim 19, 20 or 21 **characterised in that** it contains instructions for processing the third image (70) to distinguish between first objects (51) containing single selected second objects (92) from first objects (51) containing multiple selected second objects (93a, 93b, 93c).

23. A computer program according to Claim 19 **characterised in that** it contains instructions for provision of a second image (60) by:

a) thresholding the first image (50) to provide a fourth image retaining relatively darker image pixels and rejecting relatively lighter image pixels,

b) processing the fourth image by applying the following steps in succession, the first being applied to the fourth image and each after the first being applied to the outcome of the respective immediately preceding step: inversion, morphological dilation, median filtering, hole filling and morphological opening.

24. A computer program according to Claim 19 **characterised in that** it contains instructions for provision of a third image (70) by thresholding the first image (50) to provide a binary fourth image in which relatively lighter image pixels have a different binary value to that of relatively darker image pixels.

25. A computer program according to Claim 19 **characterised in that** it contains instructions for combining data from the second and third images (60, 70) by multiplying pixels in the second image (60) by or ANDing them with respective corresponding pixels located in like positions the third image (70).

26. A computer program according to Claim 19 **characterised in that** it contains instructions for grading the first image's tubules (51) with parameter threshold values set to obtain a grading comparable with that obtainable by an appropriate medical expert.

27. A computer program according to Claim 19 **characterised in that** it contains instructions for controlling computer apparatus to obtain all the parameters *NOB*, *N*, *RATIO*, *SURF*, *PERCENT* and *T*, and to use these parameters to grade the first image's tubules (51).

Patentansprüche

1. Computerimplementiertes automatisiertes Verfahren zum Klassifizieren von Tubuli in einem ersten Bild (50) eines histologischen Objektträgers, das die folgenden Schritte umfasst:

- a) Bereitstellen eines zweiten Bildes (60) erster Objekte (61) in dem ersten Bild (50), die ausreichend groß sind und an den Grenzen geeignete Pixelwerteigenschaften besitzen, um möglicherweise als Tubuli zu gelten,
- b) Bereitstellen eines dritten Bildes (70) zweiter Objekte (72) in dem ersten Bild (50), die Pixelwerteigenschaften von Fett und von Löchern in Tubuli haben,
- c) Kombinieren von Daten des zweiten und des dritten Bildes (60, 70), um ausgewählte zweite Objekte (81) zu identifizieren, die sich in den ersten Objekten (61) befinden,
- d) Ausführen eines oder mehrerer der folgenden Schritte:

- i) Zählen erster Objekte (61) in dem ersten Bild (50), die möglicherweise als Tubuli gelten können, um einen Parameter *NOB* bereitzustellen,
- ii) Zählen der ersten Objekte (51), die in sich ausgewählte zweite Objekte (81) besitzen und wahrscheinlich Tubuli sind, um einen Parameter *N* bereitzustellen,
- iii) Bestimmen der relativen Flächen ausgewählter zweiter Objekte (81) als Anteile entsprechender erster Objekte (51), in denen sie sich befinden, um Parameter *RATIO* bereitzustellen,
- iv) Bestimmen der Gesamtfläche der ausgewählten zweiten Objekte (81) als einen Anteil der Gesamtfläche der ersten Objekte (51), in denen sie sich befinden, um einen Parameter *SURF* bereitzustellen,
- v) Bestimmen eines Parameters *PERCENT* = N/NOB , und
- vi) Zählen der Anzahl erster Objekte (51), die wenigstens mittelgroße Löcher (52) enthalten, um einen Parameter *T* bereitzustellen, und

e) Klassifizieren der Tubuli (51) des ersten Bildes anhand des einen oder der mehreren Parameter wie oben angegeben in Bezug auf Parameter-Schwellenwerte.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Schritt des Bereitstellens des zweiten Bildes (60) das Füllen von Löchern (52) in den Objekten (51) des ersten Bildes umfasst, um erste Objekte (61) des zweiten Bildes ohne Löcher bereitzustellen.
- 5 3. Verfahren nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** ein Loch als eine Gruppe von Hintergrundpixeln definiert ist, die nicht durch Füllen des Hintergrundes ausgehend von einer Kante des ersten Bildes (51) erreicht werden können.
- 10 4. Verfahren nach Anspruch 1, 2 oder 3, **dadurch gekennzeichnet, dass** es den Schritt des Verarbeitens des dritten Bildes (70) umfasst, um zwischen ersten Objekten (51), die einzelne ausgewählte zweite Objekte (92) enthalten, und ersten Objekten (51), die mehrere ausgewählte zweite Objekte (93a, 93b, 93c) enthalten, zu unterscheiden.
- 15 5. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Schritt des Bereitstellens eines zweiten Bildes (60) umfasst:
 - a) Anwenden von Schwellenwerten auf das erste Bild (50), um ein viertes Bild bereitzustellen, indem verhältnismäßig dunklere Bildpixel beibehalten werden und verhältnismäßig hellere Bildpixel verworfen werden,
 - b) Verarbeiten des vierten Bildes durch aufeinander folgendes Anwenden der folgenden Schritte, wovon der erste Schritt auf das vierte Bild angewendet wird und jeder Schritt nach dem ersten Schritt auf das Ergebnis des jeweils direkt vorhergehenden Schrittes angewendet wird: Inversion, morphologische Dilatation, Medianfilterung, Lochbefüllung und morphologische Öffnung.
- 20 6. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Schritt des Bereitstellens eines dritten Bildes (70) das Anwenden von Schwellenwerten auf das erste Bild (50) umfasst, um ein binäres viertes Bild bereitzustellen, in dem verhältnismäßig hellere Bildpixel einen anderen binären Wert als verhältnismäßig dunklere Bildpixel haben.
- 25 7. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Schritt des Kombinierens von Daten aus dem zweiten und dem dritten Bild (60, 70) das Multiplizieren von Pixeln in dem zweiten Bild (60) mit entsprechenden Pixeln, die sich an ähnlichen Positionen im dritten Bild (70) befinden, oder die Anwendung einer UND-Verknüpfung auf diese umfasst.
- 30 8. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** der Schritt des Klassifizierens der Tubuli (51) des ersten Bildes Parameter-Schwellenwerte verwendet, die so gesetzt sind, dass eine Klassifizierung erhalten wird, die mit jener vergleichbar ist, die durch einen geeigneten medizinischen Experten erhalten werden kann.
- 35 9. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** im Schritt d) alle Parameter NOB, N, RATIO, SURF, PERCENT und T erhalten werden und im Schritt e) diese Parameter verwendet werden, um die Tubuli (51) des ersten Bildes zu klassifizieren.
- 40 10. Computervorrichtung zum Klassifizieren von Tubuli in einem ersten Bild (50) eines histologischen Objektträgers, wobei die Computervorrichtung so programmiert ist, dass sie:
 - a) ein zweites Bild (60) erster Objekte (61) in dem ersten Bild (50) berechnet, die ausreichend groß sind und an den Grenzen geeignete Pixelwerteigenschaften haben, um möglicherweise als Tubuli zu gelten,
 - 45 b) ein drittes Bild (70) zweiter Objekte (72) in dem ersten Bild (50) berechnet, das Pixelwerteigenschaften von Fett und von Löchern in Tubuli besitzt,
 - c) Daten aus dem zweiten und dem dritten Bild (60, 70) kombiniert, um ausgewählte zweite Objekte (61), die sich in den ersten Objekten (61) befinden, zu identifizieren,
 - 50 d) einen oder mehrere der folgenden Schritte implementiert:
 - i) Zählen erster Objekte (61) in dem ersten Bild (50), die möglicherweise als Tubuli gelten können, um einen Parameter NOB bereitzustellen,
 - ii) Zählen der ersten Objekte (51), die in sich ausgewählte zweite Objekte (81) besitzen und wahrscheinlich Tubuli sind, um einen Parameter N bereitzustellen,
 - 55 iii) Bestimmen der relativen Flächen ausgewählter zweiter Objekte (81) als Anteile entsprechender erster Objekte (51), in denen sie sich befinden, um Parameter RATIO bereitzustellen,
 - iv) Bestimmen der Gesamtfläche der ausgewählten zweiten Objekte (81) als einen Anteil der Gesamtfläche der ersten Objekte (51), in denen sie sich befinden, um einen Parameter SURF bereitzustellen,

- v) Bestimmen eines Parameters $PERCENT = N/NOB$ und
- vi) Zählen der Anzahl erster Objekte (51), die wenigstens mittelgroße Löcher (52) enthalten, um einen Parameter T bereitzustellen, und

e) die Tubuli (51) des ersten Bildes anhand des einen oder der mehreren Parameter wie oben genannt mit Bezug auf Parameter-Schwellenwerte klassifiziert.

11. Computervorrichtung nach Anspruch 10, **dadurch gekennzeichnet, dass** sie so programmiert ist, dass sie das zweite Bild (60) durch Füllen von Löchern (52) in den ersten Bildobjekten (51) bereitstellt, um erste Objekte (61) des zweiten Bildes ohne Löcher bereitzustellen.

12. Computervorrichtung nach Anspruch 10 oder 11, **dadurch gekennzeichnet, dass** sie so programmiert ist, dass sie ein Loch (52) als eine Menge von Hintergrundpixeln definiert, die nicht durch Füllen des Hintergrundes ausgehend von einer Kante des ersten Bildes (51) erreicht werden können.

13. Computervorrichtung nach Anspruch 10, 11 oder 12, **dadurch gekennzeichnet, dass** sie so programmiert ist, dass sie das dritte Bild (70) verarbeitet, um zwischen ersten Objekten (51), die einzelne ausgewählte zweite Objekte (92) enthalten, und ersten Objekten (51), die mehrere ausgewählte zweite Objekte (93a, 93b, 93c) enthalten; zu unterscheiden.

14. Computervorrichtung nach Anspruch 10, **dadurch gekennzeichnet, dass** sie so programmiert ist, dass sie ein zweites Bild (60) **dadurch** schafft, dass:

- a) auf das erste Bild (50) Schwellenwerte angewendet werden, um ein viertes Bild bereitzustellen, indem verhältnismäßig dunklere Bildpixel beibehalten werden und verhältnismäßig hellere Bildpixel verworfen werden,
- b) das vierte Bild durch aufeinander folgendes Anwenden der folgenden Schritte verarbeitet wird, wovon der erste Schritt auf das vierte Bild angewendet wird und jeder Schritt nach dem ersten Schritt auf das Ergebnis des jeweils unmittelbar vorhergehenden Schrittes angewendet wird: Inversion, morphologische Dilatation, Medianfilterung, Lochbefüllung und morphologische Öffnung.

15. Computervorrichtung nach Anspruch 10, **dadurch gekennzeichnet, dass** sie so programmiert ist, dass sie ein drittes Bild (70) durch Anwenden von Schwellenwerten auf das erste Bild (50) bereitstellt, um ein binäres viertes Bild bereitzustellen, in dem verhältnismäßig hellere Bildpixel einen anderen binären Wert haben als verhältnismäßig dunklere Bildpixel.

16. Computervorrichtung nach Anspruch 10, **dadurch gekennzeichnet, dass** sie so programmiert ist, dass sie die Daten aus dem zweiten und dem dritten Bild (60, 70) **dadurch** kombiniert, dass sie Pixel im zweiten Bild (60) mit entsprechenden Pixeln, die sich an ähnlichen Positionen im dritten Bild (70) befinden, multipliziert oder auf diese eine UND-Verknüpfung anwendet.

17. Computervorrichtung nach Anspruch 10, **dadurch gekennzeichnet, dass** sie so programmiert ist, dass sie die Tubuli (51) des ersten Bildes mit Parameter-Schwellenwerten klassifiziert, die so gesetzt sind, dass eine Klassifizierung erhalten wird, die mit jener vergleichbar ist, die durch einen geeigneten medizinischen Experten erhalten werden kann.

18. Computervorrichtung nach Anspruch 10, **dadurch gekennzeichnet, dass** sie so programmiert ist, dass alle Parameter NOB, N, RATIO, SURF, PERCENT und T erhalten werden, und dass diese Parameter verwendet werden, um die Tubuli (51) des ersten Bildes zu klassifizieren.

19. Computerprogramm für die Klassifizierung von Tubuli in einem ersten Bild (50) eines histologischen Objektträgers, wobei das Computerprogramm Befehle enthält, um eine Computervorrichtung zu steuern, damit sie

- a) ein zweites Bild (60) erster Objekte (61) in dem ersten Bild (50) berechnet, die ausreichend groß sind und an den Grenzen geeignete Pixelwerteigenschaften haben, damit sie möglicherweise als Tubuli gelten können,
- b) ein drittes Bild (70) zweiter Objekte (72) in dem ersten Bild (50) berechnet, das Pixelwerteigenschaften von Fett und von Löchern in Tubuli besitzt,
- c) Daten aus dem zweiten und dem dritten Bild (60, 70) kombiniert, um ausgewählte zweite Objekte (61), die sich in den ersten Objekten (61) befinden, zu identifizieren,

d) einen oder mehrere der folgenden Schritte implementiert:

- i) Zählen erster Objekte (61) in dem ersten Bild (50), die möglicherweise als Tubuli gelten können, um einen Parameter NOB bereitzustellen,
- ii) Zählen der ersten Objekte (51), die in sich ausgewählte zweite Objekte (81) besitzen und wahrscheinlich Tubuli sind, um einen Parameter N bereitzustellen,
- iii) Bestimmen der relativen Flächen ausgewählter zweiter Objekte (81) als Anteile entsprechender erster Objekte (51), in denen sie sich befinden, um Parameter RATIO bereitzustellen,
- iv) Bestimmen der Gesamtfläche der ausgewählten zweiten Objekte (81) als einen Anteil der Gesamtfläche der ersten Objekte (51), in denen sie sich befinden, um einen Parameter SURF bereitzustellen,
- v) Bestimmen eines Parameters PERCENT = N/NOB und
- vi) Zählen der Anzahl erster Objekte (51), die wenigstens mittelgroße Löcher (52) enthalten, um einen Parameter T bereitzustellen, und

e) die Tubuli (51) des ersten Bildes anhand des einen oder der mehreren Parameter wie oben genannt mit Bezug auf Parameter-Schwellenwerte klassifiziert.

20. Computerprogramm nach Anspruch 19, **dadurch gekennzeichnet, dass** sie Befehle enthält, um das zweite Bild (60) durch Füllen von Löchern (52) in Objekten (51) des ersten Bildes bereitzustellen, um erste Objekte (61) des zweiten Bildes ohne Löcher bereitzustellen.

21. Computerprogramm nach Anspruch 19 oder 20, **dadurch gekennzeichnet, dass** es Befehle enthält, um ein Loch (52) als eine Menge von Hintergrundpixeln zu definieren, die nicht durch Füllen des Hintergrundes ausgehend von einer Kante des ersten Bildes (51) erreicht werden können.

22. Computerprogramm nach Anspruch 19, 20 oder 21, **dadurch gekennzeichnet, dass** es Befehle enthält, um das dritte Bild (70) zu verarbeiten, um zwischen ersten Objekten (51), die einzelne ausgewählte zweite Objekte (92) enthalten, und ersten Objekten (51), die mehrere ausgewählte zweite Objekte (93a, 93b, 93c) enthalten, zu unterscheiden.

23. Computerprogramm nach Anspruch 19, **dadurch gekennzeichnet, dass** es Befehle enthält, um ein zweites Bild (60) **dadurch** bereitzustellen, dass:

- a) auf das erste Bild (50) Schwellenwerte angewendet werden, um ein viertes Bild bereitzustellen, indem verhältnismäßig dunklere Bildpixel beibehalten werden und verhältnismäßig hellere Bildpixel verworfen werden,
- b) das vierte Bild durch aufeinander folgendes Anwenden der folgenden Schritte verarbeitet wird, wovon der erste Schritt auf das vierte Bild angewendet wird und jeder Schritt nach dem ersten Schritt auf das Ergebnis des jeweils unmittelbar vorhergehenden Schrittes angewendet wird: Inversion, morphologische Dilatation, Medianfilterung, Lochbefüllung und morphologische Öffnung.

24. Computerprogramm nach Anspruch 19, **dadurch gekennzeichnet, dass** es Befehle enthält, um ein drittes Bild (70) durch Anwenden von Schwellenwerten auf das erste Bild (50) bereitzustellen, um ein binäres viertes Bild bereitzustellen, in dem verhältnismäßig hellere Bildpixel einen anderen binären Wert als verhältnismäßig dunklere Bildpixel haben.

25. Computerprogramm nach Anspruch 19, **dadurch gekennzeichnet, dass** es Befehle enthält, um Daten aus dem zweiten und dem dritten Bild (60, 70) **dadurch** zu kombinieren, dass Pixel in dem zweiten Bild (60) mit jeweils entsprechenden Pixeln, die sich an ähnlichen Positionen in dem dritten Bild (70) befinden, multipliziert werden oder auf diese eine UND-Verknüpfung angewendet wird.

26. Computerprogramm nach Anspruch 19, **dadurch gekennzeichnet, dass** es Befehle enthält, um die Tubuli (51) des ersten Bildes mit Parameter-Schwellenwerten zu klassifizieren, die so gesetzt sind, dass eine Klassifizierung erhalten wird, die mit jener vergleichbar ist, die durch einen geeigneten medizinischen Experten erhalten werden kann.

27. Computerprogramm nach Anspruch 19, **dadurch gekennzeichnet, dass** es Befehle enthält, um eine Computervorrichtung so zu steuern, dass alle Parameter NOB, N, RATIO, SURF, PERCENT und T erhalten werden, und dass diese Parameter verwendet werden, um die Tubuli (51) des ersten Bildes zu klassifizieren.

Revendications

1. Procédé automatisé implémenté par ordinateur, de classement de tubules dans une première image (50) d'une coupe histologique ayant les étapes de :

a) fourniture d'une seconde image (60) de premiers objets (61) dans la première image (50) qui sont suffisamment grands et de caractéristiques de valeur de pixel appropriées aux limites pour être potentiellement des tubules, b) fourniture d'une troisième image (80) de seconds objets (62) dans la première image (50) ayant des caractéristiques de valeur de pixel de graisse et de trous dans des tubules, c) combinaison de données à partir des seconde et troisième images (60, 70) pour identifier des seconds objets sélectionnés (81) qui sont dans les premiers objets (61), d) réalisation d'une ou de plusieurs étapes de ce qui suit :

i) comptage de premiers objets (61) dans la première image (50) qui peuvent être potentiellement des tubules pour fournir un paramètre NOB ;
 ii) comptage des premiers objets (51) ayant des seconds objets sélectionnés (81) en eux et susceptibles d'être des tubules pour fournir un paramètre N,
 iii) détermination des aires relatives des seconds objets sélectionnés (81) proportionnellement aux premiers objets respectifs (51) dans lesquelles ils sont situés pour fournir des paramètres RATIO,
 iv) détermination de l'aire totale des seconds objets sélectionnés (81) proportionnellement à une aire totale des premiers objets (51) dans lesquels ils sont situés pour fournir un paramètre SURF,
 v) détermination d'un paramètre $PERCENT = N/NOB$, et
 vi) comptage du nombre de premiers objets (51) contenant au moins des trous de taille moyenne (52) pour fournir un paramètre T, et

e) classement des premières tubules d'image (51) sur la base d'un ou de plusieurs paramètres comme susdit en référence à des valeurs de seuil de paramètre.

2. Procédé selon la revendication 1 **caractérisé en ce que** l'étape de fourniture de la seconde image (60) comprend le remplissage des trous (52) dans des premiers objets (51) pour fournir des premiers objets de seconde image (61) sans trous.

3. Procédé selon la revendication 1 ou 2 **caractérisé en ce qu'un** trou (52) est défini comme un ensemble de pixels d'arrière-plan qui ne peuvent pas être atteints par remplissage dans l'arrière-plan à partir d'un bord de la première image (51).

4. Procédé selon la revendication 1, 2 ou 3 **caractérisé en ce qu'il** comprend l'étape de traitement de la troisième image (70) pour distinguer entre des premiers objets (51) contenant des seconds objets sélectionnés uniques (92) à partir des premiers objets (51) contenant de multiples seconds objets sélectionnés (93a, 93b, 93c).

5. Procédé selon la revendication 1 **caractérisé en ce que** l'étape de fourniture d'une seconde image (60) incorpore :

a) le seuillage de la première image (50) pour fournir une quatrième image contenant des pixels d'image relativement plus foncés et pour éliminer des pixels d'image relativement plus clairs,
 b) traitement de la quatrième image en appliquant les étapes suivantes successivement, la première étant appliquée à la quatrième image et chacune après la première étant appliquée pour sortir de l'étape immédiatement précédente respective : inversion, dilatation morphologique, filtrage moyen, remplissage de trou et ouverture morphologique.

6. Procédé selon la revendication 1 **caractérisé en ce que** l'étape de fourniture d'une troisième image (70) comprend le seuillage de la première image (50) pour fournir une quatrième image binaire dans laquelle des pixels d'image relativement plus clairs ont une valeur binaire différente de celle des pixels d'image relativement plus clairs.

7. Procédé selon la revendication 1 **caractérisé en ce que** l'étape de combinaison de données à partir des seconde et troisième images (60, 70) comprend la multiplication des pixels dans la seconde image (60) par, ou en effectuant une opération ET sur eux avec, des pixels correspondants respectifs situés à des positions analogues de la troisième image (70).

8. Procédé selon la revendication 1 **caractérisé en ce que** l'étape de classement des premières images de tubules (51) emploie des valeurs de seuil de paramètre réglées pour obtenir un classement comparable à celui pouvant être obtenu par un expert médical approprié.

9. Procédé selon la revendication 1 **caractérisé en ce que** dans l'étape d), tous les paramètres NOB, N, RATIO, SURF, PERCENT et T sont obtenus, et dans l'étape e), ces paramètres sont utilisés pour classer les premières images de tubules (51).

10. Appareil informatique pour classer des tubules dans une première image (50) d'une coupe histologique, ledit appareil informatique étant programmé pour:

- a) calculer une seconde image (60) de premiers objets (61) dans la première image (50) qui sont suffisamment grands et de caractéristiques de valeur de pixel appropriées aux limites pour être potentiellement des tubules,
- b) calculer une troisième image (70) de seconds objets (72) dans la première image (50) ayant des caractéristiques de valeur de pixel et de la graisse et des trous dans des tubules,
- c) combiner des données à partir des seconde et troisième images (60, 70) pour identifier des seconds objets sélectionnés (81) qui sont dans des premiers objets (61),
- d) implémenter une ou plusieurs étapes e ce qui suit :

- i) compter des premiers objets (61) dans la première image (50) qui peuvent être potentiellement des tubules pour fournir un paramètre NOB ;
- ii) compter des premiers objets (51) ayant des seconds objets sélectionnés (81) en eux et susceptibles d'être des tubules pour fournir un paramètre N,
- iii) déterminer des aires relatives des seconds objets sélectionnés (81) proportionnellement aux premiers objets respectifs (51) dans lesquelles ils sont situés pour fournir des paramètres RATIO,
- iv) déterminer l'aire totale des seconds objets sélectionnés (81) proportionnellement à une aire totale des premiers objets (51) dans lesquels ils sont situés pour fournir un paramètre SURF,
- v) déterminer un paramètre $PERCENT = N/NOB$, et
- vi) compter le nombre de premiers objets (51) contenant au moins des trous de taille moyenne (52) pour fournir un paramètre T, et

e) classer les premières tubules d'image (51) sur la base d'un ou de plusieurs paramètres comme susdit en référence à des valeurs de seuil de paramètre.

11. Appareil informatique selon la revendication 10 **caractérisé en ce qu'il** est programmé pour fournir la seconde image (50) par le remplissage des trous (52) dans des premiers objets d'image (51) pour fournir des premiers objets de seconde image (61) sans trous.

12. Appareil informatique selon la revendication 10 ou 11 **caractérisé en ce qu'il** est programmé pour définir un trou (52) comme un ensemble de pixels d'arrière-plan qui ne peuvent pas être atteints par le remplissage dans l'arrière-plan à partir d'un bord de la première image (51).

13. Appareil informatique selon la revendication 10, 11 ou 12 **caractérisé en ce qu'il** est programmé pour traiter la troisième image (70) pour distinguer entre des premiers objets (51) contenant des seconds objets sélectionnés uniques (92) à partir des premiers objets (51) contenant de multiples seconds objets sélectionnés (93a, 93b, 93c).

14. Appareil informatique selon la revendication 10 **caractérisé en ce qu'il** est programmé pour fournir une seconde image (60) par :

- a) le seuillage de la première image (50) pour fournir une quatrième image contenant des pixels d'image relativement plus sombres et pour éliminer des pixels d'image relativement plus clairs,
- b) le traitement de la quatrième image en appliquant les étapes suivantes successivement, la première étant appliquée à la quatrième image et chacune après la première étant appliquée pour sortir de l'étape immédiatement précédente respective : inversion, dilatation morphologique, filtrage moyen, remplissage de trou et ouverture morphologique.

15. Appareil informatique selon la revendication 10 **caractérisé en ce qu'il** est programmé pour fournir une troisième image (70) par le seuillage de la première image (50) pour fournir une quatrième image binaire dans laquelle des

pixels d'image relativement plus clairs ont une valeur binaire différente de celle des pixels d'image relativement plus clairs.

5 16. Appareil informatique selon la revendication 10 **caractérisé en ce qu'il** est programmé pour combiner des données à partir des seconde et troisième images (60, 70) en multipliant des pixels dans la seconde image (60) par, ou en effectuant une opération ET sur eux avec, des pixels correspondants respectifs situés à des positions analogues de la troisième image (70).

10 17. Appareil informatique selon la revendication 10 **caractérisé en ce qu'il** est programmé pour classer les premières tubules d'image (51) avec des valeurs de seuil de paramètre réglées pour obtenir un classement comparable à celui pouvant être obtenu par un expert médical approprié.

15 18. Appareil informatique selon la revendication 10 **caractérisé en ce qu'il** est programmé pour obtenir tous les paramètres NOB, N, RATIO, SURF, PERCENT et T, et pour utiliser ces paramètres pour classer les premières tubules d'image (51).

19. Appareil informatique pour classer des tubules dans une première image (50) d'une coupe histologique, ledit programme informatique contenant des instructions pour commander un appareil informatique pour :

- 20 a) calculer une seconde image (60) de premiers objets (61) dans la première image (50) qui sont suffisamment grands et de caractéristiques de valeur de pixel appropriées aux limites pour être potentiellement des tubules,
 b) calculer une troisième image (70) de seconds objets (72) dans la première image (50) ayant des caractéristiques de valeur de pixel et de la graisse et des trous dans des tubules,
 25 c) combiner des données à partir des seconde et troisième images (60, 70) pour identifier des seconds objets sélectionnés (81) qui sont dans des premiers objets (61),
 d) implémenter une ou plusieurs étapes de ce qui suit :

- i) compter de premiers objets (61) dans la première image (50) qui peuvent être potentiellement des tubules pour fournir un paramètre NOB ;
 30 ii) compter des premiers objets (51) ayant des seconds objets sélectionnés (81) en eux et susceptibles d'être des tubules pour fournir un paramètre N,
 iii) déterminer les aires relatives des seconds objets sélectionnés (81) proportionnellement aux premiers objets respectifs (51) dans lesquelles ils sont situés pour fournir des paramètres RATIO,
 iv) déterminer l'aire totale des seconds objets sélectionnés (81) proportionnellement à une aire totale des
 35 premiers objets (51) dans lesquels ils sont situés pour fournir un paramètre SURF,
 v) déterminer un paramètre $PERCENT = N/NOB$, et
 vi) compter le nombre de premiers objets (51) contenant au moins des trous de taille moyenne (52) pour fournir un paramètre T, et

- 40 e) classer les premières tubules d'image (51) sur la base d'un ou de plusieurs paramètres comme susdit en référence à des valeurs de seuil de paramètre.

20. Programme informatique selon la revendication 19 **caractérisé en ce qu'il** contient des instructions pour fournir la seconde image (60) en remplissant des trous (52) dans des premiers objets d'image (51) pour fournir des premiers objets de seconde image (61) sans trous.

21. Programme informatique selon la revendication 19 ou 20 **caractérisé en ce qu'il** contient des instructions pour définir un trou (52) comme un ensemble de pixels d'arrière-plan qui ne peuvent pas être atteints par remplissage dans l'arrière-plan à partir d'un bord de la première image (51).

22. Programme informatique selon la revendication 19, 20 ou 21 **caractérisé en ce qu'il** contient des instructions pour traiter la troisième image (70) pour distinguer entre des premiers objets (51) contenant des seconds objets sélectionnés uniques (92) à partir des premiers objets (51) contenant de multiples seconds objets sélectionnés (93a, 93b, 93c).

23. Programme informatique selon la revendication 19 **caractérisé en ce qu'il** contient des instructions pour fournir une seconde image (60) par :

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a) le seuillage de la première image (50) pour fournir une quatrième image contenant des pixels d'image relativement plus foncés et pour éliminer des pixels d'image relativement plus clairs,

b) le traitement de la quatrième image en appliquant les étapes suivantes successivement, la première étant appliquée à la quatrième image et chacune après la première étant appliquée pour sortir de l'étape immédiatement précédente respective : inversion, dilatation morphologique, filtrage moyen, remplissage de trou et ouverture morphologique.

24. Programme informatique selon la revendication 19 **caractérisé en ce qu'il** contient des instructions pour fournir une troisième image (70) par le seuillage de la première image (50) pour fournir une quatrième image binaire dans laquelle des pixels d'image relativement plus clairs ont une valeur binaire différente de celle des pixels d'image relativement plus sombres.

25. Programme informatique selon la revendication 19 **caractérisé en ce qu'il** contient des instructions pour combiner des données à partir des seconde et troisième images (60, 70) en multipliant des pixels dans la seconde image (60) par, ou en effectuant une opération ET sur eux avec, des pixels correspondants respectifs situés à des positions analogues de la troisième image (70).

26. Programme informatique selon la revendication 19 **caractérisé en ce qu'il** contient des instructions pour classer les premières tubules d'image (51) avec des valeurs de seuil de paramètre réglées pour obtenir un classement comparable à celui pouvant être obtenu par un expert médical approprié.

27. Programme informatique selon la revendication 19 **caractérisé en ce qu'il** contient des instructions pour commander un appareil informatique pour obtenir tous les paramètres NOB, N, RATIO, SURF, PERCENT et T, et pour utiliser ces paramètres pour classer les premières tubules d'image (51).

Fig.1.

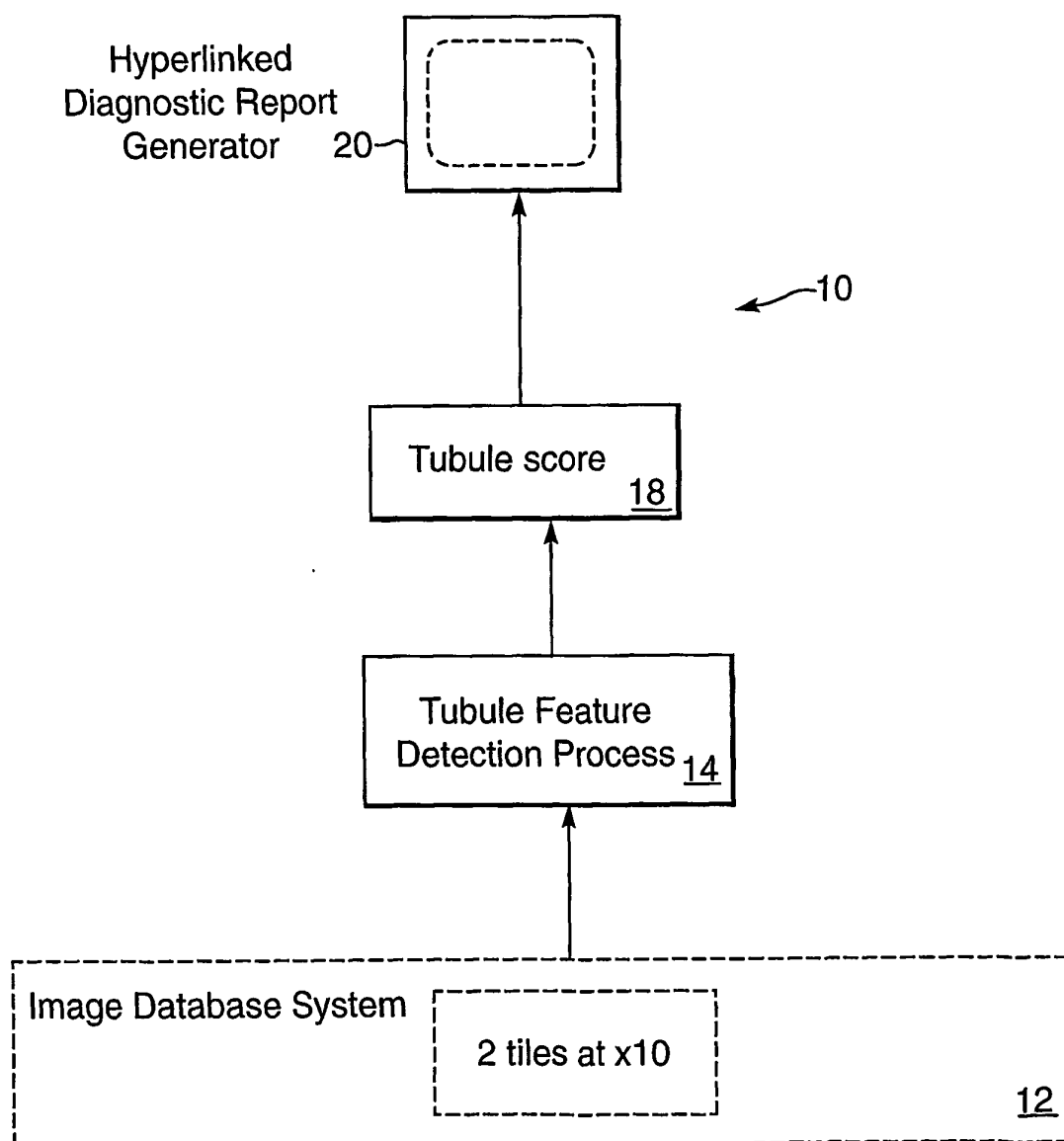


Fig.2.

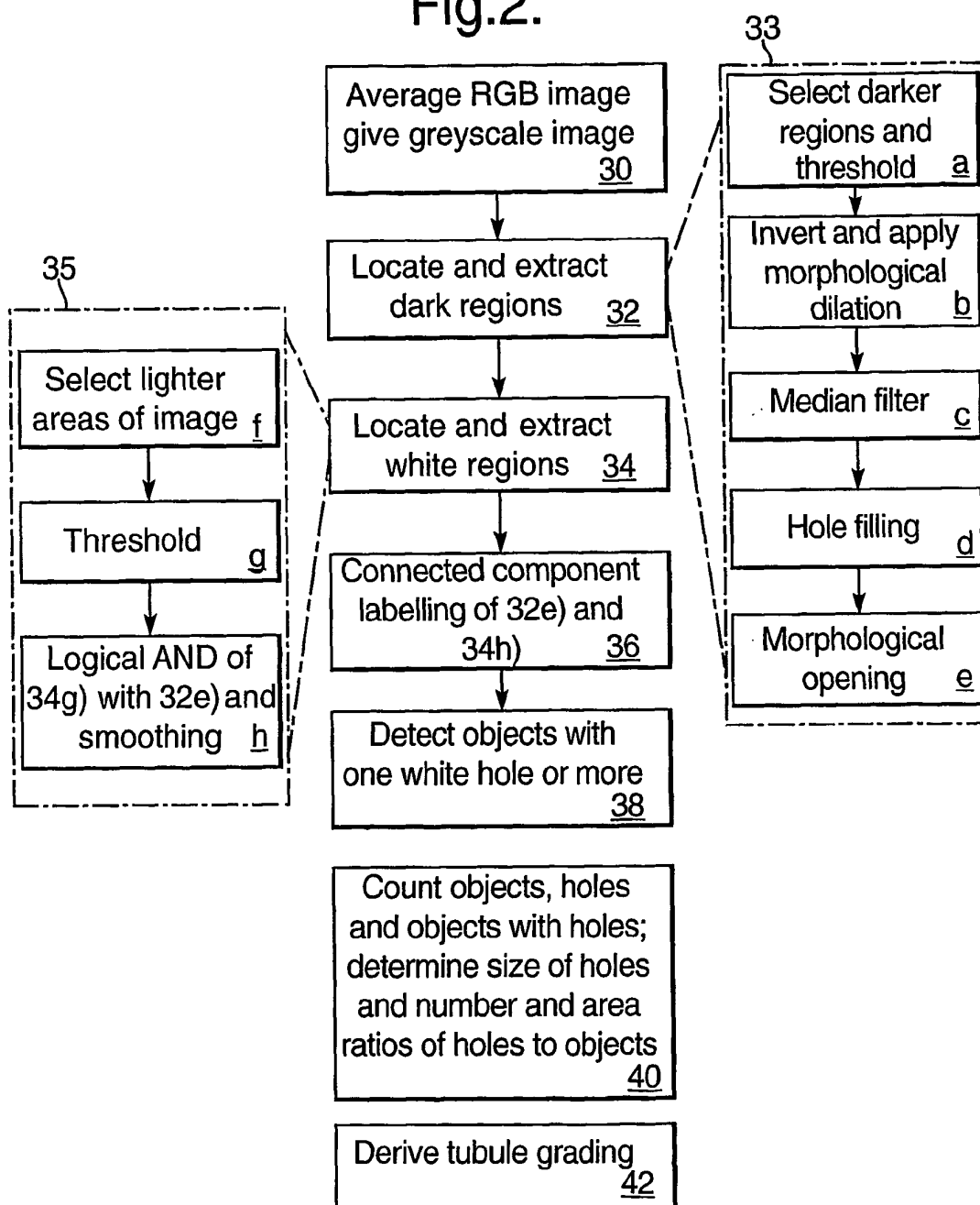


Fig.3.

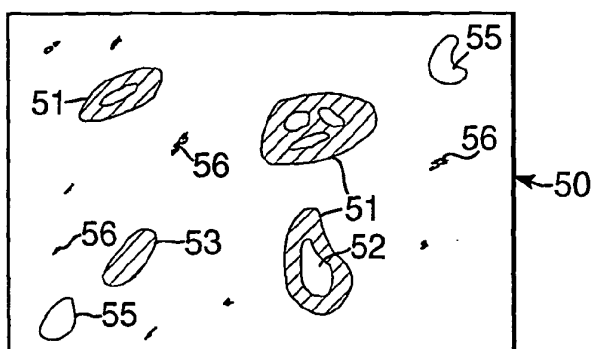


Fig.4.

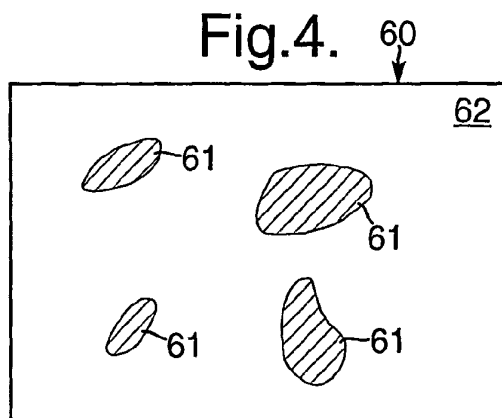


Fig.5.

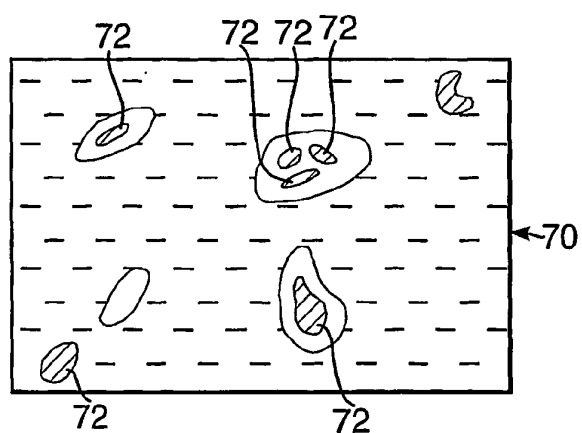


Fig.6.

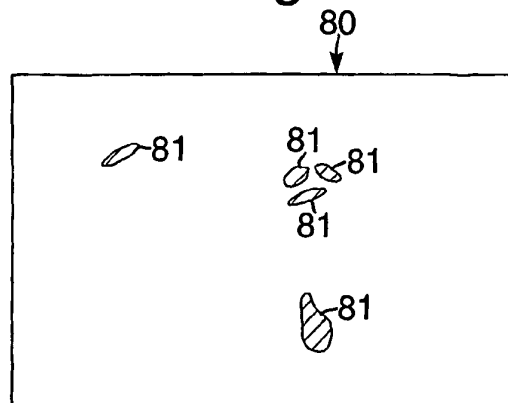


Fig.7.

