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(72) Inventors:
• **Mark, Erwin Paul**
65824 Schwalbach (DE)
• **Noll, Adrian**
61476 Kronberg (DE)

(74) Representative: **Töpert, Verena Clarita**
Procter & Gamble Service GmbH
IP Department
Sulzbacher Straße 40-50
65824 Schwalbach am Taunus (DE)

(71) Applicant: **The Procter & Gamble Company**
Cincinnati, OH 45202 (US)

(54) **METHOD AND DEVICE FOR QUANTIFYING A WEAR LEVEL OF A BRISTLE FIELD OF A BRUSH**

(57) A method and device for quantifying a wear level of a bristle field of a brush are disclosed comprising a plurality of bristle tufts grouping each a plurality of single bristles, said bristle tufts being distributed over the bristle field, the method comprising the following steps:
- recording and storing an image of the bristle field;
- converting the image into a gray scale image by use of digital image processing and storing the gray scale image;
- converting the gray scale image to at least one binarized image with only two tone values by use of digital image processing, thereby assigning one tone value to bristles and/or bristle tufts visible in the image and the other tone

value to the background in the image not showing bristles or bristle tufts, and storing the binarized image;
- applying the following evaluation method:
determining the geometrical splay of the bristle field (3) by creating a contour image, wherein the contour of the image is determined by edge detection of the grey scale image by use of digital image processing,

- comparing the results of the applied evaluation method with reference data of an unused brush and/or of used brushes with determined wear levels to classify the wear level of the bristle field of the brush.

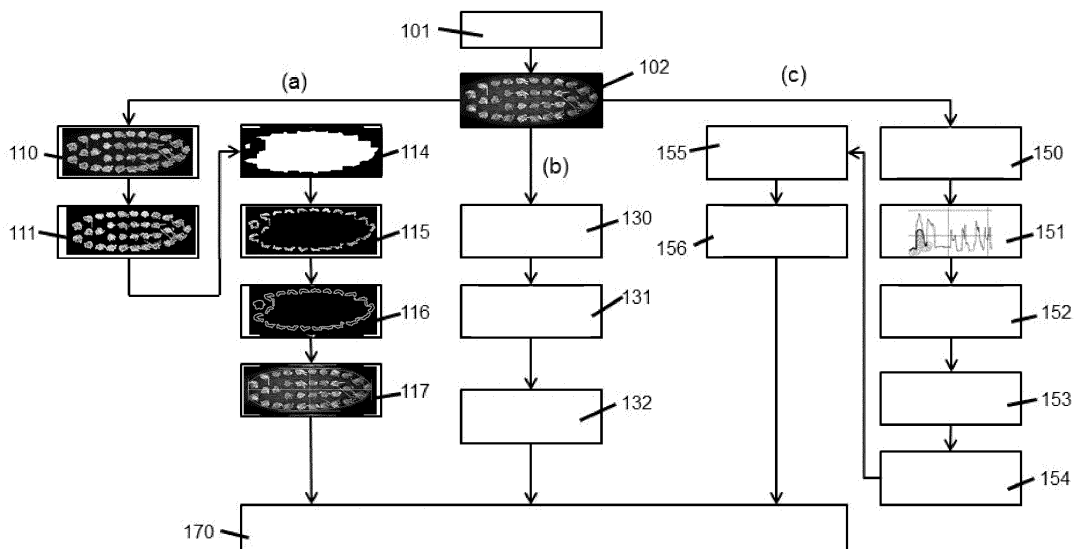


Fig. 2

Description

FIELD OF THE INVENTION

[0001] The present disclosure is concerned with a method for quantifying a wear level of a bristle field of a brush which comprises a plurality of bristle tufts. The present disclosure is further concerned with a device for quantifying a wear level of a bristle field of a brush.

BACKGROUND OF THE INVENTION

[0002] During use of brushes, bristles and bristle tufts being attached to a mounting surface of said brush are deformed leading a deteriorating cleaning efficiency of the brush with increasing use. The wear is macroscopically visible by e.g. bending of bristles or fraying of tufts. Increasing toothbrush wear is seen as less appealing by consumers. In case of toothbrushes, longer use leads to more wear, and this decreases the plaque removal efficacy. This fact is accepted across the category and supported by various studies (backed by various brush manufacturers) for manual and powered toothbrushes.

[0003] In order to have a classification of the wear of toothbrushes there do exist classifications of wear based on a subjective visual assessment of the brushes by a user defining certain criteria for certain classes of wear, e.g. five total classes according to the so called "Conforti scale" ranging from class 0 (no wear) over classes 1 (light wear), 2 (medium wear), 3 (heavy wear) to the class 4 (extreme wear).

[0004] However, these features correlated with the classification of wear are very subjective values.

[0005] It is therefore an object of the present disclosure to provide a more reliable classification of the wear of brushes, in particular of toothbrushes. Such a reliable classification might be used for scientific evaluations as well as for a consumer's decision to replace a used brush or brush head.

SUMMARY OF THE INVENTION

[0006] In accordance with one aspect, a method for quantifying a wear level of a bristle field of a brush is provided, the brush comprising a plurality of bristle tufts grouping each a plurality of single bristles, said bristle tufts being distributed over the bristle field, the method comprising the following steps:

- recording and storing an image of the bristle field;
- converting the image to a gray scale image by use of digital image processing and storing the gray scale image;
- converting the gray scale image to at least one binarized image with only two tone values, also called "binarization" in the following description, by use of digital image processing, thereby assigning one tone value to bristles and/or bristle tufts visible in the image and the other tone value to the background in the image not showing bristles or bristle tufts, and storing the binarized image;
- applying the following evaluation method:
 - determining the geometrical splay of the bristle field (3) by creating a contour image, wherein the contour of the image is determined by edge detection of the grey scale image by use of digital image processing,
- comparing the results of the applied evaluation method with reference data of an unused brush and/or of used brushes with determined wear levels to classify the wear level of the bristle field of the brush.

[0007] In accordance with one aspect, a device for quantifying a wear level of a bristle field of a brush or brush head is provided, the brush or brush head comprising a plurality of bristle tufts grouping each a plurality of single bristles, said bristle tufts being distributed over the bristle field, the device comprising:

- a camera for recording at least one image of the bristle field;
- a holder for the brush or brush head adapted to position the bristle field under the camera such that the direction of recording is directed parallel to the axis of the bristles or bristle tufts of an unused brush held in the holder;
- at least one light source arranged in particular perpendicularly to the direction of recording; and
- a processor unit adapted to perform the method according to the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The invention is described in more detail below with reference to various embodiments and figures, wherein:

Fig. 1 shows schematically an embodiment of the device according to the present disclosure;

Fig. 2 shows schematically an embodiment of the method according to the present disclosure;

Fig. 3 shows an exemplary overview of the results of the evaluation methods according to the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

[0009] The disclosure is related to determining and quantifying a wear level of a bristle field of a brush, such as in particular a manual or powered toothbrush. The bristle field is located in the brush head of the brush, the brush head might be separable from the brush e.g. for removal after reaching a certain wear level and substitution with a new brush head. In this sense, the term "bristle field of a brush" includes in this description also the bristle field of a brush head. The bristle field comprises a plurality of bristle tufts grouping each a plurality of single bristles, said bristle tufts being in particular unequally distributed over the bristle field.

[0010] Related brushes might be intended e.g. for health care purposes to e.g. remove oral plaque. Other brushes can be used for other surface cleaning, e.g. household surfaces like floors, tiles, or cleaning of devices, e.g. shoes, clothes. Typical brushes are made by e.g. stapling, hot-tufting or fixing bristles by another anchor-free technology. Examples for filament types of the bristles are Nylon, PBT, combinations thereof. The bristles might comprise two or more components, e.g. coextruded, natural hair or the like. The filaments can have cylindrical or non-cylindrical cross-sections and might be regular or end-rounded, tapered, flagged, crimped, spiral, twisted etc..

[0011] The recorded image might be a digital or analogue image. However, a digital image is preferred. Digital image acquisition might be performed by a digital camera or microscope, by tomography, by laser scanning or other scanning methods, such as a synchrotron. An analogue image, such as a classical paper or film image, will in line with the present disclosure be digitalized (e.g. by scanning) for the digital image processing steps described below.

[0012] The gray scale image of the recorded image might e.g. be an 8-bit gray scale image. The major aim of this conversion in the gray scale image is to remove redundant color information. This enables further process steps without processing complexity due to color or other redundant information, and removes image background which might lead to incorrect data interpretation. The gray scale value of one pixel in the gray scale image might be derived by summing the color values of the all colors, e.g. red, green and blue, of one pixel in the image of the bristle field and dividing by the number of colors, i.e. by three in the example of an RGB-color space. Of course, other conversions known in the art can also be used.

[0013] In accordance with the evaluation method applied to this gray scale image, the gray scale image is further processed in order to carve out the desired information.

[0014] Digital image processing tools, such as in particular suited software tools and methods are known to the one skilled in the art. This description is directed to the application of suited digital image processing methods for the specific technical aim. The technical realization of the digital image processing tools and methods are known in the art, and, thus, are not described in detail here. The one skilled in the art can apply these tools and methods by use of commercially available software tools offering a variety of different image processing possibilities, however without any advice how to use these possibilities for a certain aim. Therefore, choosing certain tools or methods from the available tools is not evident for the one skilled in the art and part of the present disclosure.

[0015] The following binarization of the gray scale image according to the present disclosure results in a digital image with only two distinguishable tone values of the gray scale, in particular black (e.g. tone value 0) and white (e.g. tone value 255 for an 8-bit gray scale image). The binarization of the image is used in particular to distinguish areas of interest attributed to one tone value (e.g. 255) of the gray scale from background areas attributed to the other tone value (e.g. 0). In particular, parts of the image identified as parts of bristles are assigned with the one tone value indicating an area of interest, in particular the tone value "white" or "255". Other parts of the image not showing parts of bristles are assigned with the other tone value indicating background areas, in particular the tone value "black" or "0".

[0016] The binarization might be a global or local binarization, wherein a global binarization applies one single threshold for a gray scale value for the complete image and a local binarization applies different thresholds for a gray scale value for different areas of the image. During the binarization, the gray scale value of a pixel is compared with the global or local threshold. In dependence of this comparison, either the one or the other of the distinguishable tones values (and the respective gray scale value) is assigned to this pixel. The aim of the binarization is a removal of potential artefacts in the pictures before applying the respective evaluation method of the picture to identify the geometrical splay indicating the wear level of the bristle field.

[0017] The contour pixels of the bristle field used in the evaluation method as described before are in particular those pixels that are border pixels between the area of interest and the area of background. The convex hull might in particular be created by straight lines of different lengths linked such that they surround one single area and that the angles between each two of the adjacent lines measured towards the surrounded area are less than 180°.

[0018] The length and width of the bristle field may be determined by the maximum difference between all of the contour pixel coordinates in the one and the other coordinate direction, i.e. typically the maximum difference between the x-coordinates and the maximum difference of the y-coordinates, respectively, of the contour pixel (x,y)-coordinates.

[0019] The area of the bristle field may be determined by counting all pixels surrounded by the lines forming the convex hull. In a similar way, the circumference of the bristle field may be determined by the sum of the length of all lines forming the convex hull.

[0020] During use of the brush, bristles of the bristle tufts are deformed. This normally leads to changes in the area covered by the bristle field due to splay of the bristle tufts. Accordingly, the geometrical splay (as examined with evaluation method (a) as described below) is a measure for the wear level of the brush. The geometrical splay of the bristle field is determined by an edge detection process by use of digital image processing.

[0021] During use of the brush, also single bristles of the bristle tufts may be deformed thus amending the filament surface (of the bristles) visible in an image. Accordingly, the filament surface (as examined with evaluation method (b) as further described below) may be a further measure for the wear level of the brush. The filament surface of all visible bristles in the image may be determined by counting the pixels in the binarized image having the one tone value of the binarized image assigned to bristles and/or bristle tufts.

[0022] Depending on the level of wear of the brush, deformed bristles of one bristle tuft may locally overlap with bristles of another tuft. Depending on the number of overlapping bristles from different tufts, the different tufts may not be separable in the gray scale image. Accordingly, the number of separable tufts - the so called tuft integrity - (as examined with evaluation method (c) as further described below) may be a further indicator for the wear level of the bristle field of the brush or brush head. The bristle tuft integrity in the image may be determined by counting separable tufts by identifying local gray value maxima in the gray scale image.

[0023] The reference data for comparing the results of the evaluation method may be obtained by the same process as described above for defined reference brushes of the same type empirically, or may have been provided based on e.g. technical drawings or other measurements of reference brushes.

[0024] It may be advisable to store the image after each process step of the digital image processing so that all images of the different processing stages are available for comparison and/or different digital image processing, e.g. by copying the images and applying other image processing methods and/or tools. This may be useful to create masks to be applied to images and/or for subtracting two images processed in different ways from each other.

[0025] At least two of the above mentioned evaluation methods may be applied. Accordingly, the results of the at least two evaluation methods "determining the geometrical splay" and "determining the filament surface", or "determining the geometrical splay" and "determining the tuft integrity" may be combined in the classification of the wear level. Generally, all results may be combined in a suited way to define the wear level, e.g. by a functional relationship determined from empirical data for each type of brush.

[0026] The image of the bristle field may be recorded using a dark field microscopy method. As the one skilled in the art will acknowledge, in the dark field microscopy the bristle field of the brush is illuminated such that the unscattered light beam from the light source is excluded from the image. The result is a picture with the bristles of the bristle field being enlightened and with the bristle head being dark for having high contrast images of the bristles to be examined. In an embodiment, the bristles may be illuminated from two opposing directions perpendicular to the direction of the recording of the image. The direction of recording of the image can be parallel to the direction of the (main) bristles in an unused brush.

[0027] If the direction of the recording is basically parallel to the direction of the bristles and the length of the bristles is varying over the bristle head, e.g. by providing different bristle tufts having bristles with a different length of the bristles, it might be useful to record a high depth-of-field image by recording different images focused between the bristles with the shortest length and the bristles with the highest length, and by combining these images into one image in which all bristles are focused by means of digital image processing. This is useful, if the depth of field obtainable by the camera is not sufficient taking into account the width of aperture.

[0028] Another aspect of the present disclosure is directed to a device for quantifying a wear level of a bristle field of a brush or brush head comprising a plurality of bristle tufts grouping each a plurality of single bristles, said bristle tufts being in particular unequally distributed over the bristle field, the device comprising:

- a camera for recording at least one image of the bristle field;
- a holder for the brush or brush head adapted to position the bristle field such that the direction of recording (i.e. the optical axis of the camera) is directed essentially parallel to the axis of the bristles or bristle tufts of an unused brush held in the holder;

- at least one light source arranged perpendicularly to the direction of recording; and
- a processor unit adapted to perform the method as described before or parts thereof.

[0029] It is also possible to perform the method with any device having a camera and a processor unit adaptable by software means to execute the method steps as described before. The image processing of the acquired image can thus take place in a processor unit which may, but does not have to be connected to the image acquisition system. The image can be transferred by file transfer, wireless (e.g. Bluetooth, wifi, radio ...) or optical or other transmission. The processing unit can be e.g. a computer (desktop, laptop), handheld/ tablet, smartphone, embedded in another device, e.g. toothbrush or be included in the camera system. The image processing can be automated by e.g. using a suitable software package or programming language. Accordingly, the proposed method can also be used by a consumer without any specific measuring device.

[0030] The following is a non-limiting discussion of an example embodiment of a method for quantifying a wear level of a bristle field, and a device for performing such method in accordance with the present disclosure, where reference to the Figures is made.

[0031] In Fig. 1, an embodiment device 1 for quantifying a wear level of a bristle field of a brush or brush head is schematically shown.

[0032] The device 1 has a camera 2 for recording at least one image of the bristle field 3 of a brush 4 (e.g. the brush head of a toothbrush). The bristle field 3 comprises several bristle tufts 5 grouping several single bristles each. The bristles of the bristle tufts 5 are fixed in the brush 4 or brush head. A holder 6 for the brush 4, in particular the brush head, adapted to position the bristle field 3 such under the camera 2 that the direction of recording of the camera is directed essentially parallel to the axis of the bristles or bristle tufts 5 of an unused brush 4 held in the holder 6. In other words, the camera 2 is directed such that the image recorded by camera 2 shows the free ends bristle tufts 5.

[0033] Further, two light sources 7 arranged opposite to each other along an axis perpendicular to the direction of recording, thus illuminating the bristle tufts 5 from the side with respect to the direction of recording. Deflection guards 8 are disposed between the brush 4 and each of the light sources 7, the deflection guards 8 extending such in the direction of recording that the part of the brush 4 or brush head fixing the bristles of the bristle tufts 5 is shielded from light of the light sources 7 (displayed as arrows extending from the light sources 7). Accordingly, the brush 4 appears dark in the recorded image thus enhancing the contrast of the bristles or bristle tufts 5 being the area of interest from the dark background. Additional top deflection guards 9 might be provided to avoid that light from the light sources directly enters into the camera 2. Further, an optional housing 10 might be provided to cover the holder 6 with the deflection guards 8 and the top deflection guards 9, if provided. The optional housing 10 leads to a darker background in the image and reduces artefacts in the recorded images.

[0034] A black colored granulate may be filled into a tray composed of the holder 6 and the deflection guards 8 covering the parts of the brush 4 held in the tray fixing the bristles. This may enhance the contrast of the bristles in the image taken by the camera 2 without impact on the form and/or color of the bristles.

[0035] The device 1 further comprises a processor unit (not shown) having access to the images recorded by the camera 2 and adapted to perform the proposed method for quantifying a wear level of a bristle field 3 of a brush 4 or brush head.

[0036] An embodiment of the method is described in the following with respect to Fig. 2. It is to be noted that the method described according to the embodiment comprises many optional steps. The one skilled in the art may amend the method as described below by way of example, in particular by cancelling certain methods steps without leaving the subject matter of the invention.

[0037] For the different message steps described below it may be useful to have access to all images produced in certain message steps, all images created in one of the message steps may be stored separately. If not all images are stored, it is useful to store at least these images to be reused later while processing the method.

[0038] In a first step 101 of the proposed method, an image of the bristle field 3 of the brush 4 is recorded, typically as a color image. The image is stored in a memory of the processing unit. Following, in step 102, the image is converted e.g. to a 8-bit gray scale image and stored as a gray scale image. Further processing of the gray scale image of step 102 depends on the evaluation method used for assessment of certain features of the bristle field 3. In line with the present disclosure, evaluation methods (a), (b) and (c) are described that might be used separately or in any combination method for quantifying a wear level of a bristle field 3.

[0039] Accordingly, the message steps are described in the following for the evaluation method (a), as well as for the further optional evaluation methods (b) and (c), beginning with the evaluation method (a) for determining the geometrical splay of the bristle field and the message steps 110 to 117.

[0040] The method steps 110 and 111 are related to converting the gray scale image into a binarized image. In step 110, the contour of the image is determined by edge detection of the grey scale image provided by step 102 by use of digital image processing. In other words, in step 110 edge detection algorithms are applied thereby generating an image emphasizing edges. The edge detection may be based on "Zero Crossing Threshold Detection". The use of a Sobel

filter using Sobel operators G_x and G_y to detect edges in the horizontal and vertical direction, respectively, have shown good results. It may be advisable to perform step 110 for high quality results and to achieve enhanced image quality, and, thus more precise geometrical splay data in step 117 which is further explained below.

[0041] In the following step 111, using the initial gray scale image provided by step 102, or preferably the image with emphasized edges provided by step 110, a binarization is performed. All pixels of the gray scale image having a gray scale value above a first specified binarization threshold are set to one tone value assigned to the bristles and/or bristle tufts (corresponding to the tone value "white"; in the following the terms "tone value white" and "tone value assigned to the bristles and/or bristle tufts" are used synonymously). In the same way, all pixels of the gray scale image having a gray scale value below the first specified binarization threshold are set to the tone value assigned to the background of the image (corresponding to the color "black"; in the following the terms "tone value black" and "tone value assigned to the background of the image" are used synonymously). The threshold is based on the IsoData algorithm according to Ridler & Calvard (Ridler TW, Calvard S. (1978) Picture thresholding using an iterative selection method, IEEE Trans. System, Man and Cybernetics, SMC-8: 630-632.)

[0042] In a first evaluation step 114 of evaluation method (a), a morphological image erosion of the binarized image provided by step 111 is performed by a so called "fill hole process", preferably with 20 iterations. The "fill hole process" is performed by testing the binarized image with a predefined structure-element and assigning the tone value "white" to a pixel covered by the center of the structure-element if the complete structure-element fits into the binarized image, and more precisely into the areas with the tone value "white". Fitting into the binarized image in particular means fitting into the pixel area with the tone value not assigned to the background, i.e. the tone value "white". In case of a circle as structure-element, its center might be chosen as the circle-midpoint. However, the form of the structure element and its center located within the structure-element might be chosen in any suited way. The result of this first evaluation step of the evaluation method (a) is a binary picture of the inside of the bristle field 3 without the border of the bristle field 3 as shown in step 114 of Fig. 2. The border of the bristle field 3 is cut off by morphological image erosion.

[0043] Following, in a second evaluation step 115, the image obtained in the first evaluation step 114 is subtracted from the binarized image used as basis in the first evaluation step, i.e. obtained in step 111, or from the gray scale image (of step 102). The resulting image is reduced to its outlines using an outline function of the digital image processing. This results in an image displaying only the contour of the brush field 3. The third evaluation step 116 comprises marking every pixel of the outlines creating the contour image with the marked pixels being the contour pixels of the bristle field, as shown in step 116 of Fig. 2.

[0044] In the fourth evaluation step 117 of evaluation method (a), the coordinates of the contour pixels are used to determine the maximum brush width and length of the bristle field. Further, a convex hull is created enwrapping all contour pixels and having the smallest possible size to determine the area and the circumference of the bristle field. This is indicated by white lines in the figure included into step 117 of Fig. 2.

[0045] Additionally, the evaluation method (b) determining the filament surface can be performed, as described in the following with regard to steps 130 to 132 as shown in Fig. 2.

[0046] In the first step 130 of binarization, all pixels of the gray scale image according to step 102 having a gray scale value above a first specified binarization threshold are set to the one tone value "white" and all pixels of the gray scale image having a gray scale value below the first specified binarization threshold to the tone value "black". The first specified binarization threshold for this binarization step 130 may be specified as mean gray value of the gray scale image of the bristle field 3 of the image of step 102. A second step 131 of the binarization might be performed identifying conglomerates of pixels with the tone value "white" that are too small to represent a bristle or a bristle tuft 5. The conglomerates of pixels identified in this step are set to the tone value "black". These steps might be performed consecutively one after the other in preparation of the evaluation method (b) determining the filament surface of the bristle field. As a result, a binarized image of the bristle in the bristle field is created as shown in step 131. Image artefacts outside of the area of the brush under consideration are removed, and the image quality is enhanced.

[0047] For determining the geometrical splay according to evaluation method (b), in the evaluation step 132 all pixels in the binarized image generated in step 130 or step 131 are counted having the tone "white". This value is indicative of the filament surface of the bristles in the bristle field 3.

[0048] Alternatively or in addition to evaluation method (b), the evaluation method (c) determining the bristle tuft integrity can be performed, as described in the following with regard to steps 150 to 156 as shown in Fig. 2.

[0049] In preparation of the evaluation method (c), the following steps 150 to 154 are performed for binarization of the gray-scale image. To this aim, in a first step 150 a median filter with a determined filter radius of e.g. 10 pixels is applied to the gray-scale image generated in step 102 replacing each tone value of a pixel with a medium tone value of all pixels in the center radius. This step leads to a more uniform gray tone value of the bristle tufts 5 as small wholes between single bristles of the bristle tufts 5 are removed, as evident from step 150 in Fig. 2. In the following second step 151, a rolling-ball algorithm with a suited ball radius, in particular corresponding to less than half of bristle tuft width is applied to the in particular 3-dimensional histogram of the tone curve values of the image received in the first step 150. Using this rolling-ball algorithm, an image of the surface is created that is reachable by the rolling ball. Such rolling-ball algorithm

is accordingly suited to identify the bristle tufts 3 in a gray-scale image with high accuracy. A following third step 152 is used for locally binarizing the image obtained in the second step 151, using a binarization radius which may be in the order of the diameter of a bristle tuft 5 of an unused brush and a local binarization threshold distinguishing the peak within the binarization radius over the background. A suited method for determining the local binarization threshold is the so called Niblack-Method, using the equation $t = mean + 0,2 \times std_dev$ with *mean* being the average gray value and *std_dev* the standard deviation of surrounding pixels within the given binarization radius. Further suitable methods known in the art are e.g. Bernsen, Mean, Median, MidGrey or Sauvola. However, it was surprisingly found out that the Method according to Niblack is advantageous to distinguish between the individual tufts more reliably.

[0050] In the optionally following fourth step 153, all conglomerates of pixels with the tone value "white" are identified that are too small to represent a bristle or a bristle tuft 5. These identified conglomerates of pixels are assigned to the tone value "black". The size of the identified conglomerates might be 1000 pixels, for example, or more generally about 20% of the pixel size of a bristle tuft 5 of an in particular unused brush 4. Optionally, in a fifth step 154, also the circularity of the shapes in the image according to the third step 152 or the fourth step 154 are measured. The tone value "black" is then assigned to all pixels of shapes in the image having a circularity below a predefined circularity threshold, e.g. in the order of 0.3 in a range between 0 and 1. The optional steps 153 and 154 improve the image quality and remove artefacts in the resulting binarized image.

[0051] For determining the tuft integrity according to evaluation method (c), the image of the surface reachable by the rolling-ball obtained from step 151 is used. In a first (optional) evaluation step 155, the image of step 153 or step 154 is inverted and subtracted from the image obtained in step 151. In the second evaluation step 156, local gray value maxima are identified in the image obtained in the first evaluation step 155 or in the image obtained in step 151. The number of maxima is counted. The number of maxima counted gives the number of separable bristle tufts 5 being a measure for the integer bristle 5 tufts.

[0052] The resulting data (results) of the evaluation methods (a), (b), (c) described above can be stored in a database. Then, the resulting data of the processes above are compared to reference data in step 170. The reference data might have been obtained by the same processes as described above for defined reference brushes, or have been provided based on e.g. technical drawings or other measurements of reference brushes.

[0053] Overall, the geometrical splay according to evaluation method (a) and the filament surface according to evaluation method (b) are proportional to the wear level. This means that for a given brush in its unused state defined as 100%, for worn or used brushes any of the parameters according to evaluation methods (a) and (b) will be equal or larger than 100% on a statistical base. The larger the parameter is, the higher is the wear level of the brush under consideration.

[0054] Tuft integrity and the resulting number of distinguishable tufts in a brush are antiproportional to the wear level. This means that for a given brush in its unused state the number of tufts is defined as 100%, for worn brushes the number of distinguishable tufts as detected by process (c) will be equal or smaller than 100% on a statistical base. The lower the number of distinguishable tufts vs. the unused brush, the higher the wear of the brush under consideration.

[0055] This is evident from Fig. 3 showing on the left side graphical indications of the wear level of toothbrushes and on the right side the classification according to the present disclosure as a result of the application for each of the evaluation methods (a), (b) and (c).

[0056] The curves on the right side show the wear levels according to an assessment of the evaluation methods (a), (b) and (c).

[0057] A set of toothbrushes (e.g. four toothbrushes per wear level) was used to generate empirical data using the assessment methods mentioned above. These data were analyzed statistically and from this the following formula was obtained, correlating parameters from the assessment methods above with wear levels:

$$\text{wear level} = a + b * \#tufts + c * \text{fil_area} + (\#tufts - d) * (\text{fil_area} - e) * f,$$

wherein "fil_area" is the result of evaluation method (b), "#tufts" is the result of evaluation method (c), and "a", "b", "c", "d", "e", "f" are fit parameters. The resulting wear level is rounded up or down and reported in whole numbers.

[0058] An advantage of the presented disclosure is an objective, parametric grading. The evaluation method (b) defines the effectively available filament surface of the bristles, while current methods may omit splay which is only visible in the central areas of the brush.

[0059] A precise correlation of the results of the present disclosure versus existing methods, e.g. conventional wear index based on splay, is possible. After having done such correlation, there is no need for specifically trained graders for wear assessment. This allows faster analysis of large number of brushes. Further, the wear level can be assessed by untrained individuals, e.g. via an app on a portable device, such as a smartphone or tablet. As evident from the graphs on the right side of Fig. 3, a fine discrimination between wear levels is possible contrary to the current parametric "big

buckets". Accordingly, with the present disclosure the following disadvantages of prior art are avoided:

- Various subjective grading systems are competing.
- Specifically trained graders are needed for wear assessment.
- Analyzing large number of brushes is time consuming.

[0060] The method proposed can be applied for manual toothbrushes, electric toothbrushes, heads thereof or their refills, manual facial/ body/ cosmetic brushes, electric facial/ body/ cosmetic brushes or other brushes for e.g. household, surface or fabric cleaning.

[0061] The dimensions and values disclosed herein are not to be understood as being strictly limited to the exact numerical values recited. Instead, unless otherwise specified, each such dimension is intended to mean both the recited value and a functionally equivalent range surrounding that value. For example, a dimension disclosed as "40 mm" is intended to mean "about 40 mm."

Claims

1. A method for quantifying a wear level of a bristle field (3) of a brush (4) comprising a plurality of bristle tufts (5) grouping each a plurality of single bristles, said bristle tufts (5) being distributed over the bristle field (3), the method comprising the following steps:

- recording and storing an image of the bristle field (3);
- converting the image into a gray scale image by use of digital image processing and storing the gray scale image;
- converting the gray scale image to at least one binarized image with only two tone values by use of digital image processing, thereby assigning one tone value to bristles and/or bristle tufts (5) visible in the image and the other tone value to the background in the image not showing bristles or bristle tufts, and storing the binarized image;
- applying the following evaluation method (a):

determining the geometrical splay of the bristle field (3) by creating a contour image, wherein the contour of the image is determined by edge detection of the grey scale image by use of digital image processing,

- comparing the results of the applied evaluation method with reference data of an unused brush and/or of used brushes with determined wear levels to classify the wear level of the bristle field of the brush.

2. The method according to claim 1, wherein the geometrical splay of the bristle field (3) is determined by creating a contour image from the binarized image with the contour pixels of the bristle field (3), and using the coordinates of the contour pixels to determine the maximum brush width and length of the bristle field (3), and/or by creating a convex hull enwrapping all contour pixels and having the smallest possible size to determine the area and the circumference of the bristle field (3).

3. The method according to claim 1 or 2, wherein at least one of the following two evaluation methods (b), (c) are further applied:

- (b) determining the filament surface of all visible bristles in the image by counting the pixels in the binarized image having the one tone value of the binarized image assigned to bristles and/or bristle tufts (5);
- (c) determining the bristle tuft integrity in the image by counting separable tufts in the gray scale image by identifying local gray value maxima in the gray scale image, optionally after separating the bristle tufts (5) by subtracting a binarized image mask generated by the conversion of the gray scale image to the at least one binarized image identifying the bristle tufts (5),

and wherein the results of the at least two evaluation methods (a), (b), (c) are combined in the classification of the wear level.

4. The method according to any of the preceding claims, wherein the image of the bristle field (3) is recorded using a dark field microscopy method.

5. The method according to any of the preceding claims, wherein a high depth-of-field image is recorded by recording different images focused between the bristles with the shortest length and the bristles with the highest length, and by combining these images into one image in which all bristles are focused.

6. The method according to any of the preceding claims, wherein converting the gray scale image to one binarized image comprises at least one of the following steps:

- in a first step (110), enhancing the image edges by using edge detection based on "search-based" and/or "zero-crossing based edge detection", and

- in a second step (111), setting all pixels of the gray scale image having a gray scale value above a first specified binarization threshold to the one tone value assigned to the bristles and/or bristle tufts (5) and setting all pixels of the gray scale image having a gray scale value below the first specified binarization threshold to the tone value assigned to the background of the image.

7. The method according to any of the preceding claims, wherein the binarized image, and in particular of the binarized image according to the second step (111) of claim 6, is used for determining the geometrical splay according to evaluation method (a), comprising the following evaluation steps:

- in a first evaluation step (114), performing a morphological image erosion of the binarized image by testing the binarized image with a predefined structure-element and assigning the tone value assigned to the bristle and/or bristle tufts (5) to a pixel covered by the center of the structure-element if the complete structure-element fits into the binarized image;

- in a second evaluation step (115), subtracting the image obtained in the first evaluation step (114) from the binarized image or from the gray scale image and reducing the resulting image to its outlines using an outline function of the digital image processing;

- in a third evaluation step (116), marking every pixel of the outlines creating a contour image with the marked pixels being the contour pixels of the bristle field (3);

- in a fourth evaluation step (117), the coordinates of the contour pixels are used to determine the maximum brush width and length of the bristle field (3), and a convex hull enwrapping all contour pixels and having the smallest possible size is created to determine the area and the circumference of the bristle field (3).

8. The method according to any of claims 3 to 7, wherein evaluation method (b) comprises at least one of the following steps:

- in a first step (130), setting all pixels of the gray scale image having a gray scale value above a first specified binarization threshold to the one tone value assigned to the bristles and/or bristle tufts (5), and setting all pixels of the gray scale image having a gray scale value below the first specified binarization threshold to the tone value assigned to the background of the image;

- in a second step (131), identifying conglomerates of pixels with the tone value assigned to bristles and/or bristle tufts (5) that are too small to represent a bristle or a bristle tuft (5) and assigning the identified conglomerates of pixels to the tone value assigned to background;

- counting all pixels in the binarized image having the tone value assigned to the bristles and/or bristle tufts (5).

9. The method according to any of claims 3 to 8, wherein evaluation method (c) comprises at least the first three of the following steps:

- in a first step (150), applying a median filter with a determined filter radius to the gray-scale image replacing each tone value of a pixel with a medium tone value of all pixels in the center radius;

- in a second step (151), applying a rolling-ball algorithm with a suited ball radius to the histogram of the tone curve values of the image received in the first step (150) and creating an image of the surface reachable by the rolling-ball;

- in a third step (152), locally binarizing the image obtained in the second step (151), using a binarization radius preferably in the order of the diameter of a bristle tuft of an unused brush and a local binarization threshold distinguishing the a peak within the binarization radius over the background;

- in a fourth step (153), identifying all conglomerates of pixels with the tone value assigned to bristles or bristle tufts (5) which are too small to represent a bristle or a bristle tuft (5), and assigning the identified conglomerates of pixels to the tone value assigned to background;

- in a fifth step (154), measuring the circularity of the shapes in the image according to the third step or the

fourth step, and assigning to all pixels of shapes in the image having a circularity below a predefined circularity threshold the tone value assigned to background.

5 10. The method according to claim 9, wherein the image of the surface reachable by the rolling-ball obtained from the second step (151) of claim 9 is used for determining the tuft integrity according to evaluation method (c), comprising at least the second of the following evaluation steps:

- in a first evaluation step (155), inverting the image of the fourth step (153) or fifth step (154) of claim 9 and subtracting the inverted image from the image obtained in second step (151) of claim 9;
- 10 - in a second evaluation step (156), identifying local gray value maxima in the image obtained in the first evaluation step (155) or in the image obtained in the second step (151) of claim 9 and counting the number of maxima.

15 11. A device for quantifying a wear level of a bristle field (3) of a brush (4) or brush head comprising a plurality of bristle tufts (5) grouping each a plurality of single bristles, said bristle tufts (5) being distributed over the bristle field (3), the device comprising:

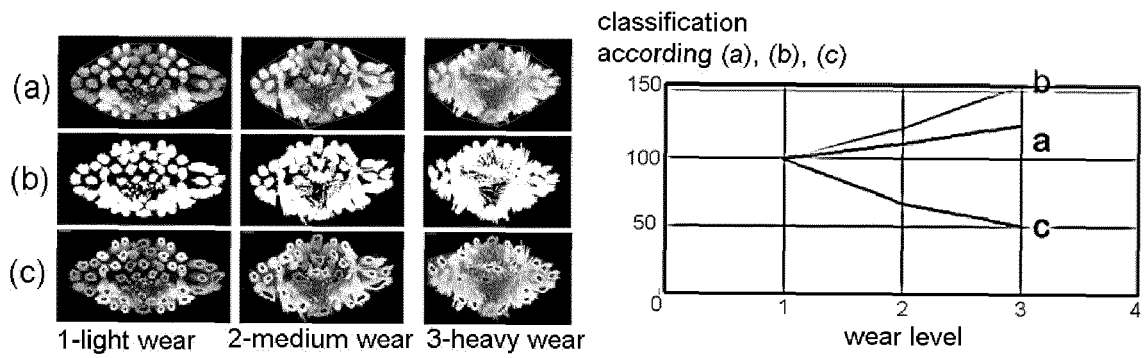
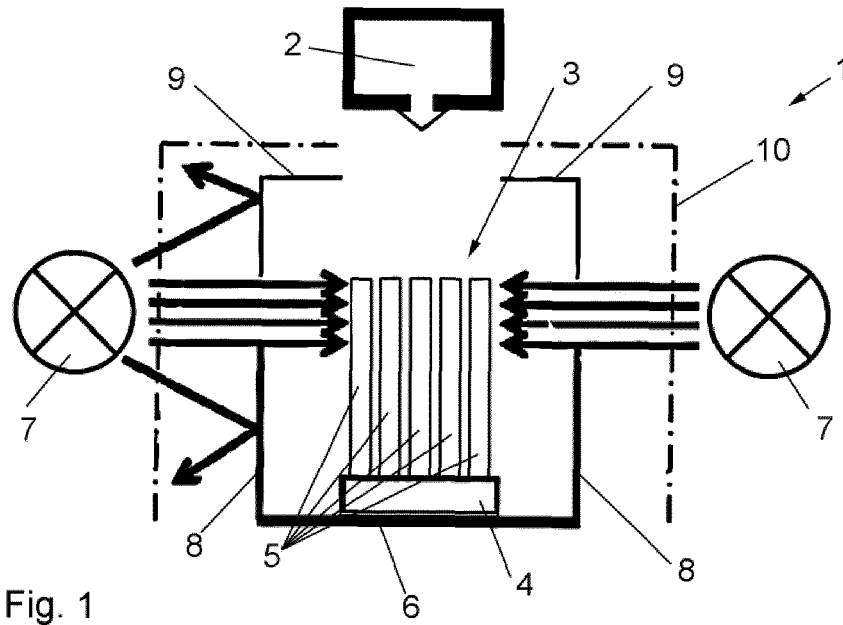
- a camera (2) for recording at least one image of the bristle field (3);
- a holder (6) for the brush (4) or brush head adapted to position the bristle field (3) under the camera (2) such that the direction of recording is directed parallel to the axis of the bristles or bristle tufts (5) of an unused brush (4) held in the holder (6);
- 20 - at least one light source (7) arranged perpendicularly to the direction of recording; and
- a processor unit adapted to perform the method according to any of the claims 1 to 10.

25 12. A device according to claim 11, wherein at least two light sources (7) are arranged perpendicular to the direction of recording.

30 13. A device according to claim 12, wherein the at least two light sources (7) are arranged opposite to each other along an axis perpendicular to the direction of recording.

35 14. The device according to any of claims 11 to 13, further comprising deflection guards (8) disposed between the brush (4) and each of the light sources (7), the deflection guards (8) extending such in the direction of recording that the part of the brush (4) or brush head fixing the bristles is shielded from light of the light sources (7).

40 15. The device according to claim 14, wherein the holder (6) and the deflection guards (8) are integrally formed with a u-formed cross section forming a tray for holding the brush (4) or brush head.



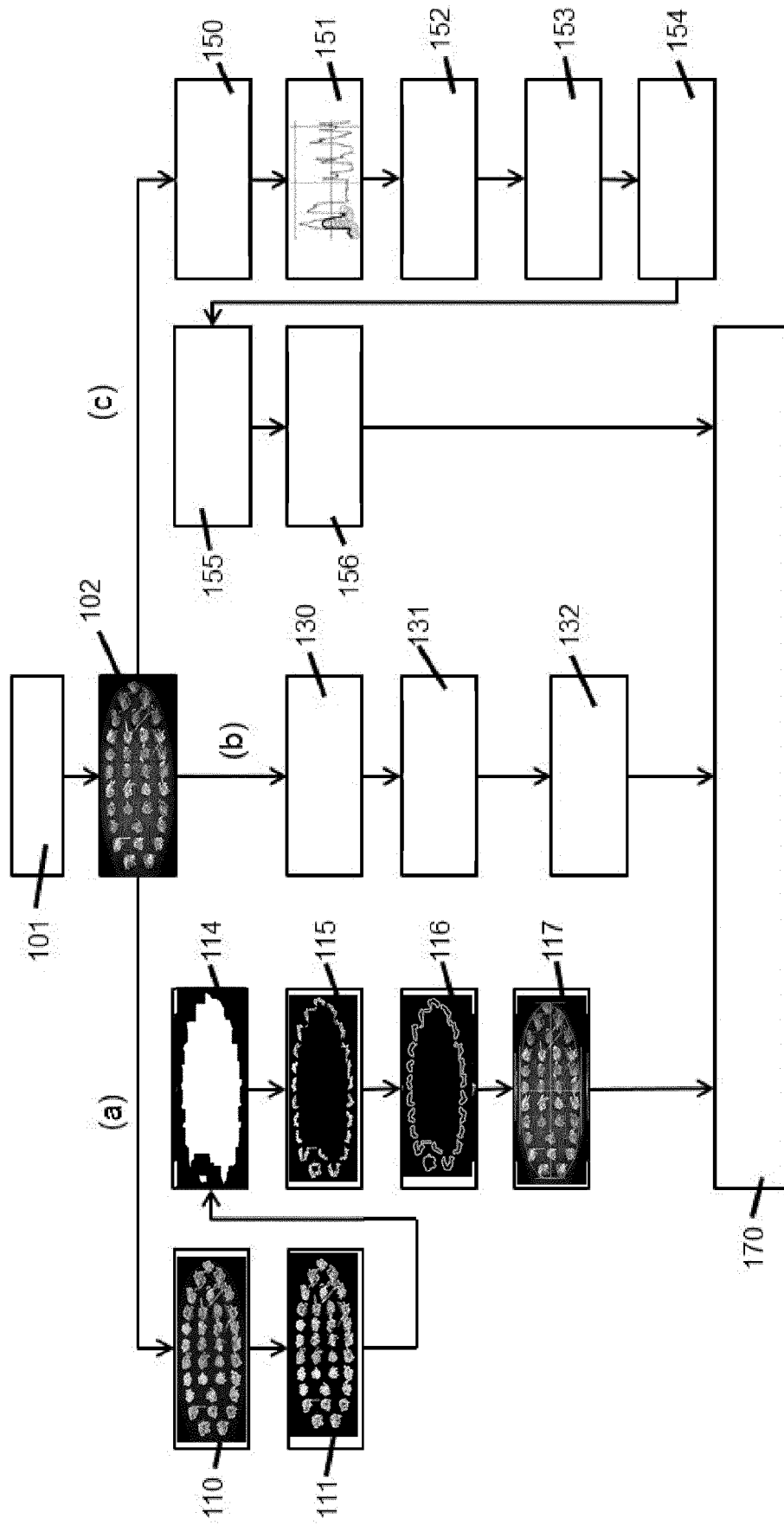


Fig. 2



EUROPEAN SEARCH REPORT

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