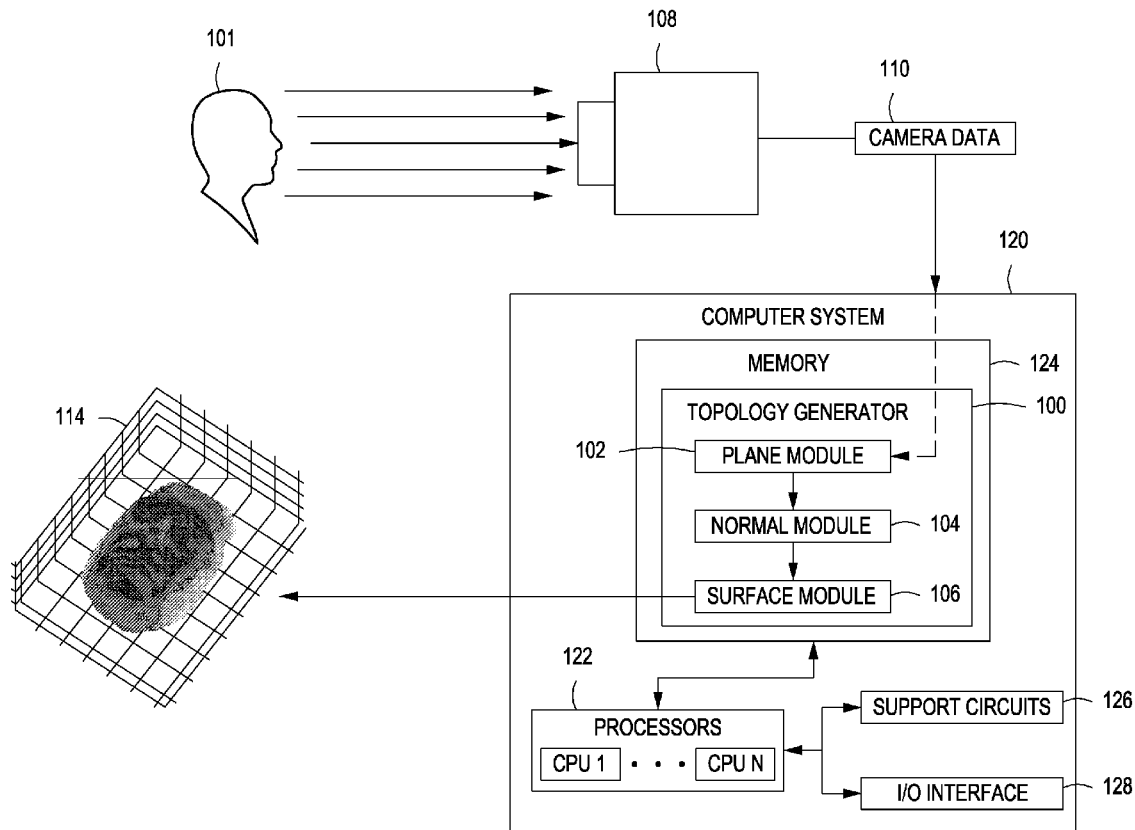




US 20160232709A1

(19) **United States**(12) **Patent Application Publication**
Videen et al.(10) **Pub. No.: US 2016/0232709 A1**(43) **Pub. Date: Aug. 11, 2016**(54) **METHOD FOR MODELING A
THREE-DIMENSIONAL TOPOLOGICAL
SURFACE OF AN OBJECT FROM
LONG-WAVE-INFRARED RADIATION
EMITTED FROM THE OBJECT****Publication Classification**(51) **Int. Cl.**
G06T 17/20 (2006.01)
H04N 5/33 (2006.01)
(52) **U.S. Cl.**
CPC *G06T 17/20* (2013.01); *H04N 5/33* (2013.01);
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MD (US)(21) Appl. No.: **14/617,393**(22) Filed: **Feb. 9, 2015**(57) **ABSTRACT**

A method and apparatus is provided for modeling a three-dimensional topological surface of an object acquiring, using a thermal imaging camera, a first image of the object, wherein the first image comprises a plurality of pixels each representative of at least one component of thermal data, calculating a normal vector for each pixel in the first image, corresponding to the normal vector on a surface of the object, generating a three-dimensional model representing a surface of the object based on aggregating the normal vector for each pixel together in the first image.



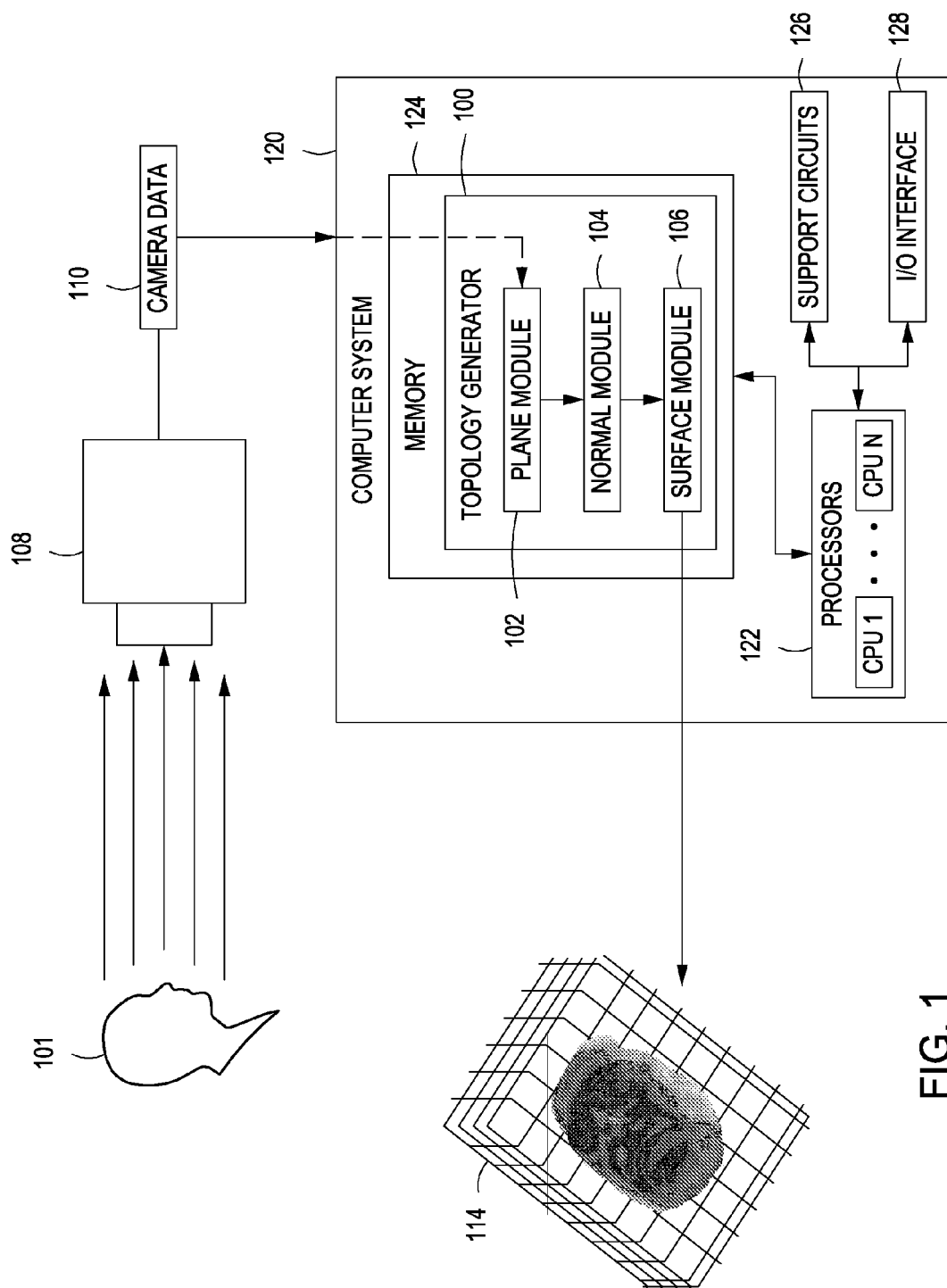


FIG. 1

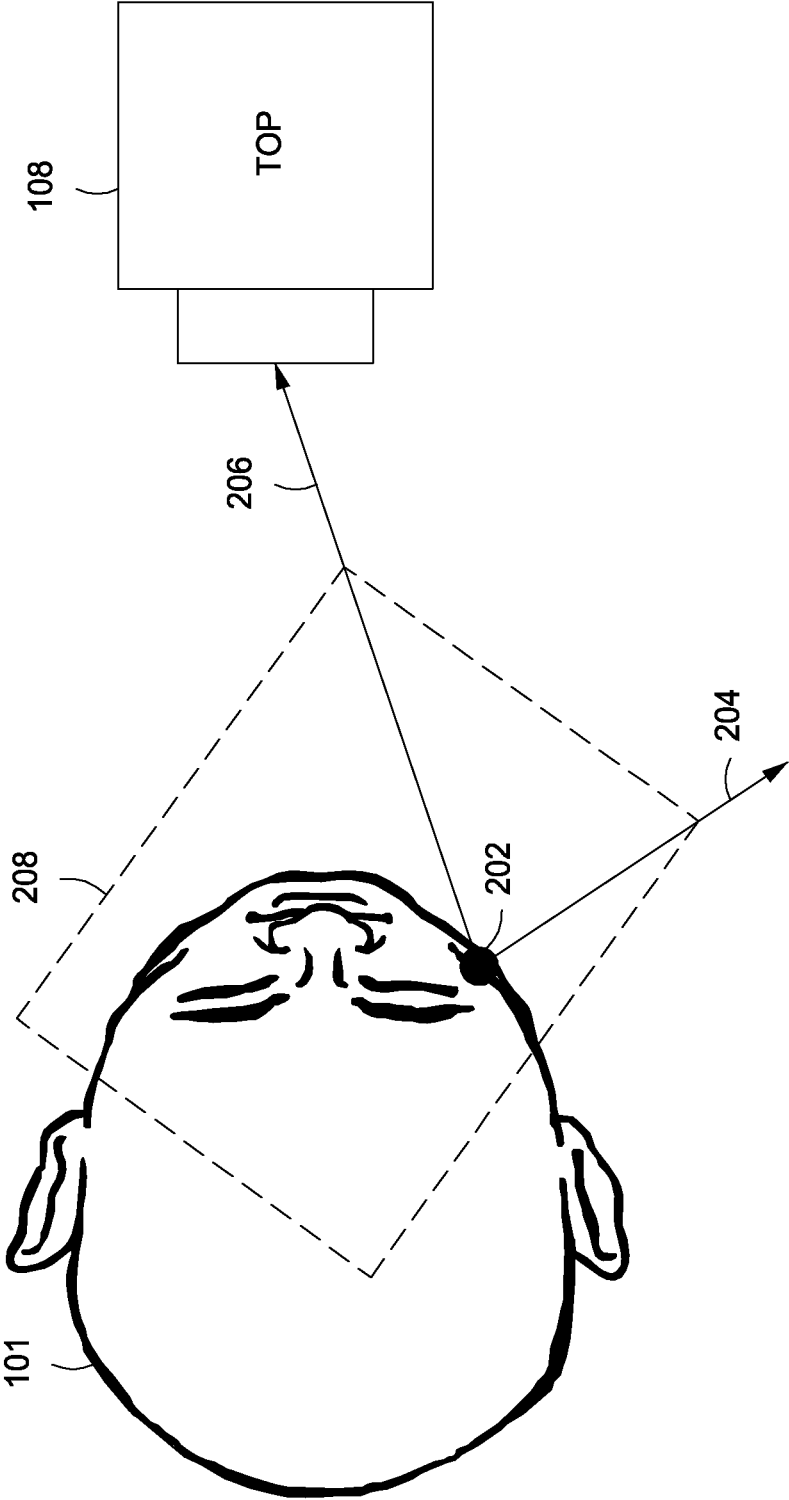


FIG. 2

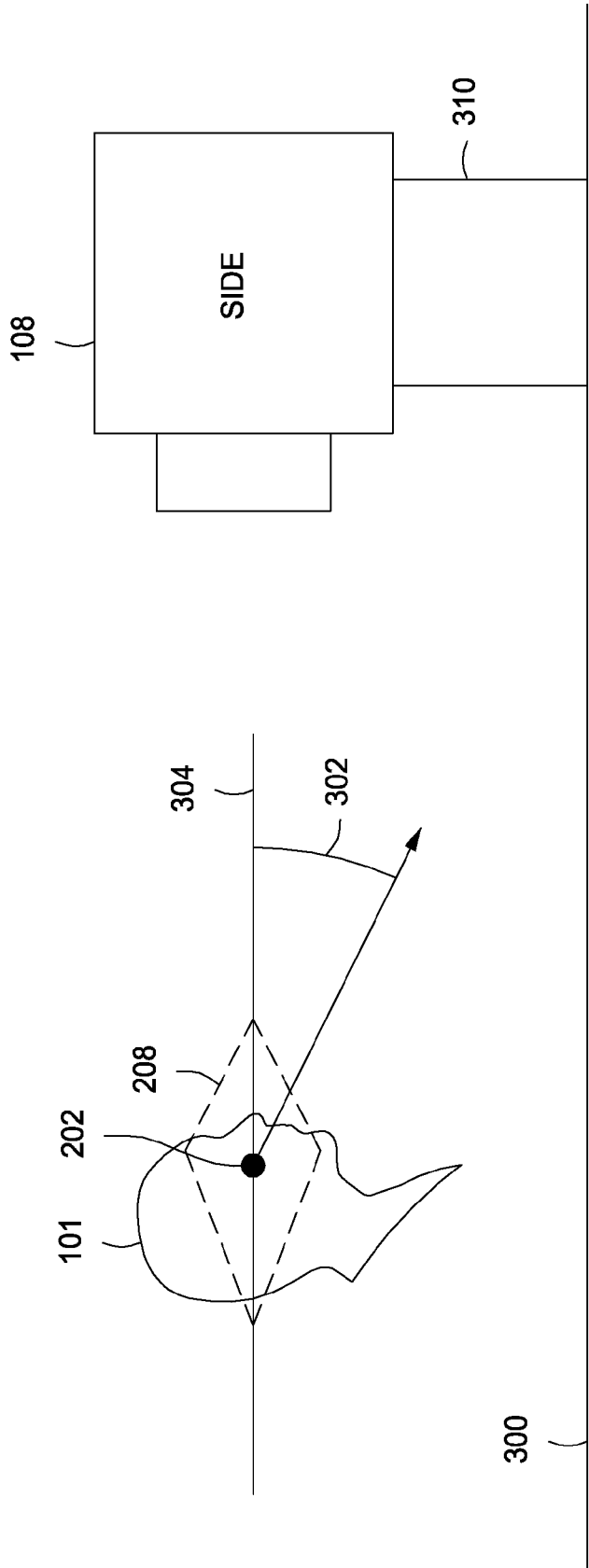


FIG. 3

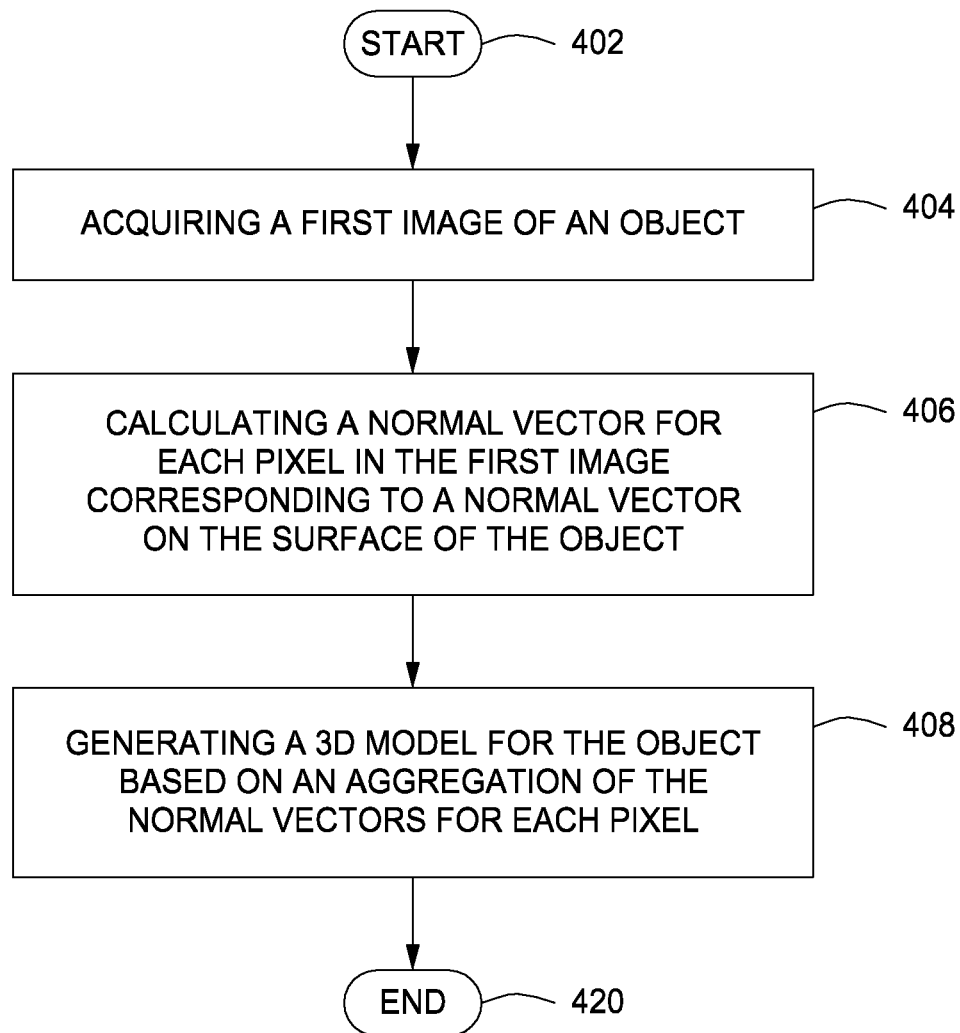


FIG. 4

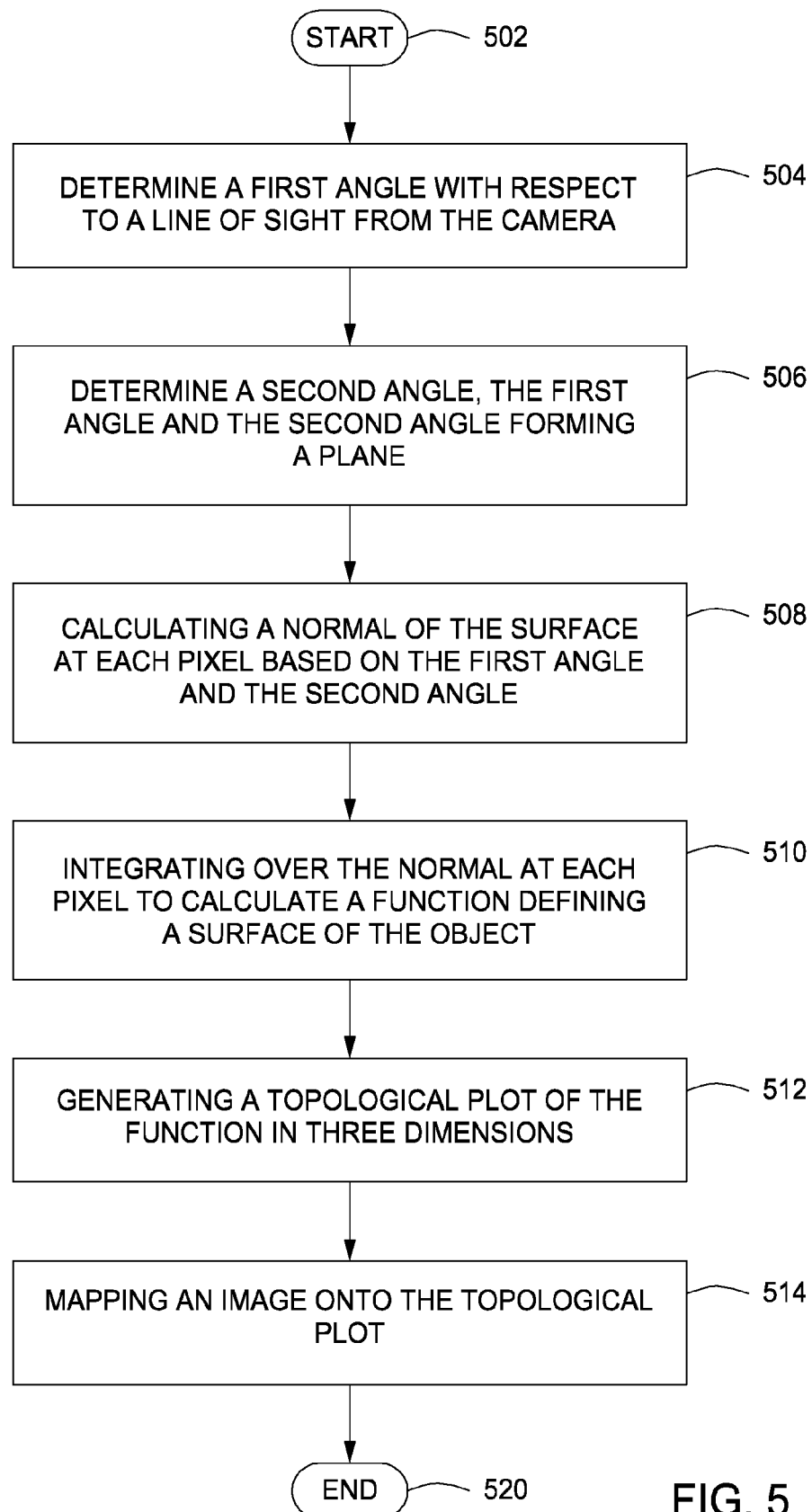
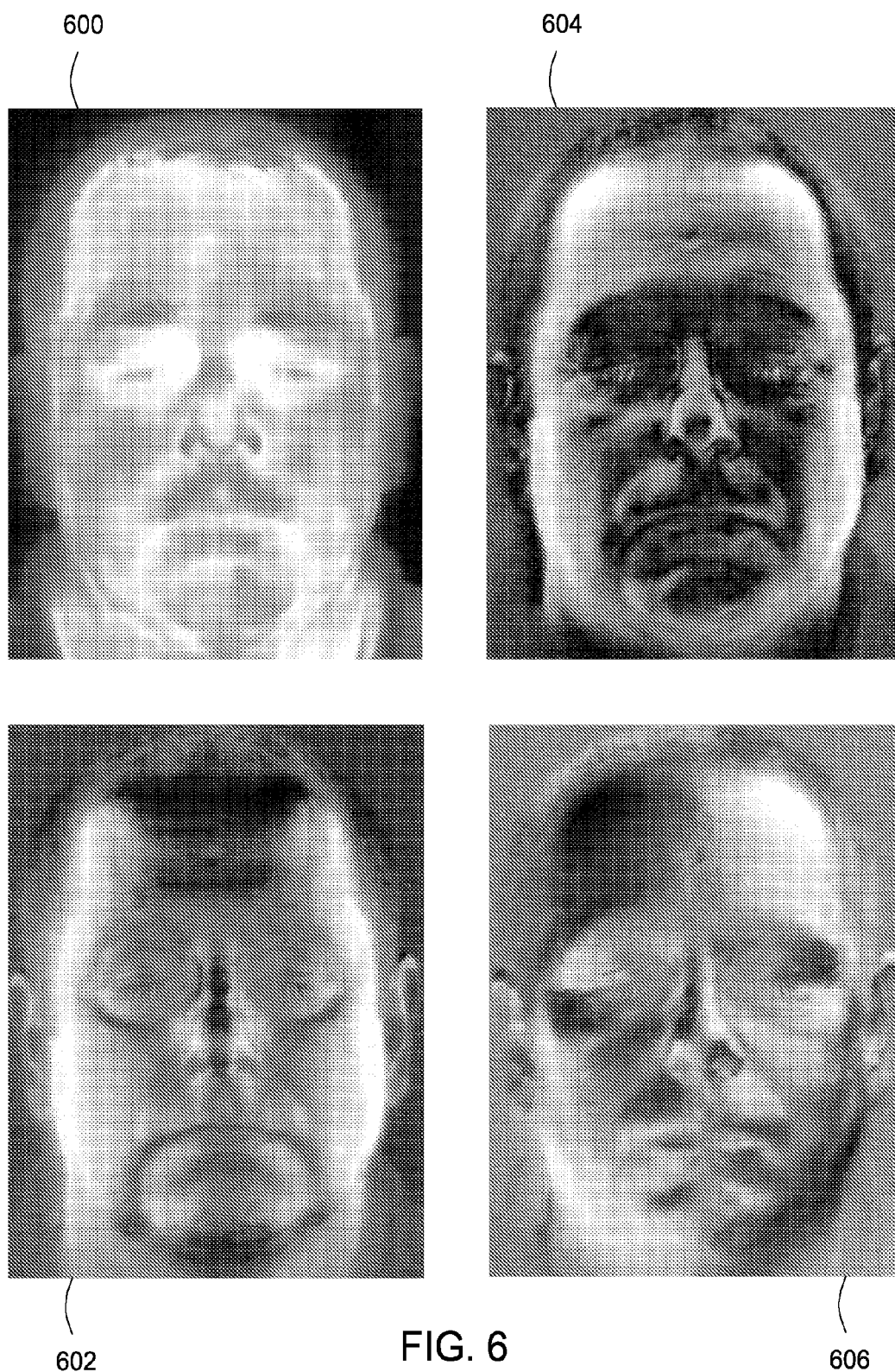


FIG. 5



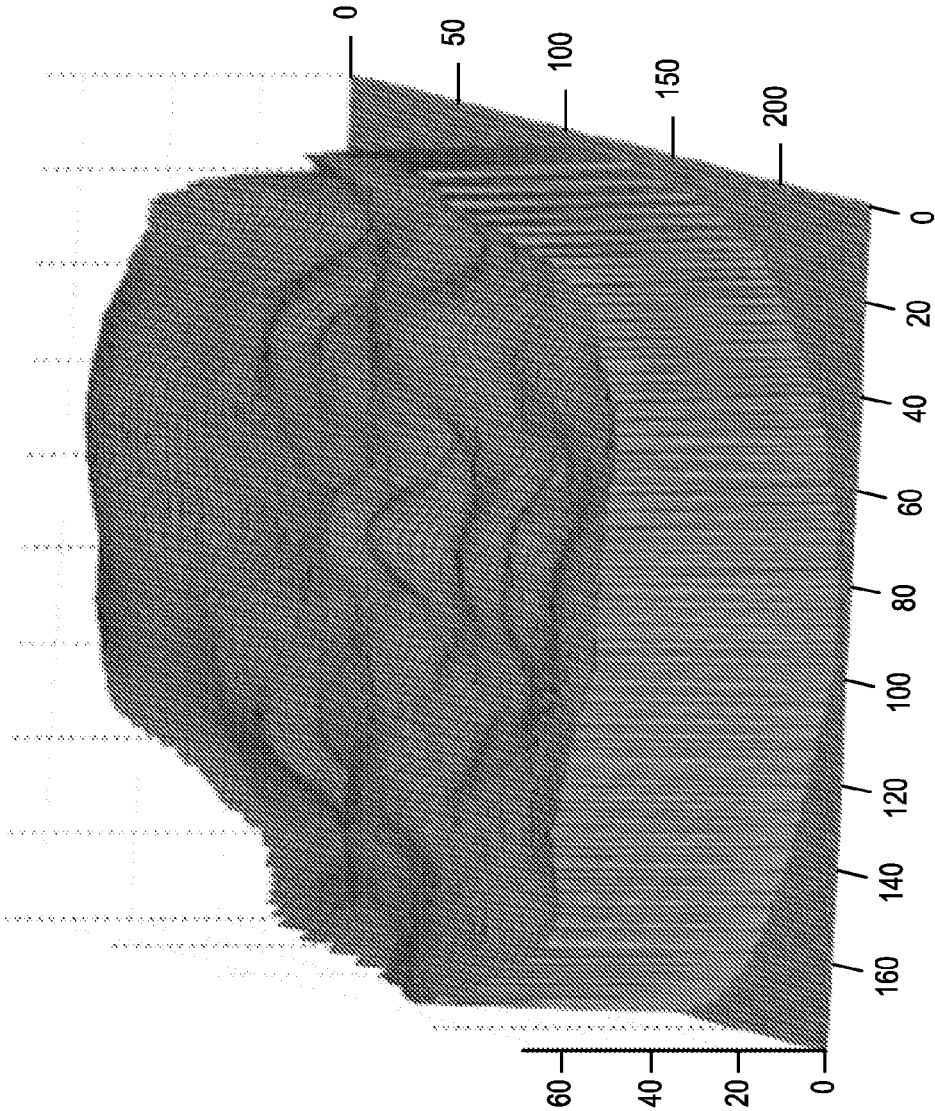


FIG. 7

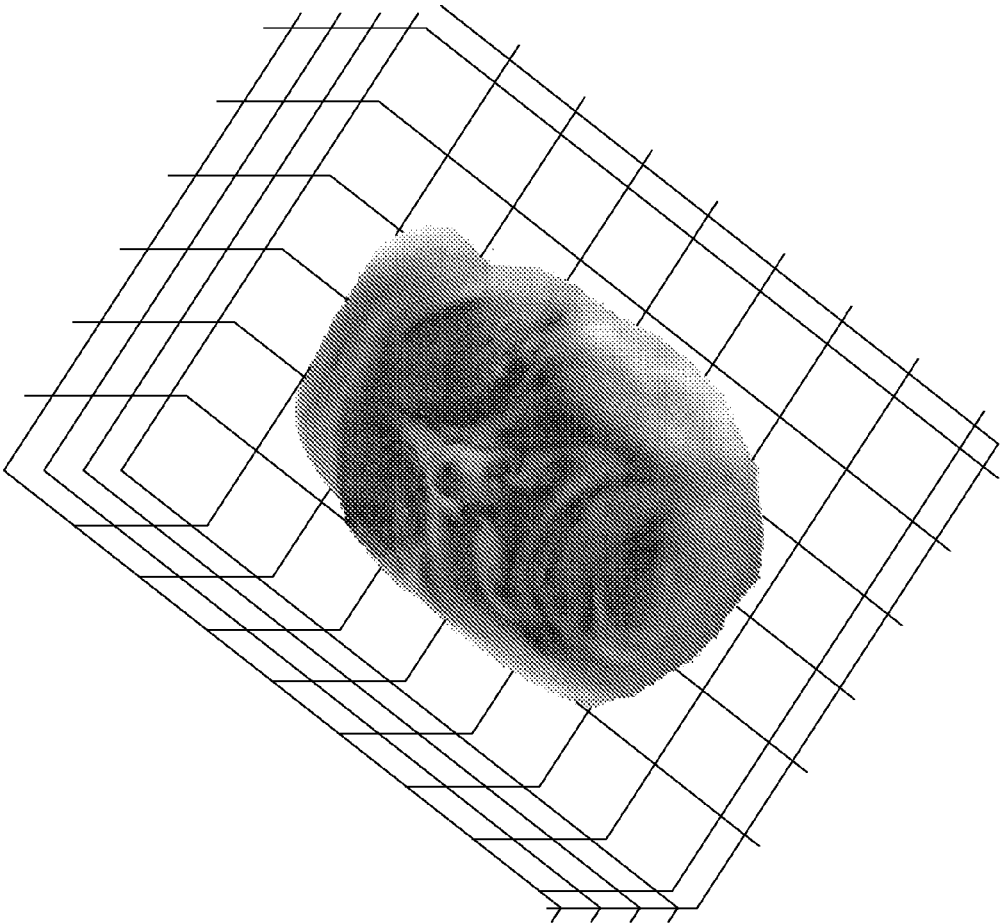


FIG. 8

**METHOD FOR MODELING A
THREE-DIMENSIONAL TOPOLOGICAL
SURFACE OF AN OBJECT FROM
LONG-WAVE-INFRARED RADIATION
EMITTED FROM THE OBJECT**

GOVERNMENT INTEREST

[0001] Governmental Interest—The invention described herein may be manufactured, used and licensed by or for the U.S. Government. Research underlying this invention was sponsored by the U.S. Army Research Laboratory (ARL) and was accomplished under Cooperative Agreement Number W911N F-12-2-0019.

FIELD OF INVENTION

[0002] Embodiments of the present invention generally relate to a method for modeling a three-dimensional topological surface of an object from thermal radiation emitted from the object.

BACKGROUND OF THE INVENTION

[0003] Long-wavelength infrared (LWIR) imaging has many practical applications. LWIR is generally a passive tool because it is a measure of a signal emitted by an object, thus not requiring an additional light source. One major disadvantage of LWIR imaging is the lack of contrast with respect to background objects and noise. Images of people tend to look washed out and ghostlike, and it is difficult to obtain information from the images, which would allow reliable and repeatable identification of a person's characterizing facial or other features.

[0004] Therefore there is a need in the art for improvements in LWIR imaging to enhance identifiability of an object in accordance with exemplary embodiments of the present invention.

BRIEF SUMMARY OF THE INVENTION

[0005] Embodiments of the present invention relate to a method for modeling a surface of an object. A method and apparatus is provided for modeling a surface of an object acquiring, using a thermal imaging camera, a first image of the object, wherein the first image comprises a plurality of pixels each representative of at least one component of thermal data, calculating a normal vector for each pixel in the first image, corresponding to the normal vector on a surface of the object, generating a three-dimensional model representing a surface of the object based on aggregating the normal vector for each pixel together in the first image.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0007] FIG. 1 is an illustration depicting the topology generator in accordance with exemplary embodiments of the present invention;

[0008] FIG. 2 is an illustration of the object being recorded by camera in a top-down view in accordance with exemplary embodiments of the present invention;

[0009] FIG. 3 is an illustration of the object being recorded by camera in a side view in accordance with exemplary embodiments of the present invention;

[0010] FIG. 4 is a flow diagram for a method for generating a three-dimensional model for an object in accordance with exemplary embodiments of the present invention;

[0011] FIG. 5 is a more detailed flow diagram for a method for generating a three-dimensional model for an object in accordance with exemplary embodiments of the present invention;

[0012] FIG. 6 illustrates several examples of images captured by a thermal imaging camera in accordance with exemplary embodiments of the present invention;

[0013] FIG. 7 illustrates a wire mesh generated by the topology generator in FIG. 1 in accordance with exemplary embodiments of the present invention; and

[0014] FIG. 8 illustrates an image mapped on top of the wire mesh in FIG. 7 in accordance with exemplary embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0015] Embodiments of the present invention are directed to a method and apparatus for generating a three-dimensional topological model of the surface of an object emitting thermal radiation using an image captured by a camera. The image captured by the thermal camera contains several component parts of data for each pixel in the image. For each pixel, a surface plane is established by calculating a set of angles with reference to the camera's line-of-sight and the base of the camera. Once the surface plane is established, a normal vector for each pixel is calculated. The normal vectors for all the pixels are integrated over the entire image, forming a function representing the surface of the object. If the result of the function at each (x, y) position is computationally-rendered and/or plotted against a third axis (z), the topology of the surface of the object can be visualized in three-dimensions.

[0016] Thermal imaging involves using heat emitted from objects to form images. Heat is emitted by all objects above absolute zero and the amount of radiation emitted by an object increases with temperature. Thermal imaging allows one to see variations in temperature across a particular object or body. When viewed through a thermal imaging camera, warmer objects are generally distinguishable from cooler backgrounds. Heat is typically captured by a thermal imaging camera in the infrared radiation (IR) spectrum. Depending on the particular object imaged, some types of thermal radiation may give rise to excessive noise, or not enough data to distinguish the features of an object. One spectrum of thermal imaging that may be of interest is LWIR, which is defined as electromagnetic radiation or light having wavelengths of about 8-15 μm . This spectrum is generally emitted by humans and other warm-blooded animals. However, those skilled in the art will appreciate that the invention is not limited to imaging using the LWIR spectra and that, in embodiments of the present invention, other spectra can be used for thermal imaging also.

[0017] FIG. 1 is an illustration depicting the topology generator **100** in accordance with exemplary embodiments of the present invention.

[0018] The topology generator **100** comprises a plane module **102**, a normal module **104** and a surface module **106**. The

topology generator may be embodied as computer software executing on the computer system **120**. A thermal camera **108** is coupled to the computer system **120**. Thermal camera **108** is configured to acquire images representative of thermal radiation emitted by one or more target object(s) such as thermal radiation-emitting object **101**. As such, the thermal camera **108** and the topology generator **100** do not require a light source to illuminate the object **101**. According to one embodiment, the thermal camera **108** is a polarimetric camera equipped with a Stirling-cooled mercury cadmium telluride focal-plane array of 640 by 480 pixels. In this embodiment, the array has a spectral response range of 7.5-11.1 μm . In this embodiment, the thermal camera **108** is configured to record a sequence of 32-bit images at a frame rate of 120 Hz, and a well-known Fourier modulation technique is applied to the images to obtain radiation data of object **101** in the form of a Stokes Vector recorded by camera **108**, collectively referred to as camera data **110**.

[0019] When positioned in a non-illuminated environment containing object **101**, thermal camera **108** captures the radiation emitting from the object **101**. In some instances, the object **101** may be a human, a running vehicle, an animal or the like. The thermal camera **108** acquires thermal data emitted from the object **101** and generates camera data **110** corresponding to the radiation (e.g., LWIR) emitted from the object **101**. In one embodiment, the camera data **110** includes the polarization state of the total wave emanating from the object along with several other parameters as components of the Stokes vector. Those of ordinary skill in the art recognize that the Stokes vector comprises 4 elements: 1) total intensity of emitted radiation, 2) tendency of emitted radiation to be horizontally or vertically polarized, 3) tendency of radiation to be polarized at ± 45 degree angle, 4) tendency of the radiation being right circularly or left circularly polarized. Those of ordinary skill in the art recognize that the degree of linear polarization (DoLP) is calculated using S_0 , S_1 and S_2 by the thermal camera **108**. The magnitude and direction of the electric field vector at each pixel is determinable based on these four elements. In this embodiment, the camera data **110** comprises at least the Stokes parameters (S_0 ; S_1 ; S_2 ; and DoLP) for each pixel of the array of camera **108**. The camera **108** may be configured to output Stokes Vector data directly, or such values may be computed externally by an image processor for the camera data **110**. The Stokes parameters may comprise a data vector in camera data **110**. In general, only parameters S_1 , S_2 and DoLP are utilized while S_0 is generally not used by the methods described below, except to normalize the quantities to the total amount of intensity.

[0020] The recorded images contain both reflected and emitted waves. As a consequence of the Fresnel equations, the emitted waves are polarized parallel to the plane of emission, which is defined by the line-of-sight of the camera and the surface normal N . In contrast, reflected waves are polarized perpendicular to this plane. In other words, the emitted and the reflected polarization states are orthogonal.

[0021] According to some embodiments, each of plane module **102**, normal module **104**, and surface module **106** comprises software instructions residing in memory **124** and executable by one or more processors **122** as CPUs CPU1 to CPU N in FIG. 1. The plane module **102** calculates the orientation of a plane **208** with respect to the ground shown in FIG. 2 and FIG. 3 for each pixel in an image captured by the thermal camera **108** based on the camera data **110**.

[0022] FIG. 2 is an illustration of the object **101** being recorded by camera **108** in a top-down view in accordance with exemplary embodiments of the present invention. Specifically, a first vector, normal vector **204** perpendicular to the surface of the object **101** at a particular pixel **202** and a second vector, vector **206**, from the particular pixel representing a small planar patch on the object **101** to the camera **108** form a plane **208**. The angle between the normal vector **204** and vector **206** must be determined along with the orientation of the plane **208** relative to some reference plane; e.g., the floor where the base of camera **108** sits upon.

[0023] FIG. 3 is an illustration of the object **101** being recorded by camera **108** in a side view in accordance with exemplary embodiments of the present invention. In FIG. 3, the camera **108** and object **101** are shown with reference to the floor **300**. Plane **304** is a plane parallel to the floor, passing through pixel **202** (i.e., the plane projects outwards towards a reader). The orientation of the plane **208** with respect to the plane **304** that is parallel to the floor **300** (or any surface the base **310** of camera **108** is mounted upon) and passing through pixel **202**, must be determined. The plane module **102** calculates the angle of the normal vector **204** in plane **208** using the DoLP from the camera data **110** and calculates the angle **302** (the orientation of plane **208** relative to the plane **304**) from S_1 and S_2 in the camera data **110** as described below with respect to FIG. 4 and FIG. 5.

[0024] Subsequently, the plane information from the plane module **102** is provided to the normal module **104**. The normal module **104** calculates the surface normal vectors at each pixel in the image, wherein the surface normal is a vector perpendicular to the surface on the object **101** at the point on the surface corresponding to pixel **202**. Once the surface normal vector for each pixel is calculated, the surface module **106** integrates the surface normal vectors for all the pixels over the entire image to obtain a function $f(x, y)$ defining the surface of the object **101**. The surface module **106** then determines the value of the function $f(x, y)$ at each point (x, y) to determine a third dimension value for each point. The value of the function $f(x, y)$ at each point represents the topological height of every pixel representing a planar patch of the object **101** visible by the camera **108**. The surface module **106** can plot the value of the function $f(x, y)$ on a third axis z perpendicular to the plane formed by the x and y axes as three-dimensional surface representation **114** of the object **101**. In some embodiments, the vectors comprising camera data **110** can be mapped to the representation **114** to generate a more visually discernible view of the surface of the object **101**.

[0025] The data points x , y , and z may be stored digitally in an array, pointer, and/or in any other electronic data structure or file structure as commonly used in computers. The data points can be rendered into a viewable model for display on a display device, for example, model **700** in FIG. 7. One such technique is by a wiremesh plot, for example. Once rendered, the image may be manipulated in many ways. For example, the vantage point of the image may be altered to view the image at various angles and/or distances. Other image processing may be implemented as conventional. The image may be printed in a 2-D form, e.g., using an ink-jet or laser printer. Alternatively or additionally, the image may be printed in a 3-D form using a 3-D printer.

[0026] According to some embodiments, the topology generator **100** requires a numerical value for the complex index of refraction (n) for particular surfaces, such as human skin. The effective refractive index is considered to be constant over a

human body. The real part of this effective n is between 1.4 and 1.6, and the imaginary part is between 0.01 and 0.03.

[0027] FIG. 4 is a flow diagram for a method 400 for generating a three-dimensional model for the surface of an object in accordance with exemplary embodiments of the present invention. The method 400 is an exemplary implementation of the topology generator 100 executed by one or more of the CPUs 1 . . . N shown in FIG. 1.

[0028] The method 400 begins at step 402 and proceeds to step 404. At step 404, a camera (e.g., camera 108 of FIG. 1) acquires a first image of an object. The image comprises a plurality of pixels each representative of at least one component of thermal data (e.g., there are values for each of the Stokes parameters in each of the pixels for the first image). According to exemplary embodiments, the camera is a thermal polarimetric camera. The camera captures various data points regarding polarization of light emitted from each portion of the object facing the camera. No light source is required in the method 400 besides the thermal data (e.g. long-wave infrared radiation) emitted from the object itself. The camera may be used in a nocturnal setting, where in some instances an object is present, such as a human or a vehicle, and in some cases no objects are present. The method 400 is invoked as described when an object is present.

[0029] In exemplary embodiments, the thermal data is embodied in several images captured by the camera. The images contain, at each pixel, polarization state information such as intensity and other information regarding the light. In exemplary embodiments, the thermal data captures spectral emissivity (ϵ_p), absorptivity (α_p) and reflectivity (r_p) of the thermal radiation being emitted by the object.

[0030] As the method proceeds to step 406, for each pixel of the image captured by the camera, a surface normal vector is calculated. The calculated surface normal vector corresponds to a normal vector on the surface of the object 101. The surface calculation is described in more detail in text accompanying FIG. 3 below. Once surface information is available, the method proceeds to step 408, when a three-dimensional model is generated for the surface of the object based on an aggregation of the normal vectors for each surface incident to the pixel together, described in more detail with respect to FIG. 5. The method terminates at step 420.

[0031] FIG. 5 is a more detailed flow diagram for a method 500 for modeling the surface of an object in accordance with exemplary embodiments of the present invention. The method 500 is an exemplary implementation of the surface module 106 executed as part of the topology generator 100 by one or more of the CPUs 1 . . . N shown in FIG. 1.

[0032] The method 500 begins at step 502 and proceeds to step 504. Given that a camera, such as camera 108 in FIG. 1, has captured thermal data emitted from an object in the form of an image, a first angle with respect to a line-of-sight from the camera to the object is determined for each pixel of the image based on the camera data 110. The first angle is measured as between a normal emanating from a point on the object (e.g., normal 204 in FIG. 2) represented by the pixel of the image and the camera's line-of-sight (e.g. vector 206 in FIG. 2).

[0033] Those of ordinary skill in the art will recognize that the components of the thermal data, spectral emissivity (ϵ_p), absorptivity (α_p) and reflectivity (r_p) of the thermal radiation being emitted by the object (the thermal data being contained in the camera data 110) are related according to the following equation:

$$\epsilon_p(\theta, \psi) = \alpha_p(\theta, \psi) = 1 - r_p(\theta, \psi) \quad (\text{Eq. 1})$$

[0034] The angle θ , the angle between N (the normal surface at the pixel) and the line-of-sight of camera 108, must be determined. The polarization state with respect to the plane of emission from the object 101 is denoted by the subscript $p=\perp$ or \parallel (\perp for perpendicular and \parallel for parallel).

[0035] In order to obtain the first angle θ , DoLP is used. The DoLP is contained within the camera data 110 for each pixel of the image captured by camera 108. The definition of DoLP can be expressed as a function of θ as follows:

$$P(\theta) = \frac{(1 - |r_{\parallel}(\theta)|^2) - (1 - |r_{\perp}(\theta)|^2)}{(1 - |r_{\parallel}(\theta)|^2) + (1 - |r_{\perp}(\theta)|^2)} \quad (\text{Eq. 2a})$$

Where

$$r_{\parallel}(\theta) = \frac{n^2 \cos \theta - \sqrt{n^2 - \sin^2 \theta}}{n^2 \cos \theta + \sqrt{n^2 - \sin^2 \theta}}, \quad (\text{Eq. 2b})$$

and

$$r_{\perp}(\theta) = \frac{\cos \theta - \sqrt{n^2 - \sin^2 \theta}}{\cos \theta + \sqrt{n^2 - \sin^2 \theta}}. \quad (\text{Eq. 2c})$$

[0036] These equations are known to those of ordinary skill in the art as simple geometrical relationships between the degree of linear polarization and the angle between the camera's line-of-sight and the normal vector of the surface at the pixel being examined.

[0037] If the surface of object 101 is partitioned into planar facets, i.e., small surfaces representing a plane at each pixel, and possible multiple reflections of the emitted radiation are neglected, then, the equation can be solved to obtain θ . By equating Equations 2a-2c to the experimentally measured DoLP and then numerically or analytically solving for θ , a value for θ is calculated for each pixel.

[0038] At step 506, a second angle ψ is calculated. Angle ψ is defined as the azimuthal angle (the angle between the plane 208 and some reference plane, e.g., the floor plane 300). The second angle is calculated according to the following formula:

$$\psi = \phi + (0 \text{ or } \pi), \quad (\text{Eq. 3})$$

[0039] where ϕ is defined as follows:

$$\phi = \frac{1}{2} \begin{cases} \arctan\left(\frac{S_2}{S_1}\right) + \frac{\pi}{2}, & S_1 \leq 0, \\ \arctan\left(\frac{S_2}{S_1}\right) + \pi, & S_1 > 0 \text{ and } S_2 < S_1, \\ \arctan\left(\frac{S_2}{S_1}\right) + 0, & S_1 > 0 \text{ and } S_2 \geq S_1 \end{cases} \quad (\text{Eq. 4})$$

[0040] The values of the Stokes parameters s_1 and s_2 are contained in the camera data 110 for each pixel in the image captured by the camera 108. Accordingly, ϕ is obtained and subsequently, ψ can be calculated.

[0041] Equation 3 determines ψ up to an ambiguity of π radians because the Stokes parameters contained in camera data 110 are invariant under a rotation of π radians. Such an ambiguity constitutes an additional unknown in the mathematical solution. To resolve this ambiguity, an additional

boundary condition is introduced: that the surface normal must point away from the subject's head on the occluding boundary in the case of a human as object **101**. In other words, ψ is set to ϕ or $\phi+\pi$ on the occluding boundary so that the normal N at a pixel satisfies the above requirement. After ψ is chosen on the occluding boundary, we move to the neighboring pixels and ψ is chosen for these neighboring pixels in such a way that the normal for these pixels points in the same direction as the normal on the occluding boundary. This process is continued iteratively for all remaining ambiguous ψ s for which the corresponding θ is larger than some threshold. The ψ s for which the corresponding θ is smaller than the threshold are left unchanged because these facets are only slightly tilted with respect to the line-of-sight of the camera. In other embodiments, this additional boundary condition may be different for objects other than human faces and bodies or the like.

[0042] Once ψ is known, the surface normal for each pixel is calculated at step **308** according to the following equation:

$$N = -\frac{\partial}{\partial x}f(x, y)\hat{x} - \frac{\partial}{\partial y}f(x, y)\hat{y} + \hat{z} \quad (\text{Eq. } 5)$$

[0043] and a simple geometric consideration leads to the following equation:

$$-\frac{\partial}{\partial x}f(x, y) = \tan\theta\cos\psi, \quad (\text{Eq. } 6)$$

and

$$-\frac{\partial}{\partial y}f(x, y) = \tan\theta\sin\psi. \quad (\text{Eq. } 7)$$

[0044] Since θ and ψ have already been solved for in equations 2a-2c, 3 and 4, these values can be substituted in Equations 6 and 7 to solve for the derivative of $f(x, y)$ with respect to x and with respect to y . Finally, the surface normal vector N for each pixel is determined through Equation 5 at step **508**.

[0045] At step **510**, each normal vector N corresponding to a pixel of the captured image is integrated to generate a surface function which defines the surface $f(x, y)$ of the object.

[0046] A number of methods are available to integrate N and obtain $f(x, y)$ up to an additive constant. According to one embodiment, the Frankot-Chellapa method is chosen for simplicity and robustness to noise. The Frankot-Chellapa method enforces the integrability condition, $\nabla \times N = 0$, for all points on the support of $f(x, y)$ and thus, the surface normal is smoothed in cases where object **101** may have some surface discontinuities.

[0047] The function $f(x, y)$ accepts 2 parameters, x , y , which correlate to a pixel location in a two-dimensional grid. Substituting a pixel location for x and y in the function $f(x, y)$, a value of the function is obtained and is interpreted as the topological depth of the object **101** at a particular location. Accordingly, a third dimension z is introduced as the value of function $f(x, y)$ showing the depth of object **101**. At step **512**, the function $f(x, y)$ is used to generate a topological plot of the object **101** in three-dimensions: x , y and z . The topological plot is shown as a wire mesh **700** in FIG. 7.

[0048] The method moves to step **514**, where one of the images shown in FIG. 6 is mapped directly onto the plot to provide a more accurate visualization of the object **101**. In one

embodiment, each pixel is painted with the corresponding value of the DoLP pixel, for example. For illustrative purposes, FIG. 8 illustrates the image **602** mapped onto the wire mesh **700** to generate model **800**. Each pixel value from image **602** is mapped to a corresponding point in the wire mesh plot by the surface module **106** so that the wire mesh **800** is easily recognizable. The method terminates at step **520**.

[0049] FIG. 6 illustrates several examples of conventional images captured by a thermal imaging camera.

[0050] Many thermal cameras can generate a Stokes vector. If a component of the Stokes vector for each pixel is taken and combined, an image can be formed. For example, the S_0 component produces the S_0 image **600**. The S_1 component produces the S_1 image **602**. The degree of linear polarization (DoLP) component produces the image **604**. Finally, the S_2 component produces the S_2 image **606**.

[0051] As readily apparent, certain portions of the subject's face are much easier to distinguish/recognize in the improved image when compared to the conventional images, i.e., eyebrows, eye-lashes, teeth, wrinkles in the forehead, etc. Image can be mapped onto the three-dimensional surface representation **114** shown in FIG. 1 to provide a better view of the object being captured by camera **108**.

[0052] Aspects related to this invention have been previously disclosed by Kristan P. Gurton, Alex J. Yu, and Gorden Videen in "LWIR Polarimetry for Enhanced Facial Recognition in Thermal Imagery," Proc. of SPIE Vol. 9099, pp. 90990G-1-G-9 (2014), and "Enhanced facial recognition for thermal imagery using polarimetric imaging," Optics Letters, Vol. 39, No. 13, pp. 3857-3859 (2014), herein incorporated by reference in their entireties.

[0053] The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments were chosen and described in order to best explain the principles of the present disclosure and its practical applications, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as may be suited to the particular use contemplated.

[0054] Various elements, devices, modules and circuits are described above in associated with their respective functions. These elements, devices, modules and circuits are considered means for performing their respective functions as described herein. While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

1. A method for modeling a surface of an object:

acquiring, using a thermal imaging camera, a first image of the object, wherein the first image comprises a plurality of pixels each representative of at least one component of thermal data;

calculating a normal vector for each pixel in the first image, corresponding to the normal vector on a surface of the object;

generating a three-dimensional model representing a surface of the object based on aggregating the normal vector for each of the pixels together in the first image.

2. The method of claim 1, further comprising:
combining the normal vector from each pixel together to calculate a function defining the surface of the object;
and
generating a plot of the function in three-dimensions.
3. The method of claim 2, wherein calculating the normal vector comprises:
determining a first angle with respect to a line-of-sight from the camera at each pixel; and
determining a second angle with respect to the base of the thermal camera, the first angle and the second angle forming a plane, wherein the first angle represents the angle of the normal of each pixel relative to the line-of-sight to the camera and the second angle represents the orientation of the plane relative to a floor where the base of the camera is located.
4. The method of claim 2, wherein combining the normal vector from each pixel together comprises:
integrating over all normal vectors in the first image to calculate the function defining the surface of the object.
5. The method of claim 1, further comprising:
mapping a second image onto the three-dimensional model.
6. The method of claim 5, wherein the second image is formed from the thermal data.
7. The method of claim 6, wherein the thermal data comprises a data vector for each pixel in the first image.
8. The method of claim 7, wherein the data vector comprises a first parameter, a second parameter, a third parameter and a fourth parameter.
9. The method of claim 1, wherein the thermal camera captures long wave infrared radiation.
10. The method of claim 1, wherein the surface is calculated using Stokes parameters contained in the thermal data.
11. An apparatus for modeling a surface of an object comprising:
a thermal camera that acquires, in a first image, wherein the first image comprises a plurality of pixels each representative of at least one component of thermal data; and
a processor, coupled to the thermal camera, configured to execute:
a topology generator that calculates, for each pixel of the first image, a normal vector for each pixel in the first image, corresponding to the normal vector on a surface of the object, and generates a three-dimensional model representing a surface of the object based on aggregating the normal vector for each pixel together in the first image.
12. The apparatus of claim 11, wherein the topology generator further comprises:
a normal module that calculates the normal vector at each pixel in the first image; and
a surface module that combines the normal vector from each pixel together to calculate a function defining the surface of the object and generates a plot of the function in three-dimensions.
13. The apparatus of claim 12, wherein the topology generator further comprises:
a plane module that determines a first angle with respect to a line-of-sight from the camera at each pixel and determines a second angle with respect to the base of the thermal camera, the first angle and the second angle forming a plane, wherein the first angle represents the angle of the normal vector of each pixel relative to the line-of-sight to the camera and the second angle represents the orientation of the plane relative to a floor where the base of the camera is located.
14. The apparatus of claim 12, wherein the surface module integrates over all normal vectors in the first image to calculate the function defining the surface of the object.
15. The apparatus of claim 12, wherein the surface module maps a second image onto the three-dimensional model.
16. The apparatus of claim 15, wherein the second image is formed from the thermal data.
17. The apparatus of claim 16, wherein the thermal data comprises a data vector for each pixel in the first image.
18. The apparatus of claim 17, wherein the data vector comprises a first parameter, a second parameter, a third parameter and a fourth parameter.
19. The apparatus of claim 11, wherein the thermal camera captures long wave infrared radiation.
20. The apparatus of claim 11, wherein the surface is calculated using Stokes parameters contained in the thermal data.

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