# METHOD AND SYSTEM FOR FACILITATING ANALYSIS OF A SKIN CONDITION

## TECHNICAL FIELD

**[001]** The present invention relates broadly, but not exclusively, to methods and systems for facilitating analysis of a skin condition.

## BACKGROUND

**[002]** In a typical consultation for skin conditions such as melanocytic nevi and melanomas, a preliminary analysis of the skin condition is conducted through a physical examination by a physician. Generally, it is difficult for the physician to provide a confident diagnosis of the skin condition based on the physical examination. Moreover, accuracy of the diagnosis based on the physical examination is highly dependent on an experience of the physician.

**[003]** Imaging devices may be used to aid the physician in diagnosing the skin condition. However, existing imaging devices may be costly and may not provide accurate results. For example, imaging devices for melanoma diagnosis currently available in the market mainly utilize computer-assisted/aided diagnosis (CAD) systems with traditional pattern analysis to differentiate between malignant and benign lesions. Such imaging devices are typically costly and have low specificity.

**[004]** A need therefore exists to provide a method and system for facilitating analysis of a skin condition that seek to address at least some of the above problems. Furthermore, other desirable features and characteristics will become apparent from the subsequent detailed description and the appended claims, taken in conjunction with the accompanying drawings and this background of the disclosure.

## SUMMARY

**[005]** According to a first aspect, there is provided a method for facilitating analysis of a skin condition, comprising: determining a deep neural network (DNN)-determined feature vector based on one or more first asymmetry related features from a digital skin

lesion image and one or more corresponding first asymmetry related features from a mirror image of the digital skin lesion image; determining one or more hand-crafted feature vectors based on one or more predefined second asymmetry related features, wherein the one or more predefined second asymmetry related features are different from the one or more first asymmetry related features; combining the DNN-determined feature vector and the one or more hand-crafted feature vectors to obtain a combined feature vector; calculating an asymmetry score based on the combined feature vector; and calculating a final score based on the asymmetry score for facilitating analysis of the skin condition.

**[006]** According to a second aspect, there is provided a system for facilitating analysis of a skin condition, comprising: a first feature vector determining device configured to determine a deep neural network (DNN)-determined feature vector based on one or more first asymmetry related features from a digital skin lesion image and one or more corresponding first asymmetry related features from a mirror image of the digital skin lesion image; a second feature vector determining device configured to determine one or more hand-crafted feature vectors based on one or more predefined second asymmetry related features, wherein the one or more predefined second asymmetry related features are different from the one or more first asymmetry related features; a feature vector combining device configured to combine the DNN-determined feature vector and the one or more hand-crafted feature vectors to obtain a combined feature vector; a first score calculating device configured to calculate an asymmetry score based on the combined feature vector; and a second score calculating device configured to calculate a final score based on the asymmetry score for facilitating analysis of the skin condition.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[007]** Embodiments are provided by way of example only, and will be better understood and readily apparent to one of ordinary skill in the art from the following written description, read in conjunction with the drawings, in which:

**[008]** Figure 1 is a flow chart illustrating a method for facilitating analysis of a skin condition, according to an example embodiment.

**[009]** Figure 2 is a schematic representation illustrating the method of Figure 1.

**[0010]** Figure 3 is another schematic representation illustrating the method of Figure 1.

**[0011]** Figure 4 is a schematic representation illustrating a digital skin lesion image and a mirror image of the digital skin lesion image.

**[0012]** Figure 5 is a block diagram illustrating a method for facilitating analysis of the skin condition, according to another example embodiment.

**[0013]** Figure 6 is a schematic diagram illustrating a system for facilitating analysis of a skin condition, according to an example embodiment.

**[0014]** Figure 7 shows a schematic diagram of a computer system suitable for use in executing at least some steps of the method for facilitating analysis of the skin condition.

**[0015]** Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been depicted to scale.

## DETAILED DESCRIPTION

**[0016]** Embodiments will be described, by way of example only, with reference to the drawings. Like reference numerals and characters in the drawings refer to like elements or equivalents.

**[0017]** Some portions of the description which follows are explicitly or implicitly presented in terms of algorithms and functional or symbolic representations of operations on data within a computer memory. These algorithmic descriptions and functional or symbolic representations are the means used by those skilled in the data processing arts to convey most effectively the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities, such as electrical, magnetic or optical signals capable of being stored, transferred, combined, compared, and otherwise manipulated.

**[0018]** Unless specifically stated otherwise, and as apparent from the following, it will be appreciated that throughout the present specification, discussions utilizing terms such as “receiving”, “scanning”, “calculating”, “determining”, “replacing”, “generating”, “initializing”, “outputting”, or the like, refer to the action and processes of a computer system, or similar electronic device, that manipulates and transforms data represented as physical quantities within the computer system into other data similarly represented as physical quantities within the computer system or other information storage, transmission or display devices.

**[0019]** The present specification also discloses apparatus for performing the operations of the methods. Such apparatus may be specially constructed for the required purposes, or may comprise a computer or other device selectively activated or reconfigured by a computer program stored in the computer. The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various machines may be used with programs in accordance with the teachings herein. Alternatively, the construction of more specialized apparatus to perform the required method steps may be appropriate. The structure of a computer suitable for executing the various methods / processes described herein will appear from the description below.

**[0020]** In addition, the present specification also implicitly discloses a computer program, in that it would be apparent to the person skilled in the art that the individual steps of the method described herein may be put into effect by computer code. The computer program is not intended to be limited to any particular programming language and implementation thereof. It will be appreciated that a variety of programming languages and coding thereof may be used to implement the teachings of the specification contained herein. Moreover, the computer program is not intended to be limited to any particular control flow. There are many other variants of the computer program, which can use different control flows.

**[0021]** Furthermore, one or more of the steps of the computer program may be performed in parallel rather than sequentially. Such a computer program may be stored on any computer readable medium. The computer readable medium may include storage devices such as magnetic or optical disks, memory chips, or other storage devices suitable for interfacing with a computer. The computer readable medium may also include a hard-wired medium such as exemplified in the Internet system, or

wireless medium such as exemplified in the GSM mobile telephone system. The computer program when loaded and executed on such a computer effectively results in an apparatus that implements the steps of the preferred method.

**[0022]** As mentioned above, in a typical consultation for skin conditions such as melanocytic nevi and melanomas, a preliminary analysis of the skin condition is conducted through a physical examination by a physician. Generally, it is difficult for the physician to provide a confident diagnosis of the skin condition based on the physical examination. Moreover, accuracy of the diagnosis based on the physical examination is highly dependent on skills and an experience of the physician. Imaging devices may be used to aid the physician in diagnosing the skin condition. However, existing imaging devices may be costly and may not provide accurate results.

**[0023]** Embodiments of the invention provide a method for facilitating analysis of skin conditions such as, but not limited to, melanocytic nevi and melanomas from digital skin lesion images. In some implementations, a user such as the physician may take a photograph of a patient's skin area to be analyzed using a digital image capturing device (e.g. his/her smart phone, a digital camera or an image capturing module that is part of a medical device). The photograph taken may be a digital skin image that comprises the digital skin lesion image and a digital surrounding skin image. Processor(s) in the smart phone may then process and analyze the digital skin image, and generate a final score that can facilitate analysis of the skin condition. The final score generated can indicate a risk of the patient having the skin condition. A smart phone application may be developed for further ease of use. Further, the smart phone may be used as an intermediate agent connected to a Server through internet. The smart phone can send the captured digital skin image to the Server and the Server can process and analyze the digital skin image to generate a final risk score that can be sent back to the smart phone application. In this way, beneficially, longitudinal records of the progress of skin conditions of the patients can be recorded and tracked by the physician for follow-up consultations and/or telehealth monitoring.

**[0024]** The techniques described in the present specification produce one or more technical effects. The final score which may indicate the risk of the patient having the skin condition can be provided to the physician in a relatively short time during the consultation. Hence, the physician can better manage the patients undergoing the skin condition screening (e.g. melanocytic nevus or melanoma screening). Patients can receive a more confident and objective diagnosis at the first consultation. This allows

for discussion and appropriate referrals to tertiary institutions for the management of highly suspicious lesions. Advantageously, this reduces patient and family anxiety and allows for prompt management if needed. This will also reduce unnecessary biopsies and clinical visits, leading to a reduction in overall healthcare costs.

**[0025]** Further, the techniques described in the present specification are easy to implement as the physician is only required to obtain the digital skin image of the patient's skin area to be analyzed. In addition, sophisticated devices are not required as a relatively simple device such as a smart phone will suffice. As such, cost is reduced.

**[0026]** In addition, the techniques described in the present specification quantifies asymmetry of a lesion based on both deep-learning-based asymmetry features and other hand-crafted/manually designed asymmetry features. The deep-learning-based asymmetry features are relatively more complex and provide enhanced performance in a computer vision task. This advantageously improves the accuracy of the risk analysis of whether the patient has the skin condition.

**[0027]** According to an embodiment, a deep neural network (DNN) such as a deep learning convolutional neural network (CNN) may be trained for a binary classification task (e.g. melanoma vs benign lesion classification task) based on a dataset of skin lesion images. As such, the trained DNN can work with a relatively smaller dataset for a task of predicting asymmetry of a lesion. The trained DNN may be used to extract asymmetry related features from an image of a skin lesion. The image may be a coloured image. The extracted asymmetry related features may then be combined with hand-crafted/manually designed features to predict an asymmetry (A) score which is one of one or more components to predict melanoma.

**[0028]** Figure 1 is a flow chart 100 illustrating a method for facilitating analysis of a skin condition, according to an example embodiment. At step 102, a deep neural network (DNN)-determined feature vector is determined or constructed based on one or more first asymmetry related features from a digital skin lesion image and one or more corresponding first asymmetry related features from a mirror image of the digital skin lesion image. At step 104, one or more hand-crafted feature vectors are determined based on one or more predefined second asymmetry related features. The one or more predefined second asymmetry related features are different from the one or more first asymmetry related features. At step 106, the DNN-determined feature vector and

the one or more hand-crafted feature vectors are combined to obtain a combined feature vector. At step 108, an asymmetry score is calculated based on the combined feature vector. At step 110, a final score is calculated based on the asymmetry score for facilitating analysis of the skin condition.

**[0029]** Figure 2 is a schematic representation 200 illustrating the method of Figure 1. As shown in Figure 2, the digital skin lesion image 202 may be provided as input to the trained DNN for extraction of asymmetry related features from the digital skin lesion image 202. The trained DNN may be a multi-layer network. A distance 204, 204', 204" between each of the one or more first asymmetry related features from the digital skin lesion image 202 and the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image may be computed at each layer of the trained DNN. More details on computation of the distance at each layer will be described later. The final DNN-determined feature vector 206 may be a n-dimension vector comprising n distances, wherein n is the number of layers in the trained DNN.

**[0030]** Based on the digital skin lesion image 202, the one or more hand-crafted feature vectors 208, 208', 208" may be determined. The DNN-determined feature vector 206 may be combined with the one or more hand-crafted feature vectors 208, 208', 208" to obtain the combined feature vector 210. For example, the DNN-determined feature vector 206 and the one or more hand-crafted feature vectors 208, 208', 208" may be concatenated to obtain the combined feature vector 210. As a non-limiting example, the DNN-determined feature vector 206 can be a 10 dimensional feature vector and the hand-crafted feature vector 208 can be a 5 dimensional feature vector. The DNN-determined feature vector 206 can be concatenated with the hand-crafted feature vector 208 by appending the hand-crafted feature vector 208 at the end of the DNN-determined feature vector 206 to form a 15 dimensional feature vector. The asymmetry score 212 may then be calculated based on the combined feature vector 210.

**[0031]** Figure 3 is another schematic representation 300 illustrating the method of Figure 1. As shown in Figure 3, the method for facilitating analysis of the skin condition may further comprise, before determining the DNN-determined feature vector, providing a digital skin image 302 comprising the digital skin lesion image 304 and a digital surrounding skin image 306. As mentioned above, the digital skin image 302 may be obtained by taking a photograph of the patient's skin area to be analyzed. The digital skin image 302 may be a colour image. The method may also comprise

processing the digital skin image 302 to segment the digital skin lesion image 304 from the digital surrounding skin image 306. Processing the digital skin image 302 may comprise using a deep-learning-based segmentation approach such as a first trained DNN to segment the digital skin lesion image 304 from the digital surrounding skin image 306.

**[0032]** After the digital skin lesion image 304 is segmented from the digital surrounding skin image 306, a center of mass of the digital skin lesion image 304 may be computed. A first axis 308 and a second axis 310 on the digital skin lesion image 304 may be determined. Each of the first axis 308 and the second axis 310 may divide the digital skin lesion image 304 into two approximate equal sections, and the second axis 310 may be perpendicular to the first axis 308. The first axis 308 can be in any orientation. In some implementations, the digital skin lesion image 304 may be divided into more than two approximate equal sections.

**[0033]** Assessment of symmetry of the lesion when reflected on the bisecting lines (e.g. the first axis 308 and the second axis 310) of the sections may be performed. As a non-limiting example, if asymmetry with regard to colour and/or image structure is determined across both the first axis 308 and the second axis 310, an asymmetry score of 2 may be allocated. If asymmetry is only determined across one of the axes, an asymmetry score of 1 may be allocated. If asymmetry is determined to be absent across both axes, an asymmetry score of 0 may be allocated. Generally, most melanomas may have the asymmetry score of 2. In contrast, only approximately 25% of benign melanocytic nevi may have the asymmetry score of 2. The assessment of asymmetry of the lesion can be relatively important for the final score as it may have a high weight factor in the calculation of the final score.

**[0034]** Determining the first axis 308 and the second axis 310 on the digital skin lesion image 304 may comprise performing an eigenvector calculation. The digital skin lesion image 304 may be represented as a two-dimensions point cloud for performing the eigenvector calculation. A first principal component resulting from the eigen-analysis may correspond to the first axis 308 while an axis perpendicular to the first axis 308 may be taken to be the second axis 310. To facilitate further analysis, the digital skin image 302 or the digital skin lesion image 304 may be rotated such that the first axis 308 and the second axis 310 on the digital skin image 302 or the digital skin lesion image 304 correspond to coordinate axes. The digital skin lesion image 304 may then be cropped out as a region of interest (ROI).

**[0035]** The digital skin image 302 or the digital skin lesion image 304 may be reflected across the first axis 308 to obtain the mirror image of the digital skin image or the mirror image of the digital skin lesion image. In a similar manner as described above, the mirror image of the digital skin lesion image may be cropped out as a ROI.

**[0036]** For a symmetrical lesion, features extracted from both the digital skin lesion image 304 and the mirror image of the digital skin lesion image would be more similar as compared to a scenario when the lesion is asymmetrical.

**[0037]** Figure 4 is a schematic representation 400 illustrating a digital skin lesion image 402 and a mirror image of the digital skin lesion image 404. As shown in Figure 4, determining the DNN-determined feature vector may comprise extracting, using a second trained DNN, the one or more first asymmetry related features 406, 408, 410 from the digital skin lesion image 402. Determining the DNN-determined feature vector may further comprise extracting, using the second trained DNN, the one or more corresponding first asymmetry related features 406', 408', 410' from the mirror image of the digital skin lesion image 404. Determining the DNN-determined feature vector may also comprise determining one or more distances between the one or more first asymmetry related features 406, 408, 410 from the digital skin lesion image and the one or more corresponding first asymmetry related features 406', 408', 410' from the mirror image of the digital skin lesion image. Each of the one or more distances may correspond to the distance between each of the one or more first asymmetry related features 406, 408, 410 from the digital skin lesion image 402 and the one or more corresponding first asymmetry related features 406', 408', 410' from the mirror image of the digital skin lesion image 404.

**[0038]** For example, the first asymmetry related feature 406 and the corresponding first asymmetry related feature 406' may be extracted from the digital skin lesion image 402 and the mirror image of the digital skin lesion image 404, respectively, at the first layer of the trained DNN. The first asymmetry related feature 406 and the corresponding first asymmetry related feature 406' may be the outputs of neurons at the first layer of the trained DNN.

**[0039]** A distance such as a Euclidean distance between the first asymmetry related feature 406 and the corresponding first asymmetry related feature 406' can be used as an indicator of asymmetry of the lesion. In a typical symmetrical lesion, both the first

asymmetry related feature 406 and the corresponding first asymmetry related feature 406' extracted may be similar leading to a smaller distance between them.

**[0040]** The final DNN-determined feature vector may then be computed. As mentioned above, the final DNN-determined feature vector may be a n-dimension vector comprising n distances, wherein n is the number of layers in the trained DNN. The DNN-determined feature vector may be combined with the one or more hand-crafted feature vectors to obtain the combined feature vector.

**[0041]** According to one embodiment, hand-crafted features can be categorized into shape or colour asymmetry features.

**[0042]** As a non-limiting example, the shape asymmetry features may be computed using grayscale images or binary segmentation masks and may comprise one or more of the following:

a) Structural Similarity Index (SSIM) and Mean Square Error (MSE) shape asymmetry features computed using the grayscale image. With reference to Figure 3, the MSE shape asymmetry feature can be a pixel by pixel difference of grayscale values in the two halves of the digital skin lesion image 304. The two halves of the digital skin lesion image 304 can be obtained by dividing the image along the first axis 308. Similar computation may also be performed corresponding to the two halves generated by the second axis 310. The two halves of the digital skin lesion image 304 can also be compared using the SSIM means. The SSIM can perform a comparison based on human visual system and extract features based on luminance, contrast and structure of the images.

b) Normalized version of MSE where a feature value may be normalized by Imax-Imin, where Imax and Imin are maximum and minimum intensity values in the grayscale image, respectively.

c) The features computed using the binary segmentation masks may be A1 and A2, and Circularity, Asymmetry Index, Eccentricity and seven Hu's moments/Hu's moment invariants. To compute A1 and A2, Ax and Ay may be computed. Referring to Figure 3, Ax may be a difference of areas of the two halves of the digital skin lesion image 304 when the digital skin lesion image

304 is divided along the first axis 308. Similarly, Ay may be the corresponding measure for the halves when the digital skin lesion image 304 is divided along the second axis 310. A1 and A2 can be defined as follows:

$$A1 = \frac{\min(A_x, A_y)}{A} \times 100$$

$$A2 = \frac{A_x + A_y}{A} \times 100$$

where A is the area of the skin lesion and computed as a number of pixels in the digital skin lesion image 304.

Circularity can be related to the perimeter of the skin lesion as per the following formula:

$$Circularity = \frac{4\pi A}{perimeter^2}$$

Asymmetry index may be computed after fitting an ellipse on the skin lesion and can be defined as:

$$\frac{|A_e - A|}{A_e}$$

where,

$$A_e = \pi ab$$

with a and b being the semi-major and semi-minor axes respectively.

Eccentricity can be defined as:

$$Eccentricity = \frac{\sqrt{a^2 - b^2}}{a}$$

**[0043]** As a non-limiting example, the colour asymmetry features may comprise one or more of the following:

a) Kullback-Leibler (KL) divergence between histograms of two halves of an image along major and minor symmetry axes. The features can be computed for each of the R, G and B colour channels. The KL divergence between two histograms, P and Q can be defined as:

$$KL = \sum_{i=1}^{N} P(i) log \frac{P(i)}{Q(i)}$$

where P(i) is the value in the $i^{th}$ bin of P and Q(i) is the value in the $i^{th}$ bin of Q. N is the number of bins in the histograms.

b) Chi-square distance between histogram of two halves computed for R, G and B channels. Chi-square distance between two histograms P and Q may be defined as:

$$X = \sum_{i=1}^{N} \frac{(P(i) - Q(i))^2}{P(i) + Q(i)}$$

c) Coloured versions of A1 and A2 (described above) computed for R, G and B channels.

d) Mean of a brightness difference between the two halves. The features can be computed for H, S, V, L, a, and b channels.

e) Standard deviation of the brightness difference between the two halves. The features may be computed for R, G, B, H, S, V, L, a, and b channels.

f) Coloured version of SSIM (described above).

**[0044]** In some implementations, 70 hand-crafted features may be computed from each image, including 50 colour asymmetry features and 20 shape asymmetry features. One or more of the hand-crafted feature vectors may be concatenated/combined with the DNN-determined feature vector to obtain the combined feature vector.

**[0045]** Referring back to Figure 3, calculating the asymmetry score 312 may comprise providing the combined feature vector 314 as an input to a classifier 316 such as a machine learning classifier. A non-limiting example of the machine learning classifier can be a Support Vector Machine classifier.

**[0046]** According to one embodiment, the method for facilitating analysis of the skin condition may further comprise calculating a colour score. The colour score may be based on detection of one or more pre-defined colours in the digital skin lesion image, and calculating the final score may comprise calculating the final score based on the colour score and the asymmetry score.

**[0047]** As mentioned above, the digital skin image comprising the digital skin lesion image and the digital surrounding skin image may be provided. The digital skin image may be obtained by taking the photograph of the patient's skin area to be analyzed. The digital skin image may be a colour image. The digital skin image may be processed to segment the digital skin lesion image from the digital surrounding skin image. Processing the digital skin image may comprise using a deep-learning-based segmentation approach such as a first trained DNN to segment the digital skin lesion image from the digital surrounding skin image.

**[0048]** A number of different colours present in the digital skin lesion image may be counted/determined. As a non-limiting example, the number of six different colours (e.g. white, red, light-brown, dark-brown, blue-grey, and black) present in the digital skin lesion image may be counted for determining the colour score. White may only be chosen if the area is lighter in colour as compared to an adjacent skin or the surrounding skin. If all the six colours are present, a maximum colour score of 6 may be allocated. A minimum colour score may be 1. Melanomas are usually characterized by three or more colours. In about 40% of melanomas, five or six colours may be present.

**[0049]** The RGB colour space may be used to delineate the six different colours. A minimum lower limit and a maximum upper limit of the RGB values for each of the six colours may be obtained empirically by correlating them to colour features' annotations. An example is shown in the table below which values of the RGB minimum and maximum limits are shown as a ratio of 255.

| | R_min | R_max | G_min | G_max | B_min | B_max |
|---|---|---|---|---|---|---|
| Black | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.1 |
| White | 0.8 | 1.0 | 0.8 | 1.0 | 0.8 | 1.0 |
| Red | 0.8 | 1.0 | 0.0 | 0.2 | 0.0 | 0.2 |
| Light Brown | 0.6 | 1.0 | 0.42 | 0.72 | 0.2 | 0.45 |
| Dark Brown | 0.2 | 0.6 | 0.06 | 0.46 | 0.0 | 0.33 |
| Blue Gray | 0.0 | 0.2 | 0.32 | 0.72 | 0.34 | 0.74 |

**[0050]** Figure 5 is a block diagram 500 illustrating a method for facilitating analysis of the skin condition, according to another example embodiment. As shown in Figure 5, an image such as the digital skin image comprising the digital skin lesion image and

the digital surrounding skin image may be provided as input. Segmentation of the digital skin image may be performed to segment the digital skin lesion image from the digital surrounding skin image.

**[0051]** The asymmetry (A) score 502, a border (B) score 504, the colour (C) score 506, and a dermatoscopic structure (D) score 508 may each be multiplied by a respective pre-determined weight factor for calculating a Melanoma Risk Score (MRS). An example formula is shown below.

$$MRS = a*A + b*B + c*C + d*D$$

where a, b, c, and d can be constants. As a non-limiting example, a, b, c and d can be 1.3, 0.1, 0.5 and 0.5, respectively.

**[0052]** As a non-limiting example, MRS value less than T1 (e.g. 4.75) may indicate a benign melanocytic lesion, while values between T1 (e.g. 4.75) and T2 (e.g. 5.45) may indicate a suspicious lesion, and values greater than T2 (e.g. 5.45) may indicate a high suspicion for melanoma. Further adjustments of T1 and T2 values may be done based on an annotated ground-truth data to better fit the dataset.

**[0053]** This specification uses the term “configured to” in connection with systems, devices, and computer program components. For a system of one or more computers to be configured to perform particular operations or actions means that the system has installed on it software, firmware, hardware, or a combination of them that in operation cause the system to perform the operations or actions. For one or more computer programs to be configured to perform particular operations or actions means that the one or more programs include instructions that, when executed by data processing apparatus, cause the apparatus to perform the operations or actions. For special-purpose logic circuitry to be configured to perform particular operations or actions means that the circuitry has electronic logic that performs the operations or actions.

**[0054]** Figure 6 is a schematic diagram 600 illustrating a system for facilitating analysis of a skin condition, according to an example embodiment. The system comprises a first feature vector determining device 602 configured to determine a deep neural network (DNN)-determined feature vector based on one or more first asymmetry related features from a digital skin lesion image and one or more corresponding first asymmetry related features from a mirror image of the digital skin lesion image. The

system also comprises a second feature vector determining device 604 configured to determine one or more hand-crafted feature vectors based on one or more predefined second asymmetry related features. The one or more predefined second asymmetry related features are different from the one or more first asymmetry related features. The system further comprises a feature vector combining device 606 configured to combine the DNN-determined feature vector and the one or more hand-crafted feature vectors to obtain a combined feature vector. The system also comprises a first score calculating device 608 configured to calculate an asymmetry score based on the combined feature vector. Further, the system also comprises a second score calculating device 610 configured to calculate a final score based on the asymmetry score for facilitating analysis of the skin condition.

**[0055]** According to one embodiment, the system may further comprise a digital image obtaining device configured to obtain a digital skin image comprising the digital skin lesion image and a digital surrounding skin image. The system may also comprise a digital image processing device configured to process the digital skin image to segment the digital skin lesion image from the digital surrounding skin image.

**[0056]** The digital image processing device may comprise a first trained DNN configured to segment the digital skin lesion image from the digital surrounding skin image.

**[0057]** The first feature vector determining device 602 may comprise an axis determining device configured to determine a first axis and a second axis on the digital skin lesion image. Each of the first axis and the second axis may divide the digital skin lesion image into two equal sections, and the second axis may be perpendicular to the first axis.

**[0058]** The axis determining device may comprise an eigenvector calculating device configured to perform an eigenvector calculation, and the digital skin lesion image may be represented as a two-dimensions point cloud for performing the eigenvector calculation.

**[0059]** The first feature vector determining device 602 may further comprise a digital image rotating device configured to rotate the digital skin lesion image such that the first axis and the second axis on the digital skin lesion image corresponds to coordinate axes.

**[0060]** The first feature vector determining device 602 may further comprise a digital image reflecting device configured to reflect the digital skin lesion image along the first axis to obtain the mirror image of the digital skin lesion image.

**[0061]** The first feature vector determining device 602 may comprise a second trained DNN configured to extract the one or more first asymmetry related features from the digital skin lesion image, and extract the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image. The first feature vector determining device 602 may also comprise a distance determining device configured to determine one or more distances between the one or more first asymmetry related features from the digital skin lesion image and the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image. Each of the one or more distances may correspond to the distance between each of the one or more first asymmetry related features from the digital skin lesion image and the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image.

**[0062]** The first score calculating device 608 may comprise a feature vector sending device configured to provide the combined feature vector as an input to a machine learning classifier such as a Support Vector Machine classifier.

**[0063]** The system may further comprise a third score calculating device configured to calculate a colour score. The colour score may be based on detection of one or more pre-defined colours in the digital skin lesion image, and the final score may be calculated based on the colour score and the asymmetry score.

**[0064]** Some implementations may seek to provide a computer system for facilitating analysis of a skin condition. The computer system may comprise at least one processor, a non-transitory computer-readable storage medium coupled to the at least one processor and storing programming instructions for execution by the at least one processor. The programming instructions can instruct the at least one processor to determine a deep neural network (DNN)-determined feature vector based on one or more first asymmetry related features from a digital skin lesion image and one or more corresponding first asymmetry related features from a mirror image of the digital skin lesion image. The programming instructions can further instruct the at least one processor to determine one or more hand-crafted feature vectors based on one or more predefined second asymmetry related features. The one or more predefined

second asymmetry related features are different from the one or more first asymmetry related features. The programming instructions can also instruct the at least one processor to combine the DNN-determined feature vector and the one or more hand-crafted feature vectors to obtain a combined feature vector. Further, the programming instructions can instruct the at least one processor to calculate an asymmetry score based on the combined feature vector. The programming instructions can also instruct the at least one processor to calculate a final score based on the asymmetry score for facilitating analysis of the skin condition.

**[0065]** Figure 7 shows a schematic diagram of a computer system 700 suitable for use in executing at least some steps of the method for facilitating analysis of the skin condition.

**[0066]** The following description of the computer system / computing device 700 is provided by way of example only and is not intended to be limiting.

**[0067]** As shown in Figure 7, the example computing device 700 includes a processor 704 for executing software routines. Although a single processor is shown for the sake of clarity, the computing device 700 may also include a multi-processor system. The processor 704 is connected to a communication infrastructure 706 for communication with other components of the computing device 700. The communication infrastructure 706 may include, for example, a communications bus, cross-bar, or network.

**[0068]** The computing device 700 further includes a main memory 708, such as a random access memory (RAM), and a secondary memory 710. The secondary memory 710 may include, for example, a hard disk drive 712 and/or a removable storage drive 714, which may include a magnetic tape drive, an optical disk drive, or the like. The removable storage drive 714 reads from and/or writes to a removable storage unit 718 in a well-known manner. The removable storage unit 718 may include a magnetic tape, optical disk, or the like, which is read by and written to by removable storage drive 714. As will be appreciated by persons skilled in the relevant art(s), the removable storage unit 718 includes a computer readable storage medium having stored therein computer executable program code instructions and/or data.

**[0069]** In an alternative embodiment, the secondary memory 710 may additionally or alternatively include other similar devices for allowing computer programs or other instructions to be loaded into the computing device 700. Such devices can include, for example, a removable storage unit 722 and an interface 720. Examples of a removable

storage unit 722 and interface 720 include a removable memory chip (such as an EPROM or PROM) and associated socket, and other removable storage units 722 and interfaces 720 which allow software and data to be transferred from the removable storage unit 722 to the computer system 700.

**[0070]** The computing device 700 also includes at least one communication interface 724. The communication interface 724 allows software and data to be transferred between computing device 700 and external devices via a communication path 726. In various embodiments, the communication interface 724 permits data to be transferred between the computing device 700 and a data communication network, such as a public data or private data communication network. The communication interface 724 may be used to exchange data between different computing devices 700 which such computing devices 700 form part of an interconnected computer network. Examples of a communication interface 724 can include a modem, a network interface (such as an Ethernet card), a communication port, an antenna with associated circuitry and the like. The communication interface 724 may be wired or may be wireless. Software and data transferred via the communication interface 724 are in the form of signals which can be electronic, electromagnetic, optical or other signals capable of being received by communication interface 724. These signals are provided to the communication interface via the communication path 726.

**[0071]** Optionally, the computing device 700 further includes a display interface 702 which performs operations for rendering images to an associated display 730 and an audio interface 732 for performing operations for playing audio content via associated speaker(s) 734.

**[0072]** As used herein, the term "computer program product" may refer, in part, to removable storage unit 718, removable storage unit 722, a hard disk installed in hard disk drive 712, or a carrier wave carrying software over communication path 726 (wireless link or cable) to communication interface 724. Computer readable storage media refers to any non-transitory tangible storage medium that provides recorded instructions and/or data to the computing device 400 for execution and/or processing. Examples of such storage media include floppy disks, magnetic tape, CD-ROM, DVD, Blu-ray™ Disc, a hard disk drive, a ROM or integrated circuit, USB memory, a magneto-optical disk, or a computer readable card such as a PCMCIA card and the like, whether or not such devices are internal or external of the computing device 700. Examples of transitory or non-tangible computer readable transmission media that may

also participate in the provision of software, application programs, instructions and/or data to the computing device 700 include radio or infra-red transmission channels as well as a network connection to another computer or networked device, and the Internet or Intranets including e-mail transmissions and information recorded on Websites and the like.

**[0073]** The computer programs (also called computer program code) are stored in main memory 708 and/or secondary memory 710. Computer programs can also be received via the communication interface 724. Such computer programs, when executed, enable the computing device 700 to perform one or more features of embodiments discussed herein. In various embodiments, the computer programs, when executed, enable the processor 704 to perform features of the above-described embodiments. Accordingly, such computer programs represent controllers of the computer system 700.

**[0074]** Software may be stored in a computer program product and loaded into the computing device 700 using the removable storage drive 714, the hard disk drive 712, or the interface 720. Alternatively, the computer program product may be downloaded to the computer system 700 over the communications path 726. The software, when executed by the processor 704, causes the computing device 700 to perform functions of embodiments described herein.

**[0075]** It is to be understood that the embodiment of Figure 7 is presented merely by way of example. Therefore, in some embodiments one or more features of the computing device 700 may be omitted. Also, in some embodiments, one or more features of the computing device 700 may be combined together. Additionally, in some embodiments, one or more features of the computing device 700 may be split into one or more component parts.

**[0076]** It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the embodiments. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

**CLAIMS**

1. A method for facilitating analysis of a skin condition, comprising:

determining a deep neural network (DNN)-determined feature vector based on one or more first asymmetry related features from a digital skin lesion image and one or more corresponding first asymmetry related features from a mirror image of the digital skin lesion image;

determining one or more hand-crafted feature vectors based on one or more predefined second asymmetry related features, wherein the one or more predefined second asymmetry related features are different from the one or more first asymmetry related features;

combining the DNN-determined feature vector and the one or more hand-crafted feature vectors to obtain a combined feature vector;

calculating an asymmetry score based on the combined feature vector; and

calculating a final score based on the asymmetry score for facilitating analysis of the skin condition.

2. The method of claim 1, further comprising:

before determining the DNN-determined feature vector, providing a digital skin image comprising the digital skin lesion image and a digital surrounding skin image; and

processing the digital skin image to segment the digital skin lesion image from the digital surrounding skin image.

3. The method of claim 2, wherein processing the digital skin image comprises using a first trained DNN to segment the digital skin lesion image from the digital surrounding skin image.

4. The method of any one of the preceding claims, wherein determining the DNN-determined feature vector comprises:

determining a first axis and a second axis on the digital skin lesion image, wherein each of the first axis and the second axis divides the digital skin lesion image into two equal sections, and wherein the second axis is perpendicular to the first axis.

5. The method of claim 4, wherein determining the first axis and the second axis on the digital skin lesion image comprises performing an eigenvector calculation, and

wherein the digital skin lesion image is represented as a two-dimensions point cloud for performing the eigenvector calculation.

6. The method of claim 4 or 5, wherein determining the DNN-determined feature vector further comprises:

rotating the digital skin lesion image such that the first axis and the second axis on the digital skin lesion image corresponds to coordinate axes.

7. The method of any one of claims 4 to 6, wherein determining the DNN-determined feature vector further comprises reflecting the digital skin lesion image along the first axis to obtain the mirror image of the digital skin lesion image.

8. The method of any one of the preceding claims, wherein determining the DNN-determined feature vector comprises:

extracting, using a second trained DNN, the one or more first asymmetry related features from the digital skin lesion image;

extracting, using the second trained DNN, the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image; and

determining one or more distances between the one or more first asymmetry related features from the digital skin lesion image and the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image, wherein each of the one or more distances corresponds to the distance between each of the one or more first asymmetry related features from the digital skin lesion image and the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image.

9. The method of any one of the preceding claims, wherein calculating the asymmetry score comprises providing the combined feature vector as an input to a machine learning classifier.

10. The method of any one of the preceding claims, further comprising calculating a colour score, wherein the colour score is based on detection of one or more pre-defined colours in the digital skin lesion image, and wherein calculating the final score comprises calculating the final score based on the colour score and the asymmetry score.

11. A system for facilitating analysis of a skin condition, comprising:

a first feature vector determining device configured to determine a deep neural network (DNN)-determined feature vector based on one or more first asymmetry related features from a digital skin lesion image and one or more corresponding first asymmetry related features from a mirror image of the digital skin lesion image;

a second feature vector determining device configured to determine one or more hand-crafted feature vectors based on one or more predefined second asymmetry related features, wherein the one or more predefined second asymmetry related features are different from the one or more first asymmetry related features;

a feature vector combining device configured to combine the DNN-determined feature vector and the one or more hand-crafted feature vectors to obtain a combined feature vector;

a first score calculating device configured to calculate an asymmetry score based on the combined feature vector; and

a second score calculating device configured to calculate a final score based on the asymmetry score for facilitating analysis of the skin condition.

12. The system of claim 11, further comprising:

a digital image obtaining device configured to obtain a digital skin image comprising the digital skin lesion image and a digital surrounding skin image; and

a digital image processing device configured to process the digital skin image to segment the digital skin lesion image from the digital surrounding skin image.

13. The system of claim 12, wherein the digital image processing device comprises a first trained DNN configured to segment the digital skin lesion image from the digital surrounding skin image.

14. The system of any one of claims 11 to 13, wherein the first feature vector determining device comprises:

an axis determining device configured to determine a first axis and a second axis on the digital skin lesion image, wherein each of the first axis and the second axis divides the digital skin lesion image into two equal sections, and wherein the second axis is perpendicular to the first axis.

15. The system of claim 14, wherein the axis determining device comprises an eigenvector calculating device configured to perform an eigenvector calculation, and

wherein the digital skin lesion image is represented as a two-dimensions point cloud for performing the eigenvector calculation.

16. The system of claim 14 or 15, wherein the first feature vector determining device further comprises:

a digital image rotating device configured to rotate the digital skin lesion image such that the first axis and the second axis on the digital skin lesion image corresponds to coordinate axes.

17. The system of any one of claims 14 to 16, wherein the first feature vector determining device further comprises a digital image reflecting device configured to reflect the digital skin lesion image along the first axis to obtain the mirror image of the digital skin lesion image.

18. The system of any one of claims 11 to 17, wherein the first feature vector determining device comprises:

a second trained DNN configured to:

extract the one or more first asymmetry related features from the digital skin lesion image; and

extract the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image; and

a distance determining device configured to determine one or more distances between the one or more first asymmetry related features from the digital skin lesion image and the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image, wherein each of the one or more distances corresponds to the distance between each of the one or more first asymmetry related features from the digital skin lesion image and the one or more corresponding first asymmetry related features from the mirror image of the digital skin lesion image.

19. The system of any one of claims 11 to 18, wherein the first score calculating device comprises a feature vector sending device configured to provide the combined feature vector as an input to a machine learning classifier.

20. The system of any one of claims 11 to 19, further comprising a third score calculating device configured to calculate a colour score, wherein the colour score is

based on detection of one or more pre-defined colours in the digital skin lesion image, and wherein the final score is calculated based on the colour score and the asymmetry score.