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Shivpure et al.

(54) NON-INVASIVE NON-CONTACT SYSTEM AND METHOD FOR MEASURING DIABETES MELLITUS CONDITION USING THERMAL IMAGING

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(Continued)

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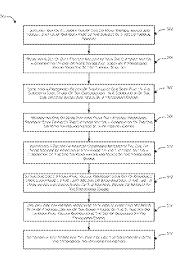
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(57) ABSTRACT

System and method for measuring diabetes mellitus condition of a subject is disclosed. The disclosed system and method includes thermal sensors for capturing thermal images and/or videos of a body part; and a processing engine to detect a predefined region of the body part in each frame of the captured images and/or videos. The processing engine segments one or more portions from the detected predefined region in each frame of the captured images and/or videos to identify a region of interest comprising major arteries in the segmented portions. Based on the ROI, the engine extracts pixel values, representing biosignals, from each frame of the captured images and/or videos so as to determine one or more parameters associated with the hemodynamic factors (Continued)



and a rate of atherosclerosis of the subject. Further, a risk score for the diabetes mellitus condition based on the determined parameters using computational models is measured.

18 Claims, 8 Drawing Sheets

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	G06T 7/00	(2017.01)
	G06T 7/11	(2017.01)

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(58) Field of Classification Search
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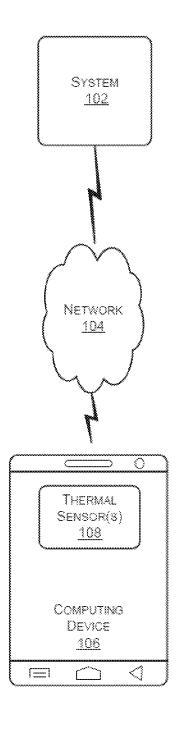


FIG. 1

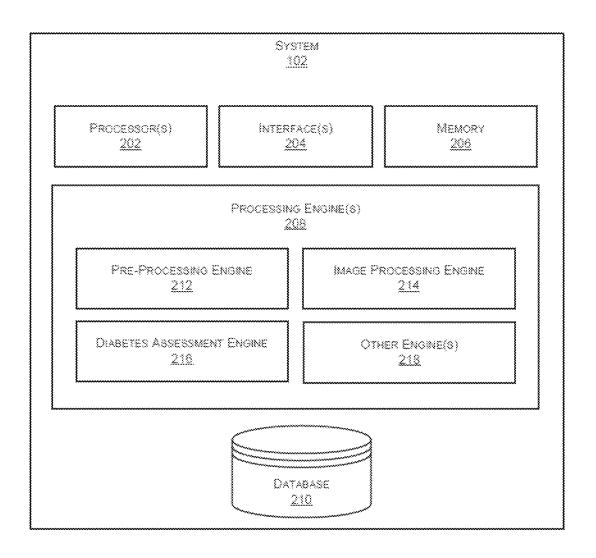


FIG. 2

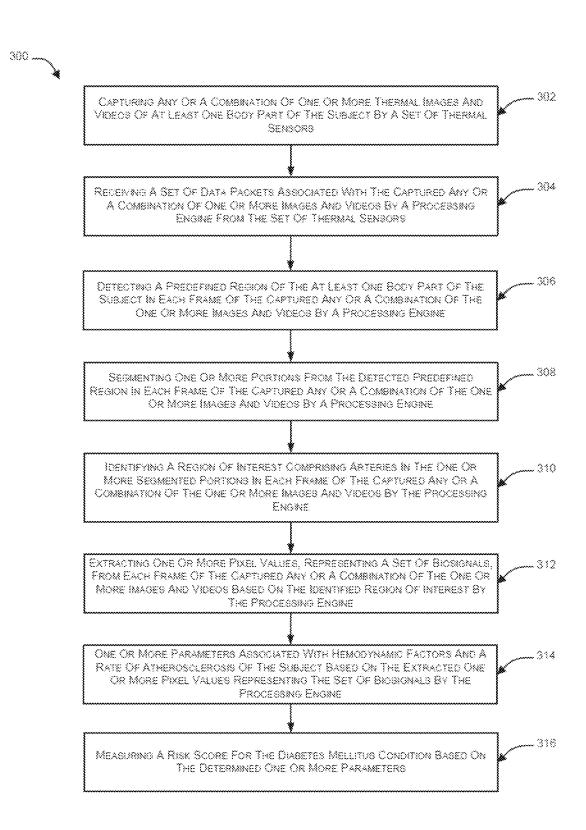




FIG. 4A

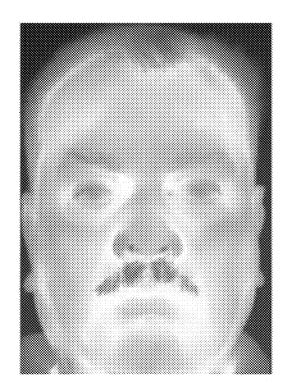


FIG. 4B

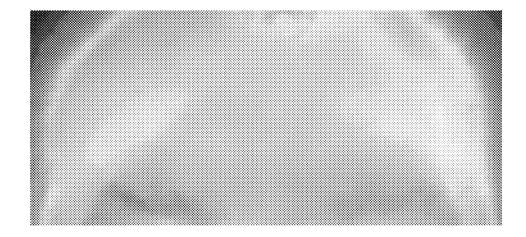
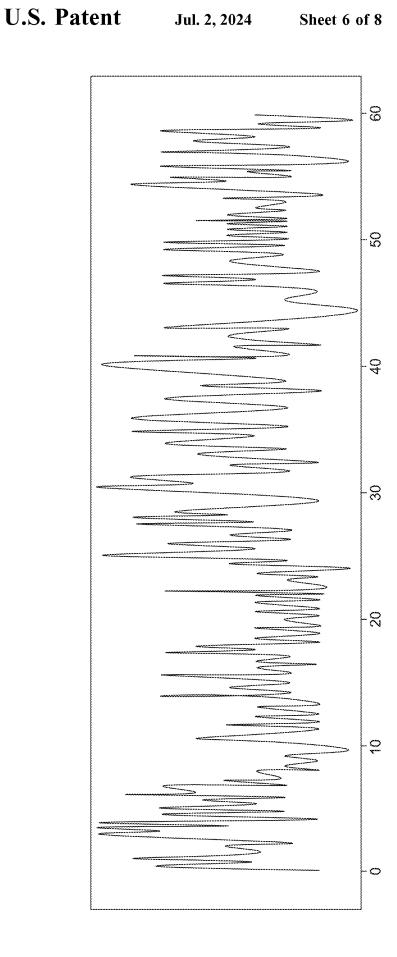
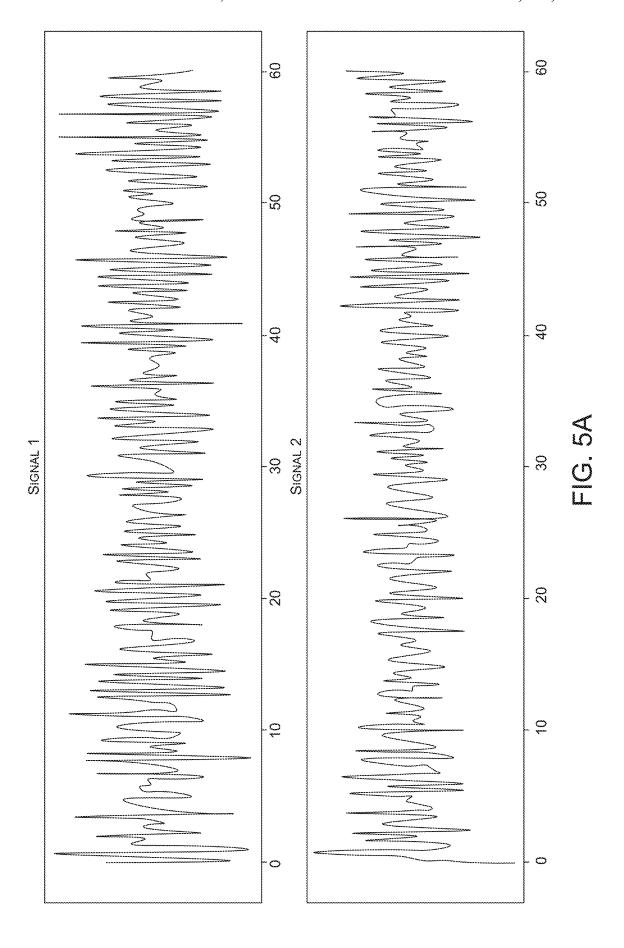
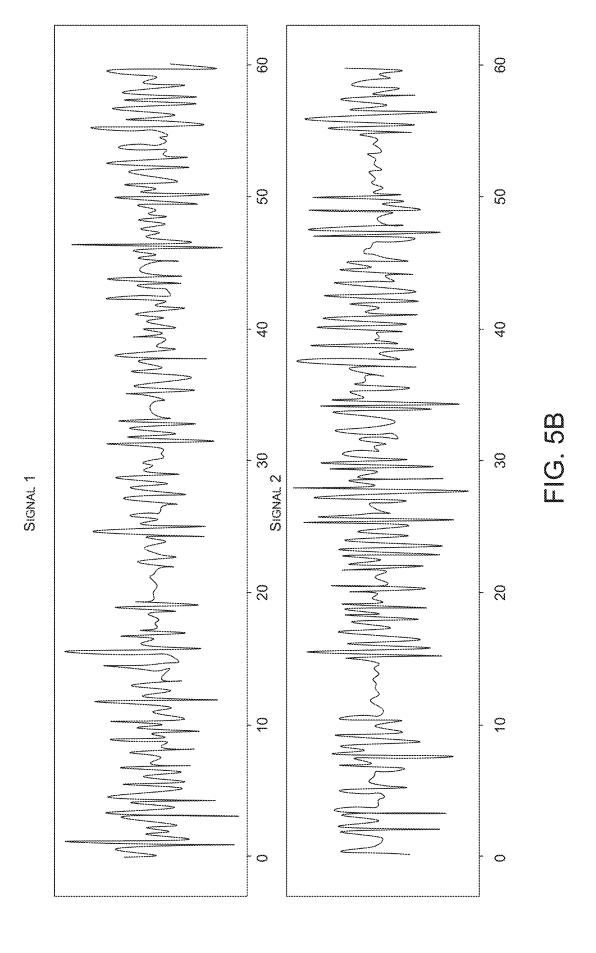


FIG. 4C







NON-INVASIVE NON-CONTACT SYSTEM AND METHOD FOR MEASURING DIABETES MELLITUS CONDITION USING THERMAL IMAGING

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to International Patent Application No. PCT/IB2020/059244, filed on Oct. 2, 2020, which claims priority to Indian Patent Application No. 201941044163, filed on Oct. 31, 2019. The contents of these applications are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

The present disclosure generally relates to the technical field of health care systems for evaluating health conditions of a person. More particularly, the present disclosure relates to a non-contact, non-invasive system and method for determining diabetes mellitus condition of a person using thermal imaging.

BACKGROUND

The background description includes information that may be useful in understanding the present invention. It is not an admission that any of the information provided herein is prior art or relevant to the presently claimed invention, or 30 that any publication explicitly or implicitly referenced is prior art.

Diabetes mellitus is a metabolic disorder characterized by chronic hyperglycemia with disturbances of carbohydrates, fat and protein metabolism caused due to defects in insulin 35 secretion and/or insulin action. Diabetes, once diagnosed, can be controlled but still may cause complications that could be life-threatening. Diabetes mellitus condition stimulates the risk of long-term damage, dysfunction, and failure of various internal organs. Symptoms of diabetes mellitus 40 include thirst, polyuria, blurring of vision and weight loss. Severe complications of the diabetes mellitus include ketoacidosis, hyperosmolar state, damage to the eyes, chronic kidney disease, foot ulcers, renal failure, coma, and in the absence of efficacious treatment can cause death. 45 People with diabetes are at increased risk of cardiovascular, peripheral vascular and cerebrovascular diseases.

Diabetes results from a combination of causes and contributing factors, including an individual's lifestyle and genetics. Lifestyle can include dietary habits, level of physi- 50 cal activity, long term usage of medication and others. Diabetes mellitus is predominantly classified into two categories as Type 1 Diabetes and Type 2 Diabetes. Type 1 Diabetes results from failure of pancreas to produce enough insulin due to loss of beta cells, causing a deficiency in 55 insulin secretion. Type 2 Diabetes is the most prevalent and is associated with resistance to insulin action resulting in inadequate insulin secretion, which in turn leads to depletion of beta cells. Type 2 Diabetes in spite of being the most common form of diabetes in the population, may not be 60 detected for many years until clinical symptoms are encountered as a degree of hyperglycemia may not be sufficient enough to cause pathological detection possible.

The degree of hyperglycemia may gradually increase over time due to the underlying dysfunction of the metabolic 65 activity and show symptoms of diabetes, requiring clinical intervention. Diagnosis, continuous monitoring and treat2

ment are essential in managing the diabetes mellitus condition. Complications associated with diabetes, such as nephropathy, retinopathy, neuropathy and cardiovascular diseases can be prevented or delayed with continuous monitoring and appropriate treatment plan. Typical clinical diagnosis of diabetes involves measurement of blood glucose level. A consistently higher glucose level in the blood over time, confirms the diabetes mellitus condition in a person. Typically glucose measurement currently includes techniques such as Fasting Plasma Glucose (FPG), Oral Glucose Tolerance (OGT) and Glycated Haemoglobin (HbA1c) test. These methods are invasive and require drawing blood samples from a vein in, generally, an arm of the individual, causing pain and discomfort. Hence, these methods are not preferred for continuous monitoring or multiple pre-screen-15 ings.

Among diabetes patients, home-based glucose monitors are preferred to monitor diabetes conditions and the blood glucose level. However, most of these glucose monitors still involve invasive techniques such as obtaining blood from a finger prick, causing pain and discomfort, which results in poor adherence to self-monitoring. Other existing techniques that uses infrared emission measurements are not explicitly equipped for risk stratification of diabetes patients who present without symptoms of loss of neuronal function as a precursor to peripheral neuropathy. These techniques are not efficient for stimulating homeostasis and measuring the related neuronal function. A significant reason is that no simple and unambiguous laboratory test has existed that can be used to identify those subjects who are at risk of developing diabetes or pre-diabetes.

There is, therefore, a need to provide a simple and efficient solution to identify subjects with either pre-diabetes or diabetes mellitus condition so that they can obtain treatment early, and can also monitor progression of the disease over time.

OBJECTS OF THE INVENTION

A general object of the present disclosure is to provide a simple and efficient solution which can obviate the foregoing limitations in the art.

An object of the present disclosure is to provide an improved system for evaluating diabetes mellitus condition of an individual.

Another object of the present disclosure is to provide an efficient system to identify individuals with either prediabetes or diabetes conditions so that they can obtain treatment early, and can also monitor progression of the disease over time.

Another object of the present disclosure is to provide a non-contact, non-invasive system and method for determining diabetes condition of a person by using thermal imaging.

Yet another object of the present disclosure is to provide an efficient system and method to use biomarkers associated with hemodynamic factors and a rate of atherosclerosis determined from thermal imaging for measuring diabetes mellitus conditions of individuals to help in diagnosis of health conditions.

Still another object of the present disclosure is to provide a simple and cost-effective system and method which can be easily implemented for measuring diabetes mellitus conditions of a person.

SUMMARY

Aspects of the present disclosure relate to a non-contact, non-invasive system and method for determining diabetes

mellitus condition in a person. The proposed system and method may be used for provisional diagnosis of diabetes of a patient and for regulating the medications or treatment suitable to the patient over time. This system and method may also be used for early detection of biomarkers indicating risk of developing the diabetes conditions, and can use biomarkers associated with vascular health conditions measured by thermal imaging for assessing diabetes complications.

Chronic hyperglycemia in a diabetes person creates vas- 10 cular complications over time, such as atherosclerosis and atherothrombosis. These complications modify the vascular structure and cause hemodynamic imbalances in the person body. Clinical manifestation of these complications typically takes several months or years while vascular dysfunction 15 exists in early stages and may act as the early indicators of the diabetes condition. The imbalances due to these complications can be seen in arteries and are used as potential biomarkers to determine diabetes condition. The movement of blood through the arteries is associated with emission of 20 heat due to inflammation and resistance of arterial wall and is measured using infrared thermal sensors on carotid arteries as they lay close to a skin surface. Atherosclerosis or dysfunction in the carotid arteries caused due to the type 2 diabetes creates more resistance for flow of blood and 25 changes the hemodynamics. Hyperperfusion of blood as seen in inflammatory, neogenic and neoplastic conditions causes hyperthermia whereas the hypoperfusion due to degeneration of tissue or plaque formation causes hypothermia. This correlation between the blood flow and the tem- 30 perature variation observed in the arterial region is used as a principle behind this system and method to measure parameters associated with the hemodynamics. Further, since plaque formation may be present only in some sections of the arteries, the hemodynamic parameters measured from 35 thermal patterns for different locations differ. These differences also serve as biomarkers of the diabetes condition.

In an aspect, the disclosed system and method for determining diabetes mellitus condition of a subject, such as a human, are based on capturing any or a combination of one 40 or more thermal images and videos of at least one body part, for example an anterior face, of the subject by a set of thermal sensor; and receiving a set of data packets associated with the captured any or a combination of one or more images and videos by a processing engine. The processing 45 engine comprises processors coupled to a memory storing a set of instructions executable by the one or more processors to detect a predefined region, for example a face, of the body part in each frame of the captured images and/or videos, and segment one or more portions, for example a forehead of the 50 subject, from the detected predefined region in each frame of the captured images and/or videos. A region of interest comprising arteries in the segmented portions in each frame of the captured images and/or videos is automatically identified by the processors to extract one or more pixel values, 55 representing a set of biosignals, from each frame of the captured images and/or videos based on the identified region of interest.

In an embodiment, one or more parameters associated with hemodynamic factors and a rate of atherosclerosis of 60 the subject are determined based on the extracted one or more pixel values to measure a risk score for the diabetes mellitus condition of the subject based on the determined parameters using computational models. Thus, it would be appreciated that the risk score for the diabetes condition is 65 determined non-invasively without contacting the subject and does not involve any harmful radiation.

4

In an embodiment, the determined one or more parameters associated with the hemodynamic factors and the rate of atherosclerosis correspond to time and frequency domain parameters including, but not limited to, average intensity, signal amplitude, signal period, signal entropy, signal power spectral density, histogram and peak count.

In an exemplary embodiment, the disclosed system and method can be used for various applications, for example provisional diagnosis of the diabetes mellitus condition, regulate medications and treatment suitable to a diabetes patient over time, early detection of biomarkers indicating the risk of developing the diabetes condition, determine efficacy of lifestyle and medical interventions.

Various objects, features, aspects and advantages of the inventive subject matter will become apparent from the following detailed description of preferred embodiments, along with the accompanying drawing figures in which like numerals represent like components.

BRIEF DESCRIPTION OF THE DRAWINGS

In the figures, similar components and/or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label with a second label that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the second reference label.

FIG. 1 illustrates an exemplary overall architecture in which or with which the proposed system can be implemented, in accordance with an embodiment of the present disclosure.

FIG. 2 illustrates exemplary functional components of the proposed system, in accordance with an embodiment of the present disclosure.

FIG. 3 illustrates a flow diagram illustrating a method for measuring diabetes mellitus condition of a subject, in accordance with an embodiment of the present disclosure.

FIG. 4A illustrates a sequence of frames from captured thermal videos/images using infrared thermal camera, in accordance with an embodiment of the present disclosure.

FIG. 4B illustrates a segment of the facial region detected using face detection algorithm and extracted from captured thermal images, in accordance with an embodiment of the present disclosure.

FIG. 4C illustrates a forehead region segmented from a face to identify a region of interest comprising arteries, in accordance with an embodiment of the present disclosure.

FIG. 4D illustrates an exemplary biosignal waveform determined from pixel values extracted from a region of interest, in accordance with an embodiment of the present disclosure.

FIG. 5A illustrates two exemplary biosignals obtained and filtered from a region of interest of a healthy person, in accordance with an embodiment of the present disclosure.

FIG. **5**B illustrates two exemplary biosignals obtained and filtered from a region of interest of a chronic diabetic person, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

The following is a detailed description of embodiments of the disclosure depicted in the accompanying drawings. The embodiments are in such detail as to communicate the disclosure. However, the amount of detail offered is not intended to limit the anticipated variations of embodiments; 00 12,023,130 E

on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the present disclosure as defined by the appended claims.

5

If the specification states a component or feature "may", 5 "can", "could", or "might" be included or have a characteristic, that particular component or feature is not required to be included or have the characteristic. As used in the description herein and throughout the claims that follow, the meaning of "a," "an," and "the" include plural reference unless the context clearly dictates otherwise. Also, as used in the description herein, the meaning of "in" includes "in" and "on" unless the context clearly dictates otherwise.

Various methods described herein may be practiced by combining one or more machine-readable storage media 15 containing the code according to the present invention with appropriate standard computer hardware to execute the code contained therein. An apparatus for practicing various embodiments of the present invention may involve one or more computers (or one or more processors within the single 20 computer) and storage systems containing or having network access to a computer program(s) coded in accordance with various methods described herein, and the method steps of the invention could be accomplished by modules, routines, subroutines, or subparts of a computer program prod- 25 uct.

While embodiments of the present invention have been illustrated and described, it is apparent that the invention is not limited to these embodiments only. Numerous modifications, changes, variations, substitutions, and equivalents 30 will be apparent to those skilled in the art, without departing from the spirit and scope of the invention, as described in the claim.

Embodiments explained herein relate to health care systems for evaluating health conditions of an individual/ 35 patient. In particular, the present disclosure relates to a non-contact, non-invasive system and method for measuring diabetes mellitus condition of a person using thermal imaging.

In an aspect, the present disclosure provides a system and 40 method for measuring diabetes mellitus condition of a person. The system and method includes a set of thermal sensors for capturing one or more thermal images or thermal videos of at least one part of a subject body; and a processing engine operatively coupled to the set of thermal sensors, the 45 processing engine comprising a processor coupled to a memory, the memory storing instructions executed by the processor to: pre-process one or more thermal images and/or videos received from the thermal sensors; for each image from the set of thermal images captured or from the captured 50 thermal videos, define a region of interest (ROI) in each of the image frames; segment the ROI in each of the plurality of image frames into a plurality of segments based on thermal gradient pattern; determine the change in thermal gradient values of each pixel in the ROI for a predefined 55 time period to obtain set of time domain values for quantitative analysis and signal processing; determine one or more parameters associated to vascular health and hemodynamics; and compare the determined parameters with a set of predetermined or predefined parameters values observed for 60 healthy subjects, to determine existence and/or degree of hyperglycemia of the subject.

In another aspect, the system and method for measuring diabetes mellitus condition uses passive thermal videos/images of an anterior face of a subject to measure vascular 65 function and analyze the blood transmission pattern. The frontal branches of major arteries on the forehead, is con-

sidered to measure biomarkers of vascular dysfunction. The frontal branch of the arteries typically lay close to a skin surface in the forehead region, and heat intensity can be

surface in the forehead region, and heat intensity can be measured from the thermal image/video captured using an infrared thermal camera. The region related to the arterial structure in the forehead is automatically segmented from each frame of the video/images. The segmented region is further processed to extract the pixel values representing the distribution of temperature or the heat intensity along the arterial section. Time domain values are evaluated using statistical analysis and signal processing techniques to calculate parameters associated with vascular health and hemodynamics.

These parameters represent hemodynamics such as, but not limited to, blood flow velocity, pulse rate, blood density and blood pressure. The variations in the thermal intensity along the segmented region represent occlusions of the arteries due to atherosclerotic lesions. By relating the variations in the intensity of heat and the measured parameters with the age of the subject and by comparison with corresponding measurements initially determined from non-diabetes subjects of comparable age, the presence of diabetes mellitus is determined. Typically, a lower mean temperature is observed in chronic diabetes patients indicating an angiopathic vascular compromise. Moreover, imbalances in the hemodynamic parameters in the ROI are observed in diabetes patients. These factors and their magnitude are considered to measure severity of the diabetes condition of the subject.

In an embodiment, the disclosed system and methods can be used to identify efficacy of therapeutic interventions, such as to manage dosage overtime of anti-diabetes medication, or to assess success of lifestyle interventions or other treatments to modify disease progression.

FIG. 1 illustrates an exemplary overall architecture in which or with which the proposed system can be implemented, in accordance with an embodiment of the present disclosure.

In an embodiment, an overall architecture 100 includes a system 102 that can be implemented in any computing device that can be configured/operatively coupled with a server. The system 102 can be implemented using any or a combination of hardware components and/or software components such as a server, a computing system, a computing device, a security device and the like, such that embodiments of the present disclosure can determine the diabetes condition for a person. The system 102 can include processors and memory storing instructions executable by the processors. Further, the system 102 can be communicatively coupled with a computing device 106 through a network 104. The computing device 106 can be integrated with a set of thermal sensors 108. The set of thermal sensors 108 can be any or a combination of, but not limited to, a digital camera, a digital single-lens reflex (DSLR) camera, or a standalone infrared camera, a thermal camera, or a monochromatic camera. Those skilled in the art would appreciate that the thermal image can be captured using a thermal camera, the thermal camera senses thermal or infrared radiation emitted from the body of the person and can render images representing the spatial intensity of radiation. Since the images can be captured from an optimal distance, therefore this technique is non-invasive and non-contact.

The network 104 can be a wireless network, a wired network or a combination thereof that can be implemented as one of the different types of networks, such as Intranet, Local Area Network (LAN), Wide Area Network (WAN), Internet, and the like. Further, the network 104 can either be

a dedicated network or a shared network. The shared network can represent an association of the different types of networks that can use a variety of protocols, for example, Hypertext Transfer Protocol (HTTP), Transmission Control Protocol/Internet Protocol (TCP/IP), Wireless Application 5 Protocol (WAP), and the like.

Examples of the computing devices 106 can include, but are not limited to, a portable computer, a personal digital assistant, a handheld device, and a workstation. In an embodiment, the computing device 106 can be a mobile 10 phone having the imaging device 108. In another embodiment, the imaging device 108 is operatively coupled with the computing device 106. In an embodiment, the system 102 facilitates a non-invasive and non-contact technique for determining biomarkers to help determine the diabetes mellitus condition of the person.

In an embodiment, the thermal sensor 108 can be used for capturing thermal images or thermal video of at least a body part, for example anterior face, of the subject/person. For example, a length of the captured thermal video may range 20 from thirty seconds to one minute. According to an embodiment, during pre-processing the system 102 can receive a set of data packets associated with the captured one or more thermal images and/or the captured thermal video from the sensors 108 and process set of frames in the captured 25 thermal video and/or the captured one or more thermal images. The system 102 can detect and extract a predefined region, for example a face, of the subject in each frame of the captured images and/or videos, and segment one or more portions, for example a forehead, from the detected pre-30 defined region in each frame of the captured images and/or videos

In another embodiment, the system 102 can identify a region of interest comprising arteries in the one or more segmented portions in each frame of the captured images 35 and/or videos, and extract one or more pixel values, representing a set of biosignals, from each frame of the captured images and/or videos based on the identified region of interest. The system 102 can further determine one or more parameters associated with hemodynamic factors and a rate 40 of atherosclerosis of the subject based on the extracted pixel values, representing a set of biosignals, and measure a risk score for the diabetes mellitus condition based on the determined one or more parameters using computational models. The determined one or more parameters can be 45 associated with potential biomarkers of hemodynamic imbalances and the rate of atherosclerosis. Further, the system 102 may compare the determined one or more parameters with predetermined reference parameters to evaluate the diabetes condition of the subject based on 50 deviation of the determined one or more parameters with respect to the predetermined reference parameters.

The determined one or more parameters associated with the hemodynamics factors and the rate of atherosclerosis can correspond to time and frequency domain parameters which 55 can be any or a combination of average intensity, signal amplitude, signal period, signal entropy, signal power spectral density, histogram and peak count.

In an embodiment, evaluation of the diabetic condition of the subject may consider demographics and medical history 60 of the subject along with the determined parameters for evaluating the vascular health condition.

In an embodiment, the determined one or more parameters can be associated with a degree of hyperglycemia of the subject.

In an embodiment, the identified region of interest can be associated with a forehead region of the subject comprising 8

frontal branches of the arteries which lay close to a skin surface on the forehead. The processors can segment the identified region of interest from each of the captured images and/or videos based on a difference between thermal intensity along the arteries and the thermal intensity in other regions of the forehead. In an exemplary embodiment, the identified region of interest can be segmented using any or a combination of morphological operations, otsu thresholding, edge detection and contour approximations techniques.

In an embodiment, the system can execute a first set of instructions associated with image filtering and enhancing techniques on each of the captured any or a combination of the one or more images and videos for removing noise and improving quality.

In an embodiment, the predefined region such as the facial region in each frame of the captured images and/or videos is detected based on execution of a second set of instruction associated with image processing including face detection and landmark detection.

In an embodiment, the system 102 can perform spatial transformation on the identified region of interest to obtain a quantitative representation of a pattern observed in each frame of the captured any or a combination of the one or more images and videos, representing a set of bio signals waveform along an arterial section associated with pulsatile nature of blood flow.

In an embodiment, the system 102 can be configured to normalize and filter the one or more extracted pixel values representing the set of bio signals to determine time domain values by applying statistical analysis on the filtered pixel values. In an exemplary embodiment, the system 102 can determine frequency domain values by applying Fast Fourier Transform and frequency filtering technique on the determined time domain values.

In an embodiment, the system 102 can determine, using signal processing techniques, signal parameters comprising the time and frequency domain parameters based on the determined frequency domain values and time domain values

In an embodiment, the determined time and frequency domain parameters can be associated with any or a combination of the hemodynamics factors, rate of atherosclerosis, general healthiness of the artery itself or physiological data indicating core temperature, blood flow velocity, blood density, arterial stiffness, and oxygen saturation in blood.

FIG. 2 illustrates exemplary functional components of the proposed system, in accordance with an embodiment of the present disclosure.

In an aspect, the system 102 may comprise one or more processor(s) 202. The one or more processor(s) 202 may be implemented as one or more microprocessors, microcomputers, microcontrollers, digital signal processors, central processing units, logic circuitries, and/or any device that manipulates data based on operational instructions. Among other capabilities, the one or more processor(s) 202 are configured to fetch and execute computer-readable instructions stored in a memory 206 of the system 102. The memory 206 may store one or more computer-readable instructions or routines, which may be fetched and executed to create or share the data units over a network service. The memory 206 may comprise any non-transitory storage device including, for example, volatile memory such as RAM, or non-volatile memory such as EPROM, flash memory, and the like.

The system **102** may also comprise an interface(s) **204**. The interface(s) **204** may comprise a variety of interfaces, for example, interfaces for data input and output devices,

referred to as I/O devices, storage devices, and the like. The interface(s) 204 may facilitate communication of system 102 with various devices coupled to the system 102 such as input and output units. The interface(s) 204 may also provide a communication pathway for one or more components of the system 102. Examples of such components include, but are not limited to, processing engine(s) 208 and data 210.

9

The processing engine(s) 208 may be implemented as a combination of hardware and programming (for example, programmable instructions) to implement one or more func- 10 tionalities of the processing engine(s) 208. In examples described herein, such combinations of hardware and programming may be implemented in several different ways. For example, the programming for the processing engine(s) 208 may be processor-executable instructions stored on a 15 non-transitory machine-readable storage medium and the hardware for the processing engine(s) 208 may comprise a processing resource (for example, one or more processors), to execute such instructions. In the present examples, the machine-readable storage medium may store instructions 20 that, when executed by the processing resource, implement the processing engine(s) 208. In such examples, the system 102 may comprise the machine-readable storage medium storing the instructions and the processing resource to execute the instructions, or the machine-readable storage 25 medium may be separate but accessible to system 102 and the processing resource. In other examples, the processing engine(s) 208 may be implemented by electronic circuitry.

The database 210 may comprise data that can be either stored or generated as a result of functionalities imple- 30 mented by any of the components of the processing engine(s) 208. The database 210 may store a set of instructions, for example a first set of instructions, a second set of instructions and/or other required predetermined parameters data/instructions/algorithms to be used by the processors/ 35 processing engine 208.

In an exemplary embodiment, the processing engine(s) 208 may comprise a pre-processing engine 212, an image processing engine 214, a diabetes assessment engine 216 and other engines (s) 218.

It would be appreciated that modules being described are only exemplary modules, and any other module or submodule may be included as part of the system 102. These modules too may be merged or divided into super-modules or sub-modules as may be configured.

Pre-Processing Engine 212

In an aspect, the pre-processing engine 212 receives a sequence of thermal image/video frames from the thermal sensors 108 of the computing device 106. FIG. 4A depicts a sequence of thermal image frames including an anterior face 50 obtained from the thermal sensors. The received thermal image/videos frames may be converted into grayscale for processing. Further, the pre-processing engine 212 applies image filtering and enhancement techniques on the received frames to remove noise and ensure quality of the thermal 55 images is sufficient before processing. The pre-processing engine 212 then uses a face detection model such as a haar cascade classifier on each of the frames in order to detect a predefined region, such as a facial region, on the frame as shown in FIG. 4B. The pre-processing engine 212 can reject 60 the captured thermal video when no face is detected. Further, the pre-processing engine 212 may also use tracking methods to detect and extract the facial region in subsequent frames to ensure a uniform set of frame segments.

In an embodiment, in order to ensure faster processing, 65 the pre-processing engine 212 may perform contrast stretching, which is efficient as well as a computationally cheap

10

technique implemented to enhance image quality. Those skilled in the art would appreciate that the pre-processing engine 212 focuses on enhancement and performs certain operations on the input image frames to ensure that processing in subsequent stages through the implementation of various other engines can be performed in less computational time. The enhancement of image frames can further be optimized to stay free from floating-point operations. Image Processing Engine 214

In an embodiment, the image processing engine 214 receives pre-processed frames of the thermal images/videos including the face region segmented in the frames. The image processing engine 214 may use facial landmark detection algorithms on the set of preprocessed frames to determine the position of eyes or eyebrows in the facial region of the frames. The position of the eyes obtained is further used to segment the forehead region from the set of the preprocessed frames as shown in FIG. 4C. In another embodiment, the image processing engine 214 further defines a region of interest (ROI) for each image frame from a set of image frames received from the pre-processing engine 212. The defined region of interest, for example a forehead region, includes various branches of major arteries in the forehead, which is segmented based on heat distribution on the forehead. The image processing engine 214 may use a bilateral 2D filter on the segmented forehead region in each of the preprocessed frames to remove noise while preserving the edge due to the thermal intensity gradient. Further, since the region comprising the blood vessel is brighter than the surrounding region of the forehead due to the heat emitted during blood flow, the region of interest in each of the frames can be segmented using a combination of morphological operations such as erosion and opening operation followed by Otsu thresholding, edge detection and contour approximations. The segments extracted from each of the set of frames resemble a vascular structure correlating to the arterial section.

Image Segmentation is the process of partitioning a digital 40 image into multiple regions or sets of pixels. Mostly, image partitions are different objects which have the same texture or color. The image segmentation results are a set of regions that cover the entire image together and a set of contours extracted from the image. All of the pixels in a region are similar with respect to some characteristics such as color, intensity, or texture. Adjacent regions are considerably different with respect to the same individuality. The different approaches include but are not limited to (i) by finding boundaries between regions based on discontinuities in intensity levels, (ii) thresholds based on the distribution of pixel properties, such as intensity values, and (iii) based on finding the regions directly. Thus, the choice of an image segmentation technique is depending on the problem being considered.

Region-based methods are based on continuity. These techniques divide the entire image into sub-regions depending on some rules like all the pixels in one region must have the same grey level. Region-based techniques rely on common patterns in intensity values within a cluster of neighboring pixels. The cluster is referred to as the region in addition to group the regions according to their anatomical or functional roles are the goal of the image segmentation. A threshold is the simplest way of segmentation. Using thresholding technique regions can be classified on the basis of range values, which is applied to the intensity values of the image pixels. Thresholding is the transformation of an input image to an output that is a segmented binary image—

segmentation methods based on finding the regions for abrupt changes in the intensity value.

When the images are processed for enhancement, and while performing some operations like thresholding, more is the chance for distortion of the image due to noise. As a 5 result, imperfections exist in the structure of the image. The primary goal of the morphological operation is to remove this imperfection that mainly affects the shape and texture of images. It is evident that morphological operations can be instrumental in image segmentation as the process directly deals with 'shape extraction' in an image. Morphology in the context of image processing means the description of the shape and structure of the object in an image. Morphological operations work on the basis of set theory and rely more on the relative ordering of the pixel instead of the numerical 15 value. This characteristic makes them more useful for image processing. Those skilled in the art would appreciate the significance of these techniques in the image segmentation.

In an embodiment, the image processing engine 214 uses the segmented regions to extract pixel values from each of 20 the frames for describing the changes in the temperature over time. The change in these pixel values correlates with transmission of the blood through the arterial cross-section. The pixel values in the region of interest are spatially transformed to obtain a quantitative representation of a 25 pattern observed in each frame. The spatial transformation includes applying block-based averaging functions and determining the maximum pixel intensity values along the cross-sectional axis. The values can be represented as a series—

$$X(t)_{1}^{T} = \text{Max}_{i=0,j=0}^{i+B_{w} <=w,j+B_{h} <=h} \left[\left(\sum_{x=i}^{B_{w}} \sum_{y=j}^{B_{h}} P(x, y) \right) / (B_{w} * B_{h}) \right]$$

where X(t) is the time domain value for the frame t, P(x,y) is the pixel intensity at position (x,y), B_w , B_h is the width and height of the block. The extracted pixel values are represented as a set of one or more time domain biosignals which 40 are then used by other modules/engines to evaluate and measure parameters correlating the degree of hyperglycemia. FIG. 4D illustrates an exemplary biosignal waveform extracted from the region of interest of an individual. Diabetes Assessment Engine 216

In an embodiment, the diabetes assessment engine **216** is used for determining the diabetes condition by determining and comparing parameters pertaining to hemodynamics factors and a rate of atherosclerosis of the subject. The pixel values representing the set of biosignals extracted from the image processing engine **214** are initially normalized using min-max normalization. The normalized time data is then transformed to obtain frequency domain data using the function P(X)

$$\omega(k)_0^T = F_{f=0.67}^{1.67} \left[\sum_{n=0}^N X[n] e^{(-2\pi i k n)/N} \right]$$

where the diabetes assessment engine **216** uses Fast Fourier Transform on the data to obtain frequency domain values. The frequency values are then filtered 'F' to select the frequencies in between 0.67 Hz and 1.7 Hz in order to select the signal in the frequency range of the pulse. The assessment engine **216** further applies signal processing techniques on these filtered data to calculate time and frequency

12

domain parameters such as, but not limited to, average intensity, signal amplitude, signal period, signal entropy, signal power spectral density, histogram and peak count for each of the signals obtained independently. The combination of one or more of these parameters is associated with hemodynamics and rate of atherosclerosis. This assessment is subject to thermal pattern analysis and signals analysis on the pulsatile nature of thermal changes in accordance with the pulsatile blood flow.

In another embodiment, computation models in the diabetes assessment engine 216 can be initially developed by first calculating the signal parameters for the set of one or more signals extracted from the region of interest of both the healthy individuals and the diabetes patients. The assessment engine 216 applies principal component analysis on the calculated signal parameters of the healthy individuals and the diabetes patients to determine the parameters that are most relevant in determining the diabetes condition. The set of selected parameters are further analyzed and compared using statistical methods to identify variations and relative differences between the signals extracted from healthy individuals and diabetes patients. FIG. 5A and FIG. 5B illustrates a set of two filtered signals/bio signals obtained from a healthy individual and a chronic diabetes patient respectively. As shown, the two signals from the healthy individual in the FIG. 5A are similar while the signals from the diabetes person are different and show temporal variations. The variations define imbalances associated with hemodynamics and atherosclerosis in the arteries and can be normalized based on age and other physical factors. The set of parameters and the variations identified are then structured as the training data to train the computation models using machine learning units including a set of algorithms for scoring the diabetes condition of a person. The score obtained using the computation model can be formulated as:

S=z/(1+z)

where,

 $z=e^{\sum_{i=1}^{n}(w_{i}p_{i})}$

where $\Sigma w_i p_i$ represents the weighted sum of the set of selected signal parameters.

In an embodiment, the assessment engine 216 uses the computational models on the determined parameters to determine a risk score that relates to a degree of hyperglycemia, and/or the rate of atherosclerosis which pertains to the diabetes condition. The risk score can have a value on a scale like 0-1, 1-10, where the severity increases with the increase in score value. The assessment also takes into consideration the demographics and medical history for comparing and calculating the diabetes risk score. The diabetes risk score can be used either to measure the diabetes condition or to evaluate the risk of developing diabetes.

FIG. 3 illustrates a flow diagram of the proposed method for measuring the diabetes health condition of a person, in accordance with an embodiment of the present disclosure.

In an aspect, the proposed method may be described in the general context of computer-executable instructions. Generally, computer-executable instructions include routines, programs, objects, components, data structures, procedures, modules, functions, etc. that perform particular functions or implement particular abstract data types. The method can also be practiced in a distributed computing environment where functions are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, computer-executable

instructions may be located in both local and remote computer storage media, including memory storage devices.

The order in which the method as described is not intended to be construed as a limitation and any number of the described method blocks may be combined in any order 5 to implement the method or alternate methods. Additionally, individual blocks may be deleted from the method without departing from the spirit and scope of the subject matter described herein. Furthermore, the method may be implemented in any suitable hardware, software, firmware, or 10 combination thereof. However, for ease of explanation, in the embodiments described below, the method may be considered to be implemented in the above-described system.

In the context of flow diagram 300, a block 302 pertains 15 to capturing any or a combination of one or more thermal images and videos of at least one body part, for example anterior face, of the subject by a set of thermal sensors.

Further, a block 304 pertains to receiving a set of data packets associated with the captured any or a combination of 20 one or more images and videos by a processing engine from the set of thermal sensors. The processing engine may perform pre-processing on the thermal images or thermal videos received from the set of thermal sensors for noise reduction and quality enhancement.

Further, a block 306 pertains to detecting a predefined region, for example a facial region, of the subject in each frame of the captured any or a combination of the one or more images and videos by the processing engine on receipt of the set of data packets.

Further, a block 308 pertains to segmenting one or more portions, for example a forehead, from the detected predefined region in each frame of the captured any or a combination of the one or more images and videos by the processing engine, and a block 310 pertains to identifying a 35 region of interest comprising one or more arteries in the one or more segmented segmented/forehead portions in each frame of the captured any or a combination of the one or more images and videos by the processing engine.

Further, a block 312 pertains to extracting one or more 40 pixel values, representing a set of biosignals, from each frame of the captured any or a combination of the one or more images and videos based on the identified region of interest by the processing engine, and a block 314 pertains to determining one or more parameters associated with 45 hemodynamic factors and a rate of atherosclerosis of the subject based on the extracted one or more pixel values representing the set of biosignals by the processing engine.

Further, a block **316** pertains to measuring a risk score for the diabetes mellitus condition based on the determined one 50 or more parameters. The risk score can be measured using computational models. The determined one or more parameters can be associated with the hemodynamic factors and the rate of atherosclerosis can correspond to time and frequency domain parameters such as average intensity, 55 signal amplitude, signal period, signal entropy, signal power spectral density, histogram and peak count.

In an embodiment, measurement of the risk score for the diabetes mellitus condition can be based on comparison of the determined parameters associated with the hemodynamic factors and the rate of atherosclerosis with the predetermined parameters of a healthy and diabetic individuals. The determined one or more parameters are associated with a degree of hyperglycemia and atherosclerosis of the subject.

In an embodiment, a process of generating the computational models can include (a) calculating signal parameters for one or more signals associated with the arterial section 14

of both a healthy subject and a diabetes patient; (b) identifying a set of parameters that correlate to complications associated with the diabetes condition using a principal component analysis on the calculated signal parameters; (d) determining patterns and differences among the parameters between the diabetes and healthy subjects by using statistical methods and visualization; and (e) training the computing models by using machine learning unit that can include a set of algorithms comprising clustering models, logistic regression, random forest, neural network model on the set of parameters.

Thus, the present disclosure provides a non-invasive, non-contact passive system method for measuring diabetes mellitus condition of an individual using thermal imaging includes assessing biomarkers pertaining to hemodynamic factors and the rate of atherosclerosis of the individual from the thermal image/video. The passive thermal images/videos comprising the front face of a person acquired using a thermal infrared camera to auto-detect and segment frontal branches of major arterial regions from a forehead region. The frontal branches of the arteries are segmented based on heat variations on the forehead. Tracking methods are used to segment an identified region of interest from the forehead in the sequence of thermograms. Parameters indicating cardiovascular health are calculated from the segmented region of interest by applying thermal pattern analysis and signal analysis on pulsatile nature of thermal changes in accordance with the pulsatile blood flow. The system and method includes analysis of determined parameters to identify imbalances and deviations of the values from a predetermined normal/reference range. The state of diabetes mellitus condition is measured based on the imbalances in the determined parameters that correlate to an increased blood glucose level or the arterial stiffness.

Thus, it will be appreciated by those of ordinary skill in the art that the diagrams, schematics, illustrations, and the like represent conceptual views or processes illustrating systems and methods embodying this invention. The functions of the various elements shown in the figures may be provided through the use of dedicated hardware as well as hardware capable of executing associated software. Similarly, any switches shown in the figures are conceptual only. Their function may be carried out through the operation of program logic, through dedicated logic, through the interaction of program control and dedicated logic, or even manually, the particular technique being selectable by the entity implementing this invention. Those of ordinary skill in the art further understand that the exemplary hardware, software, processes, methods, and/or operating systems described herein are for illustrative purposes and, thus, are not intended to be limited to any particular name.

While embodiments of the present invention have been illustrated and described, it is apparent that the invention is not limited to these embodiments only. Numerous modifications, changes, variations, substitutions, and equivalents will be apparent to those skilled in the art, without departing from the spirit and scope of the invention, as described in the claim.

In the foregoing description, numerous details are set forth. It is apparent, however, to one of ordinary skill in the art having the benefit of this disclosure, that the present invention may be practiced without these specific details. In some instances, well-known structures and devices are shown in block diagram form, rather than in detail, to avoid obscuring the present invention.

As used herein, and unless the context dictates otherwise, the term "coupled to" is intended to include both direct

coupling (in which two elements that are coupled to each other contact each other) and indirect coupling (in which at least one additional element is located between the two elements). Therefore, the terms "coupled to" and "coupled with" are used synonymously. Within the context of this 5 document terms "coupled to" and "coupled with" are also used euphemistically to mean "communicatively coupled with" over a network, where two or more devices are able to exchange data with each other over the network, possibly via one or more intermediary devices.

It should be apparent to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts herein. The inventive subject matter, therefore, is not to be restricted except in the spirit of the appended claims. More- 15 over, in interpreting both the specification and the claims, all terms should be interpreted in the broadest possible manner consistent with the context. In particular, the terms "comprises" and "comprising" should be interpreted as referring to elements, components, or steps in a non-exclusive man- 20 ner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced. Where the specification claims refer to at least one of something selected from the group consisting of A, B, 25 C... and N, the text should be interpreted as requiring only one element from the group, not A plus N, or B plus N, etc.

While the foregoing describes various embodiments of the invention, other and further embodiments of the invention may be devised without departing from the basic scope 30 thereof. The scope of the invention is determined by the claims that follow. The invention is not limited to the described embodiments, versions or examples, which are included to enable a person having ordinary skill in the art to make and use the invention when combined with infor- 35 mation and knowledge available to the person having ordinary skill in the art.

Advantages of the Present Disclosure

The present disclosure provides a simple and efficient solution which can obviate the foregoing limitations in the

The present disclosure provides an improved system for evaluating the diabetes condition of an individual.

The present disclosure provides an efficient system to identify individuals with either pre-diabetes or diabetes conditions so that they can obtain treatment early, and can also monitor progression of the disease over time.

sive system and method for determining diabetes condition of a person by using thermal imaging.

The present disclosure provides an efficient system and method to use biomarkers associated with hemodynamic factors and a rate of atherosclerosis determined from thermal 55 imaging for measuring diabetes mellitus conditions of individuals to help in diagnosis of health conditions.

The present disclosure provides a simple and cost-effective system and method which can be easily implemented for measuring diabetes mellitus conditions of a person.

We claim:

- 1. A system for measuring diabetes mellitus condition of a subject, the system comprising:
 - a set of thermal sensors for capturing any or a combina- 65 tion of one or more thermal images and videos of at least one body part of the subject; and

16

- a processing engine operatively coupled to the set of thermal sensors, and comprising one or more processors coupled to a memory, the memory storing a set of instructions executable by the one or more processors
 - receive a set of data packets associated with the captured any or a combination of one or more images and videos from the set of thermal sensors;
 - detect a predefined region of the at least one body part of the subject in each frame of the captured any or a combination of the one or more images and videos on receipt of the set of data packets;
 - segment one or more portions from the detected predefined region in each frame of the captured any or a combination of the one or more images and videos;
 - identify a region of interest comprising one or more arteries in the one or more segmented portions in each frame of the captured any or a combination of the one or more images and videos;
 - extract one or more pixel values, representing a set of biosignals, from each frame of the captured any or a combination of the one or more images and videos based on the identified region of interest;
 - determine one or more parameters associated with hemodynamic factors and a rate of atherosclerosis of the subject based on the extracted one or more pixel values representing the set of biosignals; and
 - measure a risk score for the diabetes mellitus condition based on the determined one or more parameters, wherein measuring the risk score is performed using computational models, and wherein for generating the computational models, the processing engine is configured to:
 - calculate signal parameters for one or more signals associated with the one or more arteries of both a healthy subject and a diabetes subject;
 - identify a set of parameters that correlate to complications associated with the diabetes condition using a principal component analysis on the calculated signal parameters;
 - determine patterns and differences among the parameters between diabetes and healthy subjects by using statistical methods and visualization; and
 - train the computational models by using machine learning units comprising clustering models, logistic regression, random forest, or neural network models on the parameters.
- 2. The system as claimed in claim 1, wherein the set of The present disclosure provides a non-contact, non-inva- 50 thermal sensors are selected from the group consisting of a digital camera, a digital single-lens reflex (DSLR) camera, an infrared camera, and a thermal camera, and wherein the set of thermal sensors sense heat radiation or infrared radiation emitted from the body part of the subject and renders the one or more images and videos representing a spatial intensity of the heat radiation or the infrared radia-
 - 3. The system as claimed in claim 1, wherein the determined one or more parameters are associated with potential biomarkers of hemodynamic imbalances and atherosclerosis, and wherein measurement of the risk score for the diabetes mellitus condition is based on comparison of the determined one or more parameters with predetermined set of reference parameters that are stored in a database operatively coupled to the processing engine.
 - 4. The system as claimed in claim 1, wherein the subject is a human.

- 5. The system as claimed in claim 1, wherein the at least one body parts of the subject is an anterior face of the subject, and wherein the segment one or more portions are associated with a forehead of the subject.
- **6.** The system as claimed in claim **5**, wherein the identified region of interest is associated with a forehead region of the subject comprises frontal branches of the arteries.
- 7. The system as claimed in claim 6, wherein the one or more processors are configured to segment the identified region of interest from each of the captured any or a combination of the one or more images and videos based on a difference between thermal intensity along frontal branches of the arteries and thermal intensity in other regions of the forehead.
- **8**. The system as claimed in claim **7**, wherein the identified region of interest is segmented using any or a combination of morphological operations, otsu thresholding, edge detection and contour approximations techniques.
- 9. The system as claimed in claim 1, wherein the one or 20 more processors are configured to execute a first set of instructions associated with image filtering and enhancing techniques on each of the captured any or a combination of the one or more images and videos for removing noise and improving quality.
- 10. The system as claimed in claim 1, wherein the one or more processors are configured to execute a second set of instruction associated with image processing including face detection and landmark detection to detect the predefined region of the at least one body part in each frame of the ³⁰ captured any or a combination of the one or more images and videos.
- 11. The system as claimed in claim 1, wherein the one or more processors are configured to perform spatial transformation on the identified region of interest to obtain a quantitative representation of a pattern observed in each frame of the captured any or a combination of the one or more images and videos, representing a set of biosignals waveforms along the one or more arteries associated with pulsatile nature of blood flow.
- 12. The system as claimed in claim 1, wherein the one or more processors are configured to normalize and filter the one or more extracted pixel values representing the set of biosignals, and wherein the one or more processors are configured to determine time domain values by applying 45 statistical analysis on the filtered pixel values.
- 13. The system as claimed in claim 12, wherein the one or more processors are configured to determine frequency domain values by applying Fast Fourier Transform and frequency filtering technique on the determined time domain 50 values.
- 14. The system as claimed in claim 13, wherein the one or more processors are configured to determine, using signal processing techniques, signal parameters comprising time and frequency domain parameters based on the determined 55 frequency domain values and time domain values.
- 15. The system as claimed in claim 14, wherein the determined time and frequency domain parameters comprises any or a combination of average intensity, signal amplitude, signal period, signal entropy, signal power spectral density, histogram and peak count, and wherein the time and frequency domain parameters are also associated with any or a combination of the hemodynamics factors, rate of atherosclerosis, general healthiness of the artery itself or

18

physiological data indicating core temperature, blood flow velocity, blood density, arterial stiffness, and oxygen saturation in blood.

- 16. The system as claimed in claim 1, wherein the measurement of the risk score for the diabetes mellitus condition of the subject considers demographics and medical history of the subject along with the determined one or more parameters.
- 17. The system as claimed in claim 1, wherein the determined one or more parameters are associated with a degree of hyperglycemia of the subject.
- 18. A method for measuring diabetes mellitus condition of a subject, the method comprising:
 - capturing, by a set of thermal sensors, any or a combination of one or more thermal images and videos of at least one body part of the subject;
 - receiving, by a processing engine, a set of data packets associated with the captured any or a combination of one or more images and videos from the set of thermal sensors operatively coupled to the processing engine;
 - detecting, by the processing engine, a predefined region of the at least one body part of the subject in each frame of the captured any or a combination of the one or more images and videos on receipt of the set of data packets;
 - segmenting, by the processing engine, one or more portions from the detected predefined region in each frame of the captured any or a combination of the one or more images and videos;
 - identifying, by the processing engine, a region of interest comprising one or more arteries in the one or more segmented portions in each frame of the captured any or a combination of the one or more images and videos;
 - extracting, by the processing engine, one or more pixel values, representing a set of biosignals, from each frame of the captured any or a combination of the one or more images and videos based on the identified region of interest;
 - determining, by the processing engine, one or more parameters associated with hemodynamic factors and a rate of atherosclerosis of the subject based on the extracted one or more pixel values representing the set of biosignals; and
 - measuring, by the processing engine, a risk score for the diabetes mellitus condition based on the determined one or more parameters, wherein measuring the risk score is performed using computational models, and wherein generation of the computational models comprises:
 - calculating, by the processing engine, signal parameters for one or more signals associated with the one or more arteries in both a healthy subject and in a diabetes subject;
 - identifying, by the processing engine, a set of parameters that correlate to complications associated with the diabetes condition using a principal component analysis on the calculated signal parameters;
 - determining, by the processing engine, patterns and differences among the parameters between diabetes and healthy subjects by using statistical methods and visualization; and
 - training, by the processing engine, the computational models by using machine learning units comprising clustering models, logistic regression, random forest, or neural network models on the parameters.

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