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(71) Applicant *(for all designated States except US)*: **TOUDAI TLO, LTD.** [JP/JP]; 3-1, Hongo 7-chome, Bunkyo-ku, Tokyo 113-0033 (JP).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **MIZOTA, Terukazu** [JP/JP]; c/o Toudai TLO, Ltd., 3-1, Hongo 7-chome, Bunkyo-ku, Tokyo 113-0033 (JP). **KAMIYAMA, Kazuto** [JP/JP]; 3-21-1, Oodomomachi, Maebashi-shi, Gunma 371-0847 (JP). **KAJIMOTO, Hiroyuki** [JP/JP]; 828-362, Shimokuratacho, Totsuka-ku, Yokohama-shi, Kanagawa 244-0815 (JP). **KAWAKAMI, Naoki** [JP/JP]; Mansion Tachibana 2nd Floor, 2-35-2, Hakusan, Bunkyo-ku, Tokyo 112-0001 (JP). **TACHI, Susumu** [JP/JP]; 2-31-14, Umezono, Tsukuba-shi, Ibaraki 305-0045 (JP).

(74) Agent: **INABA, Shigeru**; Naruse, Inaba & Inami, Hanabishi Imas Hirakawacho Building 4th Floor, 3-11, Hirakawacho 2-chome, Chiyoda-ku, Tokyo 102-0093 (JP).

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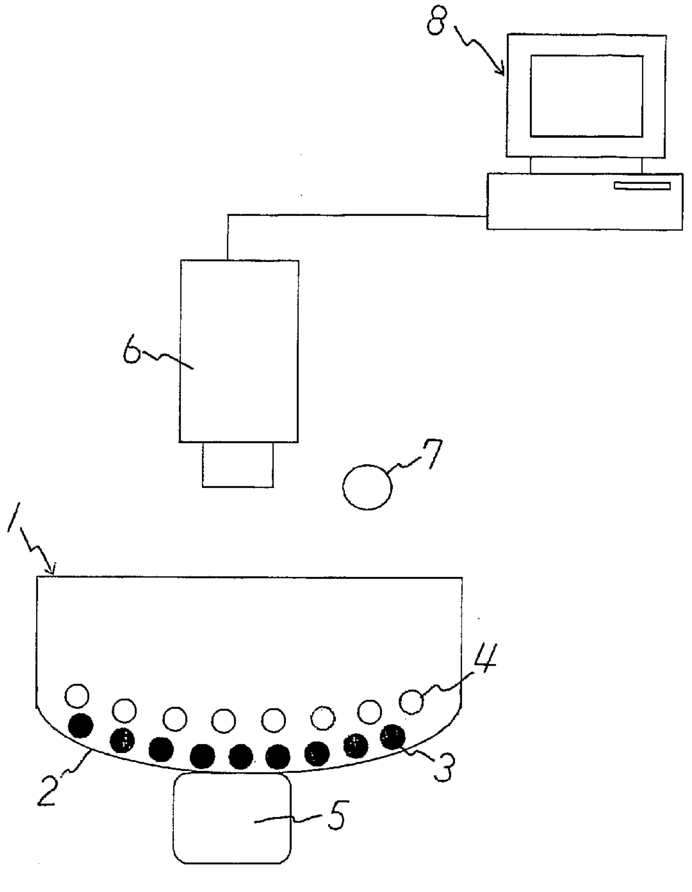
(54) Title: OPTICAL TACTILE SENSOR AND METHOD OF RECONSTRUCTING FORCE VECTOR DISTRIBUTION USING THE SENSOR



(57) Abstract: The invention relates to a tactile sensor capable of obtaining information for a plurality of degrees of freedom at each point on a surface. An optical tactile sensor is provided with a sensing part and a photographing device, the sensing part comprising a transparent elastic body and a plurality of groups of markers provided inside the elastic body, each marker group being made up of a number of colored markers, with markers making up different marker groups having different colors for each group. The elastic body has an arbitrary curved surface. The behavior of the colored markers when an object touches the curved surface of the elastic body is obtained as image information of markers by photographing device. The sensor further comprises a force vector distribution reconstructing device for reconstructing forces applied to said surface from information as to the behavior of markers that is obtained from said image information of markers.

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DESCRIPTION

OPTICAL TACTILE SENSOR AND METHOD OF RECONSTRUCTING FORCE VECTOR DISTRIBUTION USING THE SENSOR

FIELD OF THE INVENTION

The present invention relates to an optical tactile sensor, and preferably to a tactile sensor used for a robot hand.

BACKGROUND OF THE INVENTION

When considering understanding the contact state of a contact surface using a tactile sensor, there are vectors of three components representing magnitude and direction of force acting at each point of the contact surface. This is represented as f(x,y) in the coordinate system of Fig. 1. Here, f is a vector, and so actually has three components x, y and z at each point. When explicitly expressing each component, it is represented as f(x,y) = [fx(x,y), fy(x,y), fz(x,y)].

Some of inventors of the present invention et al. have proposed an optical tactile sensor that is capable of measuring three-dimensional force vector distribution. The optical tactile sensor is disclosed in WO02/188923 A1 and incorporated herein by reference. A principle of the optical tactile sensor will be explained based on Fig. 2. The optical tactile sensor comprises a transparent elastic body and a CCD camera. By photographing spherical markers embedded in the transparent elastic body by the CCD camera, internal strain information of the elastic body is measured when a force is applied on the surface of the elastic body, and force vector distribution is reconstructed from the information.

By taking an image of the spherical markers by a CCD camera from z-direction where an elastic body surface is taken as the x-y plane and an orthogonal direction to the x-y plane is taken as the z-axis, movement of a point to be measured when force is applied is measured as a movement vector in the x-y plane. However, it is difficult to reconstruct the force vector distribution from the strain information because an amount of information is insufficient. Therefore, N x N red spherical markers and blue spherical markers are arranged at different depths in the elastic body as points to be measured to obtain two sets of two-dimensional movement vectors with different depths as two pieces of different information, thereby increasing the amount of information to reconstruct the force vector distribution.

According to the above-mentioned optical tactile sensor, the optical tactile sensor having a flat surface is generally employed. Since the surface is photographed as two-dimensional image information, application of flat surface that corresponds to the two-dimensional image information may be a natural choice. Also, in case of a sensor with a flat surface, it is easier to reconstruct force vector distribution.

This type of optical tactile sensor has advantages in that it can measure three-dimensional force vector distribution and has an elastic body providing a flexible surface to be contacted by an object. For example, in a situation where the optical tactile sensor is provided at a robot hand of a humanoid, it is necessary to hold a glass without breaking and dropping. To prevent the glass from dropping, it is necessary to sense a force acting in the direction parallel to the surface of the glass. This is possible with the above-mentioned optical tactile sensor. Here, when considering applications of this type of optical tactile sensor for various purposes, it is necessary to construct a tactile sensor with an arbitrary curved surface not with a flat surface. However, it is difficult to reconstruct force vector distribution with an arbitrary curved surface. In this regard, a tactile sensor with an arbitrary curved surface is disclosed in "Development of arbitrary curved type tactile sensor using pressure conductive rubber", Shimojo et al., Robotics Society of Japan, 1 G24, 2002. However, it is not possible to acquire force vector distribution by this sensor.

An object of the present invention is to provide an optical tactile sensor with an arbitrary curved surface.

Another object of the present invention is to reconstruct force vector distribution applied to an arbitrary curved surface from marker information.

Still another object of the present invention is to provide an optical tactile sensor that is capable of being used as a tactile sensor for a robot hand or a computer interface.

Still further object of the present invention is to provide a method of obtaining a transfer function by which a force vector distribution is calculated by using marker information.

SUMMARY OF THE INVENTION

The present invention relates to an optical tactile sensor provided with a tactile section and a photographing device. The tactile section comprising a transparent elastic body and a plurality of groups of markers provided inside the elastic body, each marker group being made up of a number of colored markers, with markers making up different marker groups having different colors for each group. The elastic body comprises an arbitrary curved surface (a non-flat surface). The photographing device takes an image of the colored makers in the transparent elastic body to obtain image information of markers when an object touches the surface of elastic body. The sensor further comprises a force vector distribution reconstructing device that reconstructs force vector distribution from information as to the behavior of the markers (movement vectors of the markers, for example). The information as to the behavior of markers can be obtained from the image information of markers.

At least one of displacement, strain and inclination of the colored markers when the elastic body contacts an object is observed by photographing behavior of the colored markers. Strain information inside the transparent elastic body is detected from information about the behavior colored markers when a contact object touches the sensor, and the shape of the contact object calculated from strain information, and information about force acting on a contact interface (including both the elastic body surface and the contact object surface) are also detected. According to the present invention, it is possible to separately collect a plurality of types of information with a simple method called "color coding", and it is possible to acquire a plurality of types of tactile information at the same time with an optical system. According to the present invention, independent observed information whose number is equal to or greater than the number of unknowns are collected using color coding, and it is possible to estimate and reconstruct force vectors by stably resolving a inverse problem.

The colored markers are photographed by photographing device, in a preferred example, a CCD camera, and image processing is carried out by a processor. For example, an image at the time of body contact and an image of a previous condition (a condition where external force is not acting on the transparent elastic body) are compared, and an amount of movement of the markers is detected. Alternatively, the markers are embedded in the transparent elastic body in such an arrangement that they can not be recognized normally (in a state where external force is not acting on the transparent elastic body), and a configuration is such that markers are recognized in response to displacement deformation and inclination of markers caused by strain in the vicinity of positions where each of the markers exist when an object contacts the transparent elastic body, and information is detected from the appearance of the colored markers. In another preferable aspect, the behavior of markers (step-like strip markers, for example) can be obtained by variance of marker intensity.

The force vector distribution reconstructing device comprises a transfer function by which force vectors or force vector distribution applied to the surface of the elastic body are reconstructed from information (movement vectors of each marker when an object contacts the surface, for example) obtained by photographing device as to behavior of markers. The transfer function is a function that associates force information applied to the surface of the sensor with information as to the behavior of markers (movement vectors, for example). The image information of markers is obtained by photographing the colored markers when the object contacts the sensing surface of the elastic body, and the information as to the behavior of markers is obtained from the image information of markers. In one aspect, the information as to the behavior of markers is obtained by comparing marker information in a contact state where the elastic body is contacted by an object and maker information in a normal state where the elastic body is free of an object. In one aspect, the marker information in the normal state may be stored in a memory device in the form of numerical information such as positional information or intensity information. The information as to the behavior of markers can be obtained from the image information of markers in the contact state and the pre-stored marker information in the normal state.

The force vector is obtained as an output by inputting the obtained information to the transfer function. The number of information as to the behavior of markers that is input to the transfer function is more than the number of force vectors to be obtained. Generally, the force vector distribution reconstructing device is comprised of a computer having a memory device and a processor. The transfer function is stored in the memory device and the calculation is performed by the processor. In one aspect, the force vector distribution device comprises a first processor for calculating the information as to the behavior of markers from the maker image information and a second processor for calculating the force vector from the information as to the behavior of markers. In one aspect, the first processor is a local processor and the second processor is a central processor.

The transfer function, depending on the shape of the elastic body, may be obtained based on an equation derived from theory of elasticity. However, when the surface of elastic body is an arbitrary curved surface, preferably, the transfer function is obtained by measurement or simulation. The transfer function by measurement or simulation can be obtained from information (movement vectors, for example) as to behavior of markers when x-directional force, y-directional force, and z-directional force having predetermined magnitude, for example, are applied to sampling points arranged on the surface of the sensor.

The steps for obtaining the transfer function by measurement comprises the following steps. A large number of sampling points are discretely arranged on the surface of the sensor. Information as to the behavior of markers when a force having predetermined magnitude is applied to each sampling point in each direction of predetermined directions is obtained. In one preferable aspect, the predetermined directions include x-direction, y-direction and z-direction. The transfer function can be obtained from the force with predetermined known magnitude applied to each sampling point in each direction of predetermined directions such as x-direction, y-direction and z-direction and the obtained information as to the behavior of markers.

In one preferable aspect, the optical tactile sensor with an arbitrary curved surface is a finger-shaped tactile sensor that comprises a transparent elastic body constituting a finger tip muscle, the surface of which constitutes a surface of the sensor. More preferably, the sensor further comprises a nail-like base provided at the back of the elastic body and the nail-like base fixes the elastic body. In one preferable aspect, the photographing device such as a camera is mounted on the nail-like base. In another preferable aspect, the sensor comprises a local processor and a central processor. The local processor calculates information as to the behavior of markers from the image information of markers and the central processor calculates force vector distribution from the information as to the behavior of markers by using the transfer function. Preferably, the local processor is mounted on the back of hand or palm of robot.

In another aspect, the optical tactile sensor with an arbitrary curved surface comprises a computer interface. As the computer interface, non-limiting example is a modeling tool for constructing three-dimensional graphics. In one preferable aspect, the optical tactile sensor used for the interface comprises a spherical elastic body or a partial spherical body having a spherical or partial spherical surface.

In one preferred aspect, the imaging device is arranged at a position opposite to the side of the transparent elastic body contacted by the object. Also, in the case where there exists a plurality of colored markers having different colors from each other, it is desirable to carry out convenient processing after imaging by selecting only markers of a particular color and looking at them separately. Selection of a particular color marker is carried out by, for example, using a color filter. It is desirably to provide a light shielding layer on the sensing surface to stabilize an image of markers.

In one preferred embodiment, a plurality of groups of markers are embedded in the transparent elastic body, each group of markers being made up of a large number of markers, markers constituting different marker groups having different colors for each group, and the marker groups having a different spatial arrangement. As an example of this differing spatial arrangement, a plurality of marker groups are arranged in a layered manner inside the elastic body. As an example of layered markers, the markers constituting the marker groups are microscopic spherical particles and the spherical markers constituting the marker group for each layer have different colors from each other. As another example of this differing spatial arrangement, a plurality of marker groups are arranged so as to intersect each other. As still another example of this differing spatial arrangement, each marker group is a plane group comprised of a plurality of planes extending in the same direction, and extending directions and colors thereof are different between each marker group. The shape of the colored markers is not particularly limited, and preferable examples can be spherical, cylindrical, columnar, strip shaped or flat.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view showing force vector distribution exerted between a tactile sensor and a contact object;

Fig. 2 is a view showing the principle of an optical tactile sensor;

Fig. 3 is a schematic view showing the construction of a sensor of the present invention;

Fig. 4 is a view showing force vector distribution applied to a contact surface and movements of markers;

Fig. 5 is a view showing a method of making a transfer function for reconstructing force vector distribution by measurement;

Fig. 6 is a schematic view showing an embodiment of hemispherical tactile sensor;

Fig. 7 is a schematic view showing an embodiment of finger-shaped tactile sensor;

Fig. 8 is a schematic view showing another embodiment of finger-shaped tactile sensor;

Fig. 9 is a schematic view showing still another embodiment of finger-shaped tactile sensor;

Fig. 10 is a schematic view showing an embodiment of marker configuration;

Fig. 11 is a view showing another embodiment of marker configuration;

Fig. 12 is a view showing another embodiment of marker configuration; and

Fig. 13 is a view showing still another embodiment of marker configuration.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Fig. 3, the construction of an optical tactile sensor of the present invention is shown. The sensor comprises a transparent elastic body 1 formed of a transparent elastic material and a curved surface 2, or a surface for sensing. The transparent elastic body 1 is provided with a plurality of colored markers 3, 4 embedded in the transparent elastic body 1 in the vicinity of the surface 2 and along the curved surface 2. A sensing section is comprised of the transparent elastic body 1 and the colored markers 3, 4 arranged inside the elastic body.

The colored markers 3, 4 are comprised of two groups of colored markers and the two marker groups are embedded in different depths respectively from the surface 2. Colored markers 3 constituting one marker group and colored markers 4 constituting the other marker group have different colors to each other. For example, one marker group consists of a plurality of blue markers 3 and the other marker group consists of a plurality of red markers 4.

When an object 5 comes into contact with the transparent elastic body 1, the colored markers 3, 4 provided inside the transparent elastic body 1 are moved due to the internal strain of the elastic body. The sensor is also provided with a camera 6 as a photographing device and a light source 7. The optical camera 6 is arranged at a position on an opposite side to where an object 5 touches so that the transparent elastic body 1 is provided between the optical camera 6 and the object 5, and behavior or movement of the markers 3, 4 is photographed by the camera 6. The light source 7 may transmit light through a waveguide such as an optical fiber for example. Images of markers 3, 4 obtained by the photographing device are transmitted to a computer 8 constituting a force vector distribution device. The force vector distribution device comprises a processor, a memory device, a display device, an input device, an output device and other devices that are normally installed in a general-purpose computer. The processor calculates the marker information (movement vectors, for example) regarding the movement or motion of markers in the images. The processor further reconstructs the distribution of forces applied to the surface 2 by an object 5 using the marker information (movement information, for example) and a transfer function that is stored in the memory device.

The transparent elastic body 1 is preferably made of silicone rubber, but it can also be made from another elastic material such as another type of rubber or elastomer. The markers are preferably made from an elastic material, and more preferably made from the same material as the transparent elastic body 1. In one preferred embodiment, the colored markers are formed by adding pigment to silicone rubber. Since deformation of the elastic body should not be inhibited by the markers, the markers are also preferably made from an elastic material (preferably having the same elastic constant as the elastic body). The material of the markers is not particularly limited as long as the extent to which deformation of the elastic body is inhibited is sufficiently small. It is also possible for a part of the elastic body to constitute the markers.

With the present invention, a plurality of optical markers are distributed within the transparent elastic body 1, and information about the behavior (movement) of markers within the elastic body produced by contact is detected by the photographing device where the marker movements arise due to deformation of the elastic body 1 as a result of the object coming into contact with the elastic body 1. Fig. 3 shows two marker groups, but the number of marker group is not limited, and three marker groups may be located in a layered manner along the surface 2.

A camera, as a photographing device, is a digital camera, namely a camera for outputting image data as electrical signals, and in one preferred example is a CCD camera. It is also possible to use, for example, a digital camera using a C-MOS type image sensor. If three types of markers are prepared in red, green and blue, there are two methods of perceiving these three colors individually. The first method is to use color filters for separation where each marker can be regarded as being individually photographed directly by looking at RGB output from the camera. The second method is a method where imaging elements perceive only light intensity and light sources of red green and blue are prepared. When red is shone, light is only reflected from the red markers while the red light is absorbed by the markers of the other two colors, and so the camera effectively only perceives the red markers. If this is also carried out at separate times for green and blue, information equivalent to that using the first method can be acquired.

To obtain force vector distribution applied to a surface of the sensor from obtained information (movement vectors of markers, for example) as to behavior of markers by an optical tactile sensor, a transformation from information (movement information, for example) M as to the behavior of markers to force information F is required. The transformation from the marker information M to the force information F is obtained by an equation F=HM. Referring to Fig. 4, a method of reconstructing the force vector distribution from the marker information will now be described based on a method of obtaining the force vector distribution from the movement vectors of markers. In Fig. 4, four arrows starting from the contact surface represent force vectors and eight horizontal arrows represent observed movement vectors of the markers. Here, though, for the purpose of simplification, only two-dimensional section (y-axial direction is omitted) is considered, an algorithm is the same for a general three-dimensional space.

Reference f refers to a force vector applied to a contact surface, and references m and n refer to a movement vector of a blue marker and movement vector of a red marker in the CCD element. Discrete finite points (four points in Fig. 4) are considered. As foregoing, force vector distribution has three components (x component, y component and z component), but only two components (x component and z component) are considered. Generally, taking an image by a camera means a projection of a three-dimensional object to a pixel plane of a two-dimensional plane so that marker movements only in the horizontal direction (x component and y component) are projected in the plane. Here, marker movement only in x direction component is observed.

Here, eight components, f=[fx(1), fx(2), fx(3), fx(4), fz(1), fz(2), fz(3), fz(4)] are force vector distribution to be obtained, where m=[m(1), m(2), m(3), m(4)] and n=[n(1), n(2), n(3), n(4)] are movement vectors to be measured. The vectors m and n are represented as X. Namely, X=[m(1), m(2), m(3), m(4), n(1), n(2), n(3), n(4)]. Here, movement vectors m and n that are observed when a unit force (magnitude of 1) in the x-direction is applied to a point 1 are represented as Mx(1).

Namely, Mx(1)=[m(1), m(2), m(3), m(4), n(1), n(2), n(3), n(4)] when f=[1, 0, 0, 0, 0, 0, 0, 0]. Similarly, a movement vector of each marker when a unit force in the z-direction is applied to a point 1 are represented as Mz(1), a movement vector of each marker when a unit force in the x-direction is applied to a point 2 are represented as Mx(2), and so on. In case of a linear elastic body where linear summation relationship holds between applied forces and strains (most elastic bodies meet this characteristics), movement vectors are represented as

X=Mx(1) x fx(1) + Mz(1) x fz(1) + Mx(2) x fx(2)+...+Mz(4) x fz(4),

when general forces f=[fx(1),fx(2),fx(3),fx(4),fz(1),fz(2),fz(3),fz(4)] are given. Conversely, the fact that the movement vectors can be represented as foregoing means that superposition of forces holds, therefore, the elastic body is a linear elastic body.

When the equation is represented as a matrix form, X = H x f, where H=[Mx(1); Mx(2); ...; Mz(4)]. The H is called a transfer function because the H is a map that transfers a force f to deformation x. The matrix form written with an element is the following.

$$\begin{bmatrix} m(1) \\ m(2) \\ m(3) \\ m(4) \\ n(1) \\ n(2) \\ n(3) \\ n(4) \end{bmatrix} = \begin{bmatrix} Hmx(1,1) & Hmz(1,1) & Hmx(1,2) & Hmz(1,2) & Hmx(1,3) & Hmz(1,3) & Hmx(1,4) & Hmz(1,4) \\ Hmx(2,1) & Hmz(2,1) & Hmx(2,2) & Hmz(2,2) & Hmx(2,3) & Hmz(2,3) & Hmx(2,4) & Hmz(2,4) \\ Hmx(3,1) & Hmz(3,1) & Hmx(3,2) & Hmz(3,2) & Hmx(3,3) & Hmz(3,3) & Hmx(3,4) & Hmz(3,4) \\ Hmx(4,1) & Hmz(4,1) & Hmx(4,2) & Hmz(4,2) & Hmx(4,3) & Hmz(4,3) & Hmx(4,4) & Hmz(4,4) \\ Hnx(1,1) & Hnz(1,1) & Hnx(1,2) & Hnz(1,2) & Hnx(1,3) & Hnz(1,3) & Hnx(1,4) & Hnz(1,4) \\ Hnx(2,1) & Hnz(2,1) & Hnx(2,2) & Hnz(2,2) & Hnx(2,3) & Hnz(2,3) & Hnx(2,4) & Hnz(2,4) \\ Hnx(3,1) & Hnz(3,1) & Hnx(3,2) & Hnz(3,2) & Hnx(3,3) & Hnz(3,3) & Hnx(3,4) & Hnz(3,4) \\ Hnx(4,1) & Hnz(4,1) & Hnx(4,2) & Hnz(4,2) & Hnx(4,3) & Hnz(4,3) & Hnx(4,4) & Hnz(4,4) \end{bmatrix} \begin{bmatrix} fx(1) \\ fz(1) \\ fx(2) \\ fz(2) \\ fx(3) \\ fz(3) \\ fx(4) \\ fz(4) \end{bmatrix}.$$

where Hmx(x1, x2) represents a displacement amount in x-direction of m marker in a certain depth at a coordinate x=x1 with a unit force in the x-direction applied to a surface at a coordinate x=x2. Similarly, Hnz(x1, x2) represents a displacement amount in z-direction of n marker in a certain depth at a coordinate x=x1 with a unit force in the z-direction applied to a surface at a coordinate x=x2.

This is a simple multiplication of matrices where reference x is 1 x 8 matrix、 reference H is 8x8 square matrix, and reference f comprises 1 x 8 components. Thus, f can be obtained from observed x by multiplying an inverse matrix of H. Namely, f = inv(H) x X (Equation 1) where inv represents inverse matrix (generalized matrix inverse).

The matrix form written with an element is the following.

$$\begin{bmatrix} fx(1) \\ fz(1) \\ fx(2) \\ fz(2) \\ fx(3) \\ fz(3) \\ fx(4) \\ fz(4) \end{bmatrix} = \begin{bmatrix} Imx(1,1) & Imx(2,1) & Imx(3,1) & Imx(4,1) & Inx(1,1) & Inx(2,1) & Inx(3,1) & Inx(4,1) \\ Imz(1,2) & Imz(2,2) & Imz(3,2) & Imz(4,2) & Inz(1,2) & Inz(2,2) & Inz(3,2) & Inz(4,2) \\ Imx(1,3) & Imx(2,3) & Imx(3,3) & Imx(4,3) & Inx(1,3) & Inx(2,3) & Inx(3,3) & Inx(4,3) \\ Imz(1,4) & Imz(2,4) & Imz(3,4) & Imz(4,4) & Inz(1,4) & Inz(2,4) & Inz(3,4) & Inz(4,4) \\ Imx(1,1) & Imx(2,1) & Imx(3,1) & Imx(4,1) & Inx(1,1) & Inx(2,1) & Inx(3,1) & Inx(4,1) \\ Imz(1,2) & Imz(2,2) & Imz(3,2) & Imz(4,2) & Inz(1,2) & Inz(2,2) & Inz(3,2) & Inz(4,2) \\ Imx(1,3) & Imx(2,3) & Imx(3,3) & Imx(4,3) & Inx(1,3) & Inx(2,3) & Inx(3,3) & Inx(4,3) \\ Imz(1,4) & Imz(2,4) & Imz(3,4) & Imz(4,4) & Inz(1,4) & Inz(2,4) & Inz(3,4) & Inz(4,4) \end{bmatrix} \begin{bmatrix} m(1) \\ m(2) \\ m(3) \\ m(4) \\ n(1) \\ n(2) \\ n(3) \\ n(4) \end{bmatrix}$$

where Imx(1,1) and the like represent each element of inv(H) and represent contribution of m(1) for calculating fx(1).

The important thing is that the number of observed data must be equal to or more than the number of unknowns when determining unknowns by using an inverse matrix defined by a transfer function. If the requirements are not met, it is quite difficult to obtain the inverse matrix, namely, the number of unknowns is redundant and the unknowns cannot be precisely obtained. In the example shown in Fig. 4, if there is only one marker layer, force vector components cannot be precisely determined because only four movement vector components are observed whereas distribution of eight force vectors is to be obtained (this is the case with the conventional surface distribution type tactile sensor). To solve this problem, the present invention employs two layers of differentially colored marker groups so as to increase the number of independent observed data up to eight by observing a movement of each marker in the two layered marker groups.

In case of three-dimensional space (where y-axis is added to the drawing), at a point, a force vector has three degrees of freedom, and a horizontal movement vector of markers has two degrees of freedom. If the number of sampling points is four, the number of unknowns f is twelve, where f=[fx(1), fy(1), fz(1), fx(2), fy(2), fz(2), fx(3), fy(3), fz(3), fx(4), fy(4), fz(4)], whereas the number of observed movement vectors is eight and is insufficient, where m = [mx(1), my(1), mx(2), my(2), mx(3), my(3), mx(4), my(4)].

By providing two layered markers, it is possible to obtain sixteen observed data by observing the layered markers and to determine twelve unknowns. Due to redundancy in the number of obtained information, robust extrapolation can be performed. Using the foregoing algorithms, the force vectors are extrapolated from the CCD image. Even with other measurement methods of the present invention using other types of marker configurations as shown in Figs.10 to 13, for example, the measurement methods are substantially the same.

From the foregoing description, it is essentially important for the optical tactile sensor of the present invention to obtain the transfer function (matrix H) representing the relationship between the surface stress and the internal strain of the elastic body. In this regard, the present optical tactile sensor is inherently different than the conventional matrix-type tactile sensors. Though the conventional matrix-type tactile sensor (the sensor by Shimojo, for example) comprises an elastic body layer provided on a sensor element, it only measures a force applied to each arrayed sensor element and does not calculate force vector distribution applied on an elastic body surface.

Next, a method of obtaining the transfer function will be described. Theory of elasticity basically leads an equation that holds between a force applied to a surface ($x=0, \Delta x$, $y=0, \Delta y$, $z=0, \Delta z$) of an internal microscopic region (a micro cube $\Delta x \Delta y \Delta z$, for example) and strain of the microscopic region ($d\Delta x/dx$, $d\Delta y/dx$, $d\Delta z/dx$, $d\Delta x/dy$, $d\Delta y/dy$, $d\Delta z/dy$, $d\Delta x/dz$, $d\Delta y/dz$, $d\Delta y/dz$). An overall elastic body is comprised of (spatially integrated) infinite number of the microscopic regions.

In an elastic body having a characteristic shape (a semi-infinite elastic body, for example), as a function defining a force applied to a surface and an internal strain, a function where the foregoing equation held in the microscopic region can hold in any regions of the internal portion of the elastic body has been found as a numerical equation. In this case, a matrix H can be obtained by substituting coordinates of finely divided elastic body surfaces and coordinates of internal markers into the function.

Here, the numerical equation is a function G by which the internal strain can be obtained from the surface stress in the form of m(x2, y2) = G(f(x1), x2, y2), where f(x1) represents surface stress and m(x2, y2) represent internal strain. For example, when a force is applied to a point 1 in Fig. 4, displacement of marker 2 can be obtained by m(2, y2) = G(f(1), 2, y2), where y2 is a known marker depth.

However, such characteristic shape is rare, for example, even with a spherical body, a function for the relationship between surface stress and internal strain has not been found. According to the related optical tactile sensor, a matrix H is obtained using the foregoing equation assuming that an elastic body is a semi-infinite elastic body. It is found that surface stress cannot be correctly obtained when the equation for semi-infinite elastic body is applied for an arbitrary curved surface such as a hemispherical surface. It is therefore necessary to associate a surface stress with an internal strain by any other means.

A first method is to associate a surface stress with an internal strain by numerical simulation. According to a commercially available elasticity simulation software, by dividing an elastic body into meshes, it is possible to numerically calculate elastic deformation that holds for the relationship between surface stress and strain of each mesh (above-mentioned microscopic region) and the relationship between the adjacent meshes where forces having the same magnitude are exerted at an interface. Therefore, by dividing the surface of the sensor into meshes, it is possible to calculate the movement amount of markers when a unit force is applied to each mesh in x-direction, y-direction and z-direction by simulation.

A second method is to actually apply a force to the surface as shown in Fig. 5. Forces F1, F2, F3, F4..., Fn having known magnitude are applied to an arbitrary curved surface of elastic body. Movement vectors (Movements of markers caused by each known force) M1, M2, M3, M4, .., Mn of markers as to each force applied are measured and stored. F1 represents three vectors F1x, F1y, F1z and movement vectors of respective markers are given as M1x, M1y, M1z when these forces are applied. A matrix H is obtained from the forces having known magnitude and obtained information (movement vector). The transfer function H is prepared by using each movement of markers Mn. The second method will be explained in detail.

Firstly, discretely arranging numerous sampling points on the surface of elastic body. In one preferable aspect, the sampling points are arranged so as to cover an overall area of the surface. In one aspect, numerous discrete sampling points are arranged (concentrically arranged in plan view) according to curvilinear coordinates. In another aspect, the sampling points are arranged to provide a grid arrangement in a plan view.

At each sampling point, information that associates forces having known magnitude applied in x-direction, y-direction, and z-direction with corresponding movement vectors of markers when the forces are applied is obtained. In one preferable method, forces having the predetermined magnitude are independently applied to each sampling point in x-direction, y-direction and z-direction, and each movement vector of markers is measured and stored. Orientations of x-direction, y-direction and x-direction of force vectors applied on the sampling points are not limited as long as an arbitrary force applied to the surface can be represented by using these force vectors.

In one aspect, a tangential plane is provided at a sampling point, x-direction and y- direction are determined in the orthogonal direction to each other in the plane, and z -direction is determined in an orthogonal direction as to the plane. Alternatively, x-y plane is set regardless of the shape of surface, and z-direction is set in an orthogonal direction as to the x-y plane.

Forces applied to each sampling point have known magnitude, and in one preferable aspect, a force with constant magnitude, 100 [gf] for example, is applied to the sampling point in x-direction, y-direction, and z-direction, respectively and movement vectors of each instance are measured. It is not necessary that forces applied to each sampling point have the same magnitude as long as the magnitude of each force is known. Movement vector of markers may be measured based on forces having different magnitudes, and later on, the magnitude of movement vector can be normalized.

As long as information that associates forces in x-direction, y-direction, and z-direction with movement vectors of markers eventually is obtained, directions of forces applied to each sampling point are not limited to x-direction, y-direction and z-direction. Assume that an elastic body is a linear elastic body, the following method is also considered. First, applying a force to a point in z-direction, and a movement amount of each marker is measured and stored. Next, applying a force to the point in xy-direction, and a component in x-direction can be obtained by subtracting the force component in z-direction from the xz component. This is the same for the y-direction.

It will be explained by using an equation.

Suppose that

Mz(n,m) represents a movement of marker when a force is applied to a grid point n, m in z-direction,

Mx(n,m) represents a movement of marker when a force is applied to a grid point n, m in x-direction,

Mxz(n,m) represents a movement of marker when a force is applied to a grid point n, m in xz-direction,

it can be considered that Mxz(n,m)=Mx(n,m)+Mz(n,m), and Mx(n,m) can be calculated if Mz(n,m) and Mxz(n,m) are known.

This is the same for a situation where a force is applied to a plurality of grid points not to one point and the applied force can be divided.

As foregoing, the matrix H can be obtained by simulation or measurement where the matrix H is the transfer function that associates force information F with information M as to the behavior of marker (movement information, for example). The optical tactile sensor comprises a memory device and a processor. The matrix H obtained is stored in the memory device. A marker image is obtained by a photographing device when an object contacts the transparent elastic body and an arbitrary force is applied to a surface of a sensor. A movement vector of marker is measured from the obtained marker image by the processor. The measured movement vector of marker is input to the matrix H and calculated by the processor, thereby outputting force vector that is applied to the surface of the elastic body.

Embodiments of an optical tactile sensor with an arbitrary curved surface will be described.

Referring to Fig. 6, a semi-spherically shaped or hemispherical tactile sensor is shown. A transparent elastic body 1 constituting a tactile portion of the tactile sensor has a semi-spherical shape and comprises a semi-spherically shaped surface and a circular bottom plane. The semi-spherically shaped surface constitutes a surface 2. The transparent elastic body 1 is a semi-spherical body having a radius of 25mm and is made of a silicone. A black light shielding layer is provided on the surface 2 so as to stabilize a marker image obtained by the CCD camera.

The blue spherical markers 3 are arranged in a depth of 2 mm from the sensing surface 2, along the curved surface of the surface 2 to provide a blue spherical marker group. The red spherical markers 4 are arranged in a depth of 3.5 mm from the surface 2, along the blue spherical marker group to provide a red spherical marker group. An interval between markers is 4 mm. The markers 3, 4 are colored plastic spherical body. The bottom plane of the transparent elastic body is fixed to a transparent acrylic plate 9. A CCD camera is provided such that the camera is opposed to the bottom plane through the transparent acrylic plate 9. A light source (not shown) is provided in the vicinity of the CCD camera. Movements of markers inside the elastic body 1 are photographed by the CCD camera through the acrylic plate 9. An image as a NTSC output is transmitted to a computer via a capture unit using a USB connection.

Though the figure shows a hemispherical tactile portion, the tactile portion may comprise a substantially spherical surface or a potion of spherical surface. The portion of spherical shape may be a shape where sensing portion may have a substantially spherical shape or a partial spherical shape. If the shape of tactile portion is close to a sphere, the wider viewing angle is required by the photographing device. Non-limiting example of such photographing device is a photographing device employing a fish eye lens.

In one preferable aspect, the tactile sensor having a surface with a spherical or partial spherical surface constitutes an input device such as a mouse and keyboard, and other computer interfaces. More specifically, the tactile sensor having a surface with a spherical or partial spherical surface may comprise an interface for modeling tool that provides three-dimensional graphics by just like handling clay on a computer screen. By squeezing, pinching, or rubbing the surface, the sensor senses forces applied to the surface, and information obtained is transmitted to a processor of the computer so as to deform the shape of an object shown in the screen, or polish the surface of an object.

Referring to Fig. 7, a finger-shaped optical tactile sensor is shown. The finger-shaped tactile sensor has a shape that is similar to the shape of a human finger tip. A portion corresponding to a digital pulp or a finger tip muscle is made of a transparent elastic body 1 and a portion corresponding to a finger tip surface constitutes a surface 2. A surface opposite to the surface of the finger tip muscle is provided with a nail-like member 10 made of aluminum. The finger-shaped tactile sensor has an overall shape with height 23mm, vertical 35mm and transverse 23mm. The transparent elastic body 1 is made of silicone. The surface 2 of the transparent elastic body 1 has a curved surface similar to the surface or contour of an actual digital pulp.

In the transparent elastic body 1 constituting a finger tip muscle, a number of blue spherical markers 3 are arranged in a depth of 2mm from the curved surface 2 and along the curved surface 2 with an interval of 3 mm, and the blue spherical markers 3 constitute a blue spherical marker group. A number of red spherical markers 4 are arranged in a depth of 3mm from the curved sensing surface 2 and along the blue spherical marker group with an interval of 2 mm, and the red spherical markers 4 constitute a red spherical marker group. The surface 2 is provided with a black light shielding layer. By providing the light shielding layer, it is possible to stabilize a marker image photographed by the CCD camera.

An end of nail-like base 10 is integrally provided with an inclined portion 11 opposed to the surface 2 constituting a finger tip surface. The inclined portion 11 constitutes a mounting member for mounting a photographing device 60. The photographing device 60 comprises a video scope having a CCD element at distal end, and the proximal end of the video scope is connected to a computer. The CCD element is mounted at the inclined portion 11 such that the CCD element faces the finger tip surface, i.e. the surface 2 and markers 3, 4. At the elastic body side of the inclined portion 11, a transparent acrylic plate 9 is provided between the elastic body and the CCD element. A light source (not shown) is provided in the vicinity of the CCD element. The markers 3, 4 inside the elastic body 1 are photographed by the video scope and the image is transmitted to the computer.

At an end of the inclined portion 11, a mounting portion 12 is provided for detachably mounting tactile sensor body to a robot hand. According to the sensor shown in Fig. 7, the mounting portion 12 is provided with an internal thread into which a screw (not shown) of a robot hand is threaded such that the tactile body is supported by the robot hand. In Fig. 7, the finger-shaped tactile sensor does not include a member corresponding to the distal phalanx of the actual finger tip but the mounting portion 12 is positioned at an joint between the distal phalanx and the middle phalanx so that the mounting portion 12 may correspond to an joint or a portion of finger bone.

Mounting means for mounting a tactile portion to a robot hand is not limited to the described means. The photographing device such as a CCD element may be provided at a portion where the internal thread is provided. It is also possible to provide a distal end of optical fiber for facing the transparent elastic body and to provide the CCD element constituting the photographing device at a position distance from the elastic body. Specifically, the finger shaped tactile sensors are provided at each finger tip of five fingers and marker information from each finger shaped tactile sensor may be photographed by a common CCD element and transmitted to a computer.

However, the finger shaped tactile sensor employing a video scope or an optical fiber has a disadvantage in that a wide viewing angle cannot be obtained. For providing a compact finger-shaped sensor, the viewing angle of 90 degrees or more is desired. If the viewing angle is insufficient, it is necessary to photograph the markers from the distant position and it is impossible to make the sensor smaller. In addition, lenses for optical fiber or video scope only have a viewing angle of about 60 degrees. Further, with an optical fiber, it is difficult to acquire sufficient resolution.

Referring to Fig.8, another embodiment of finger shaped tactile sensor for solving the above problems is shown. The finger-shaped tactile sensor has a shape that is similar to the shape of a human finger tip. A portion corresponding to a digital pulp or a finger tip muscle is made of a transparent elastic body 1 and a portion corresponding to a finger tip surface constitutes a surface 2. A surface opposite to the surface of the finger tip muscle is provided with a nail-like member 100 made of aluminum. The transparent elastic body 1 is made of silicone. The surface 2 of the transparent elastic body 1 has a curved surface similar to the surface or contour of an actual digital pulp. In the transparent elastic body 1, a number of blue spherical markers 3 constituting a blue marker group and a number of red spherical markers constituting a red marker group are arranged in different depths from the curved surface. The surface 2 is provided with a black light shielding layer. The nail-like member 100 is provided at the back of the transparent elastic body 1 and supports the transparent elastic body 1.

A photographing device 60 is comprised of a photographing element 60 such as a CCD element or CMOS element and a lens with a viewing angel of more than 90 degrees (110 degrees in the embodiment). The nail-like member 100 has an aperture therein for mounting the photographing device 60. The photographing element is mounted on the aperture of the nail-like member 100 with the lens facing the embedded markers 3, 4 and surface. A plate 70 for conducting light therethrough is provided between the nail-like member 100 and the transparent elastic body 2. The plate 70 acts as a light guide or source.

Referring to Fig.9, still another embodiment of a finger-shaped tactile sensor is shown. As shown in Fig.9, each finger tip of five fingers is provided with a tactile portion comprising a transparent elastic body with markers and a photographing device such as a camera. The finger-shaped tactile sensor of Fig.9 comprises a local processor and a central processor (not shown). The local processor is provided at a proximal side, and at a portion corresponding to the back of a hand or a palm for example. Non-limiting example of the local processor is a FPGA device. The central processor is provided at a distal side. Each camera installed on the finger tips is electrically connected to the local processor such that each data obtained by each camera is transmitted to the local processor where information as to marker movements is calculated from the obtained image information of markers. The local processor is electrically connected to the central processor such that the information as to the marker movements is transmitted to the central processor where force vector distribution is calculated from the information as to the maker movements. Since image information contains a great amount of information, it is difficult to transfer the image information through data transfer standard such as USB and IEEE1394 with a desired speed. According to the arrangement shown in Fig.9, information required for reconstructing force vector distribution (information as to maker movements, for example) is extracted by the local processor provided near the camera and only the extracted information, amount of which is greatly reduced from the original image data is transferred to the central processor.

Though the present invention is described based on the spherical markers as one of preferable aspects, the shape and/or arrangement of markers are not limited to the foregoing. Referring to Figs 10 to 13, other shapes and arrangements of markers will now be described. Detail descriptions of these markers are described in WO02/18893 A1 and incorporated herein by reference. Further, the shape and/or arrangement of markers are not limited to the drawings of the present application and WO02/18893 A1. Though, in Fig. 12 and Fig.13, a tactile body having a flat contact surface is shown, the arrangements of these markers can be applied to a tactile body having an arbitrary curved surface.

Referring to Fig. 10, colored markers being comprised of extremely thin cylinders or columns having microscopic cross sections are shown. Two marker groups are arranged at different depths from the surface 2. A marker group made up of extremely thin blue cylindrical markers 40 is embedded in a section of transparent elastic body 1 in the vicinity of a surface 2. Another marker group made up of extremely thin red cylindrical markers 30 is embedded in a section that is deeper than the red marker group. The markers 30, 40 are embedded vertically inside a transparent elastic body. The markers 30, 40 extend along imaginary lines connecting an object coming into contact with the elastic body and a camera. The number of marker group is not limited to two but it is possible to provide three or more groups of marker each having different depths from the surface in the elastic body.

Referring to an upper view of Fig. 11, inclined plane markers 300, 400 are arranged in the elastic body 1 in a step-like fashion. In one preferable aspect, parts (a step-shaped interface) of the elastic body 1 constitute markers 300, 400. In another aspect, separate plane markers may be embedded in the elastic body 1. The interface can be divided into two surface groups, all surfaces in a group having the same direction. The surfaces in each group are made the same color (here one interface 300 is blue, and the other interface 400 is red). It is possible to acquire observation values containing vertical and horizontal components of force vectors at a particular point as information by observation of intensity of the two colors at that point. By sensing the observed intensity, it is possible to reconstruct surface distribution of force vectors.

A method using two colors has been described based on the upper view of Fig. 11, but as shown in a lower view of Fig. 12, using so called pyramid manufacturing where microscopic cubes are gathered at a bottom surface, if three groups of surfaces facing in the same direction are respectively made the same color (for example, red, green and blue), then similarly to the previous discussion it is possible to respectively obtain two degrees of freedom for force acting in a horizontal direction on a contact surface as intensity ratios for three colors, and force acting in a vertical direction using a total intensity of the three colors.

Referring to Fig.12, two marker groups 200A (marker group comprising a plurality of thin red strips arranged in a row) and 200B (marker group comprising a plurality of thin blue strips arranged in a row) are aligned so that respective markers are orthogonal to each other, but the spatial arrangement relationship between the plurality of marker groups is not limited. It is also possible for the two sides of the strips constituting the marker to have different colors. In Fig. 11, side portions of the strip markers extend along an observation direction but the side portions of the strip markers may be inclined to an observation direction.

Fig. 13 shows a sensing part having a plurality of plane markers. The plane markers are normally concealed by concealment markers and each plane marker is partitioned into a plurality of portions having different colors for each portion, and the partitioned portions having the same color constitute each marker group. The plane markers and said concealment markers are provided and spaced with each other in the elastic body, and an arrangement is made such that said the markers are concealed by the concealment markers and not observed in a state where external force is not acting on the transparent elastic body. When shear strain arises, the positions of the concealment markers 6 and the colored markers 20 become offset, giving color. With the sensor in the drawing, the markers are coated with three colors RGB, and it is possible to ascertain the strain direction from the color produced.

INDUSTRIAL APPLICABILITY

The present invention can be widely applied to tactile sensors, and as an applied example can be used in a tactile sensor for a robot hand and an interface for a computer.

CLAIMS

1. An optical tactile sensor comprising:

a sensing part comprising a transparent elastic body and a plurality of marker groups provided in said body, each marker group being comprised of a number of colored markers, with markers constituting different marker groups having different colors for each group, said elastic body having an arbitrary curved surface;

a photographing device for taking an image of behavior of colored markers when said curved surface of elastic body is contacted by an object to obtain image information of markers, and

a force vector distribution reconstructing device including a transfer function by which a force vector applied to the surface is reconstructed from information as to the behavior of markers that is obtained from the image information of markers, and said force vector distribution reconstructing device reconstructing forces applied to said surface from said information as to the behavior of markers by using the transfer function.

2. The sensor of claim 1, wherein said transfer function is obtained by measurement.

3. The sensor of claim 1, wherein said transfer function is obtained by simulation.

4. The sensor of any one of claims 1 to 3, wherein said transfer function is obtained from information as to behavior of markers when forces having predetermined magnitude in predetermined directions are applied to sampling points arranged on the surface.

5. The sensor of claim 4, wherein said predetermined directions include x-direction, y-direction and z-direction.

6. The sensor of any one of claims 1 to 5, wherein said sensor comprises a

finger-shaped sensor, and wherein the transparent elastic body constitutes a finger tip muscle and the surface of the elastic body constitutes a finger tip surface.

7. The sensor of claim 6, wherein a nail-like base is provided on the back of said transparent elastic body, and wherein said nail-like base supports said elastic body.

8. The sensor of claim 7, wherein the photographing device is mounted on said nail-like base and is opposed to said finger tip surface.

9. The sensor of claim 7, wherein the photographing device is mounted on an end portion of said nail body and is opposed to said finger tip surface.

10. The sensor of any one of claims 1 to 5, wherein said surface of the transparent elastic body comprises a spherical shape or a portion of spherical shape including a hemispherical shape.

11. The sensor of any one of claims 1 to 10, wherein said force vector reconstructing device comprises a memory device and a processor, and wherein said memory device stores the transfer function and said processor calculates information as to the behavior of markers from the image information of markers and calculates force vector distribution from the information as to the behavior of markers by using the transfer function.

12. The sensor of claim 11, wherein said force vector reconstructing device comprises a first processor and a second processor, and wherein said first processor calculates information as to the behavior of markers from the image information of markers and said second processor calculates force vector distribution from the information as to the behavior of markers by using the transfer function.

13. The sensor of any one of claims 1 to 12, wherein said behavior of colored markers

comprises at least one of displacement, strain and inclination of the markers.

14. The sensor of any one of claims 1 to 13, wherein said information as to the behavior of markers is obtained as movement information of markers.

15. The sensor of any one of claims 1 to 13, wherein said information as to the behavior of markers is obtained as variance of marker intensity.

16. The sensor of any one of claims 1 to 15, wherein said marker groups have different spatial arrangements from each other.

17. A finger-shaped optical tactile sensor comprising:

one or more transparent elastic bodies, each body constituting a finger tip muscle having an arbitrary curved surface;

a plurality of marker groups provided in said each elastic body, each marker group being comprised of a number of colored markers, with markers constituting different marker groups having different colors for each group;

one or more photographing devices for taking an image of behavior of colored markers when said curved surface or surfaces of one or more elastic bodies are contacted by an object to obtain image information of markers; and

a force vector distribution reconstructing device for reconstructing forces applied to said surface from information as to the behavior of markers that is obtained from said image information of markers.

18. The sensor of claim 17, said sensor further comprising one or more nail-like bases, each of which is provided on the back of each of said one or more transparent elastic bodies, and wherein each of said one or more nail-like bases supports each of said one or more elastic bodies.

19. The sensor of claim 18, wherein each of said one or more photographing devices is

mounted on each of said one or more nail-like bases and is opposed to said finger tip surface.

20. The sensor of claim 18, wherein each of said one or more photographing devices is mounted on an end portion of each of said one or more nail bodies and is opposed to said finger tip surface.

21. The sensor of any one of claims 17 to 20, wherein said force vector reconstructing device includes a transfer function by which a force vector applied to the surface or surfaces is reconstructed from information as to the behavior of markers, and said force vector distribution reconstructing device reconstructs forces applied to said surface from said information as to the behavior of markers by using the transfer function.

22. The sensor of claim 21, wherein said force vector reconstructing device comprises a memory device and a processor, and wherein said memory device stores the transfer function and said processor calculates information as to the behavior of markers from the image information of markers and calculates force vector distribution from the information as to the behavior of markers by using the transfer function.

23. The sensor of claim 22, wherein said force vector reconstructing device comprises a local processor and a central processor, and wherein said local processor calculates information as to the behavior of markers from the image information of markers and said central processor calculates force vector distribution from the information as to the behavior of markers by using the transfer function.

24. A method for reconstructing force vector distribution by using the optical tactile sensor of any one of claims 1 to 23, the method comprising the steps of:

obtaining one or more marker images by photographing the colored markers when the object contacts the sensing surface of the elastic body;

obtaining information as to the behavior of markers from the one or more marker images, and the number of information being greater than the number of force vectors to be obtained;

and reconstructing the force vector distribution from the obtained information using the transfer function.

25. The method of claim 24, wherein said the transfer function is obtained by :

discretely arranging a large number of sampling points on the surface of the elastic body;

obtaining information as to the behavior of markers when a force having predetermined magnitude is applied to each sampling point in each direction of predetermined directions;

and obtaining the transfer function from the force having predetermined known magnitude applied to each sampling point in said each predetermined direction and the obtained information as to the behavior of markers.

26. The method of claim 25, wherein said predetermined directions include x-direction, y-direction and z-direction.

27. A method of obtaining the transfer function for the optical tactile sensor of any of one of claims 1 to 23, the method comprising the steps of:

discretely arranging a large number of sampling points on the surface of the elastic body;

obtaining information as to the behavior of markers when a force having predetermined magnitude is applied to each sampling point in each direction of predetermined directions;

and obtaining the transfer function from the force having predetermined known magnitude applied to each sampling point in said each direction and the obtained information as to the behavior of markers.

28. The method of claim 27, wherein said predetermined directions include x-direction, y-direction and z-direction.

29. An optical tactile sensor comprising:

a sensing part comprising a transparent elastic body and a plurality of marker groups provided in said body, each marker group being comprised of a number of colored markers, with markers constituting different marker groups having different colors for each group, said elastic body having an arbitrary curved surface;

a photographing device for taking an image of behavior of colored markers when said curved surface of elastic body is contacted by an object to obtain image information of markers;

a memory device storing a transfer function by which force vector applied to the surface is reconstructed from information as to the behavior of markers; and

one or more processors, said one or more processors calculating the information as to the behavior of markers from said image information of makers, and said one or more processors further calculating the force vector applied to said surface from said information as to the behavior of markers by using said transfer function.

FIG. 1

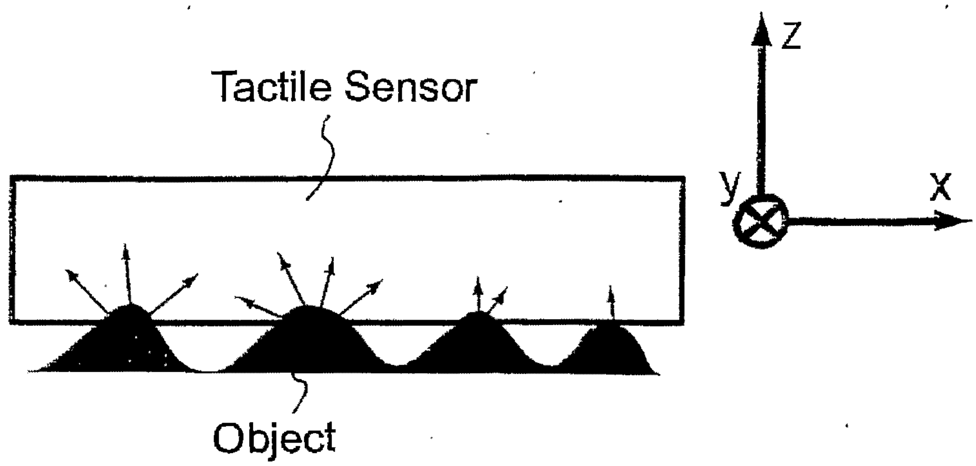

Tactile Sensor
Z
y
X
Object

FIG. 2

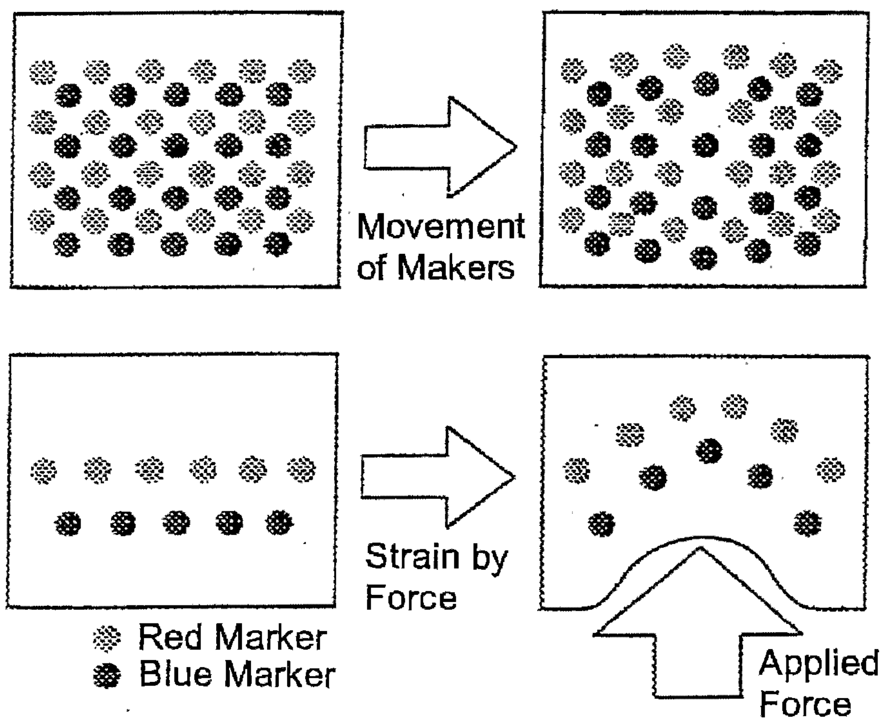

Movement of Makers
Strain by Force
Red Marker
Blue Marker
Applied Force

FIG. 3

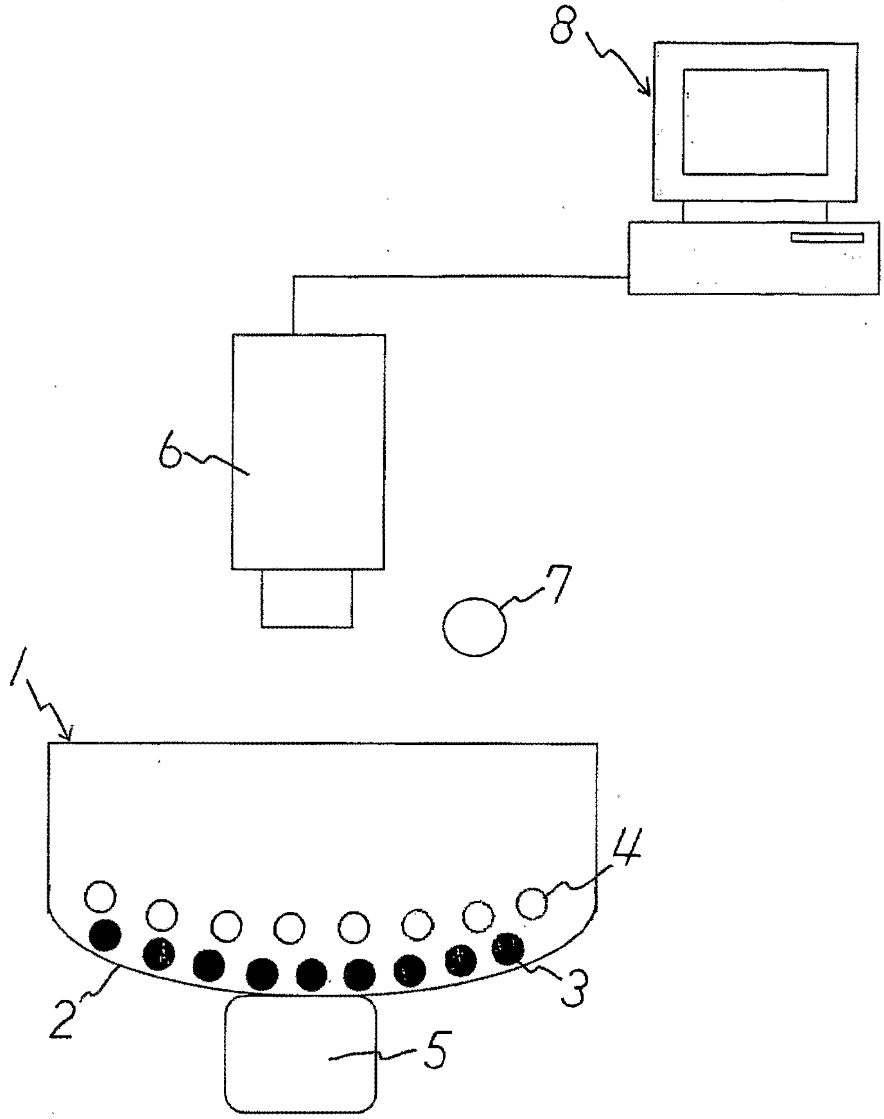


FIG. 4

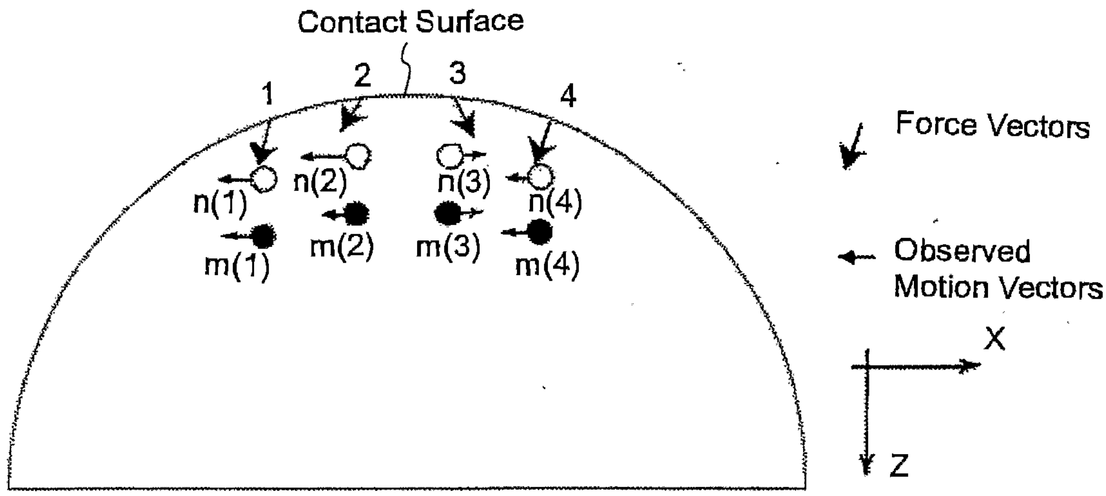

Contact Surface
1
2
3
4
n(1)
n(2)
n(3)
n(4)
m(1)
m(2)
m(3)
m(4)
Force Vectors
Observed
Motion Vectors
X
Z

FIG. 5

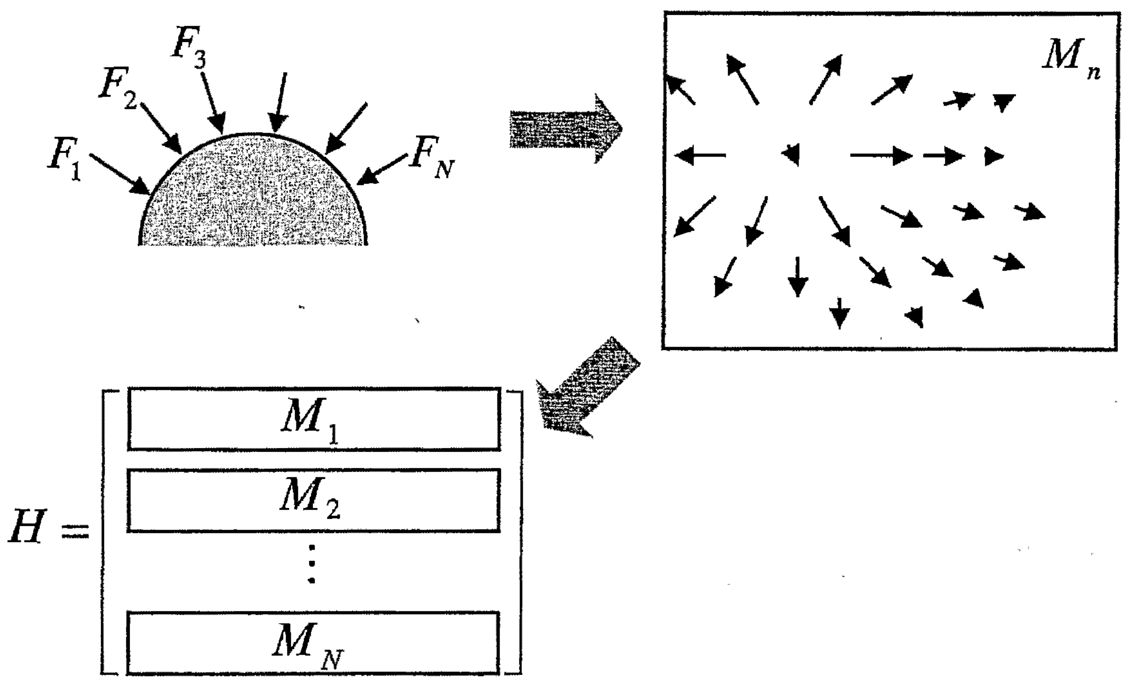

F_1
F_2
F_3
F_N
M_n
$H =$
M_1
M_2
M_N

FIG. 6

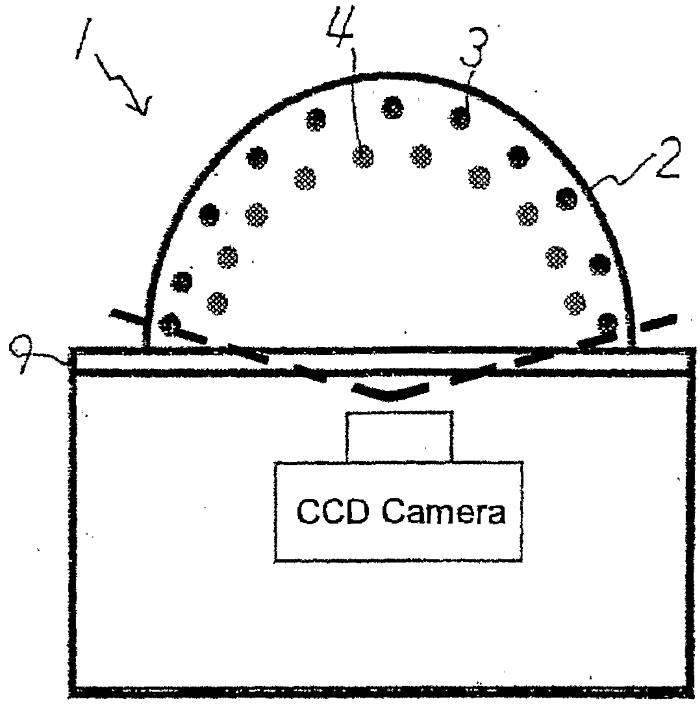


FIG. 7

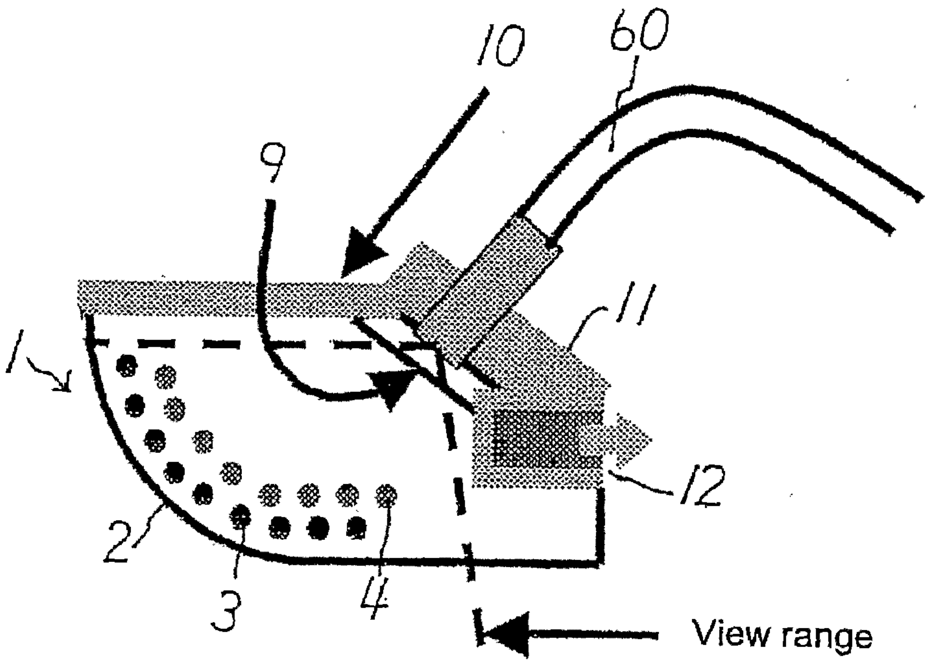


FIG. 8

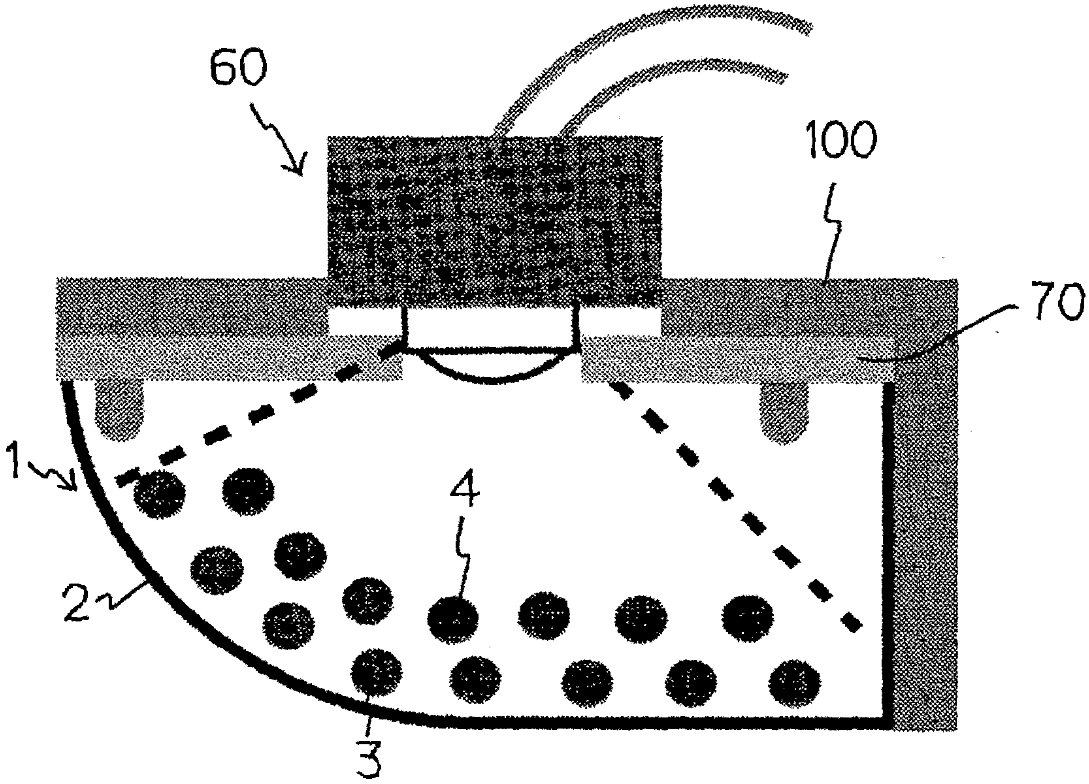


FIG. 9

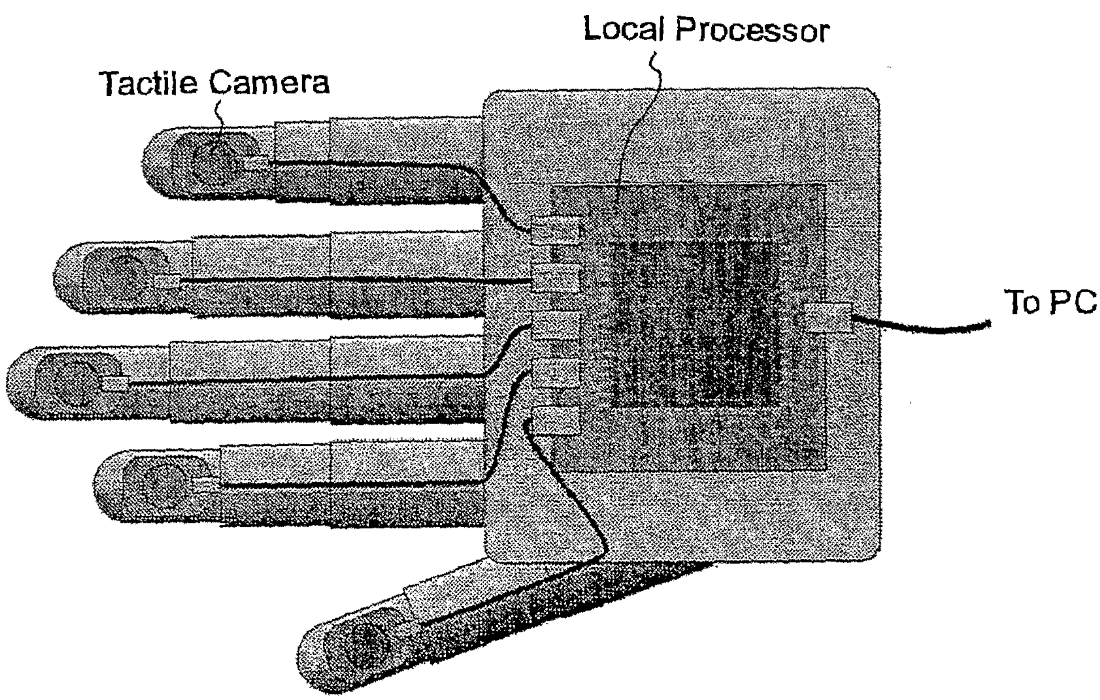


FIG. 10

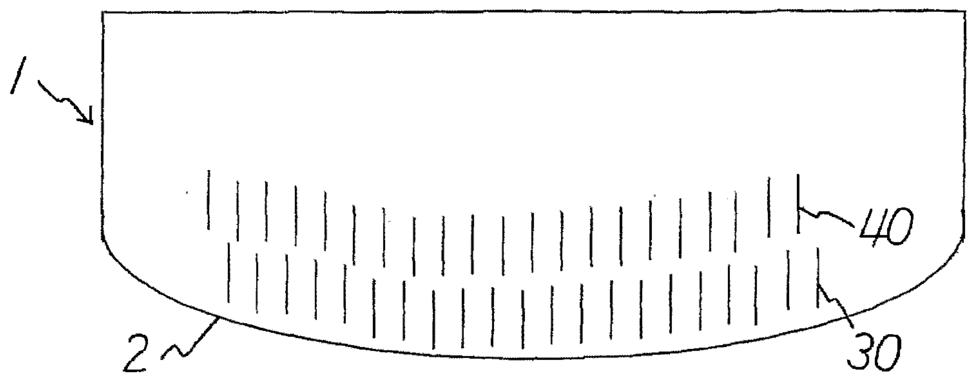
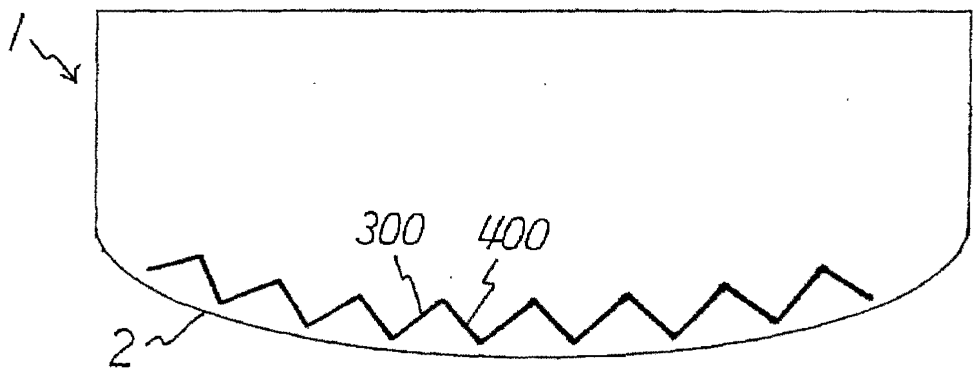


FIG. 11



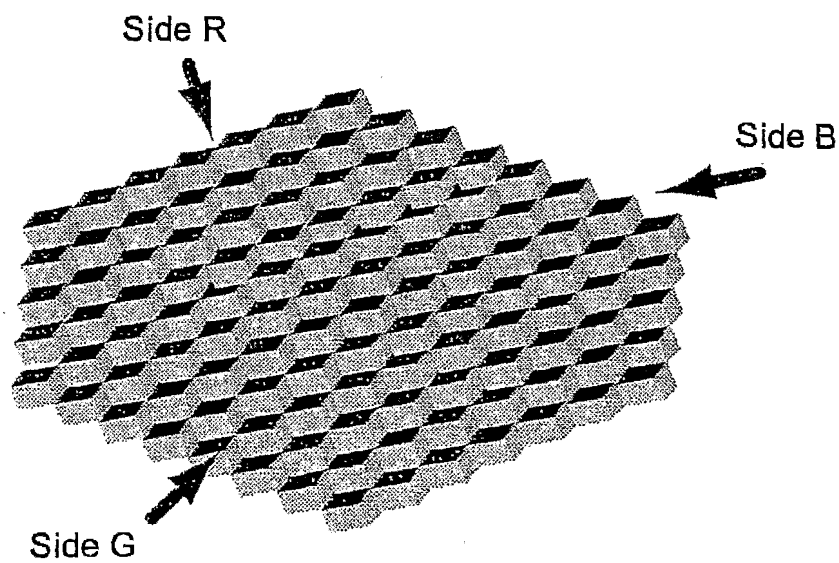


FIG. 12

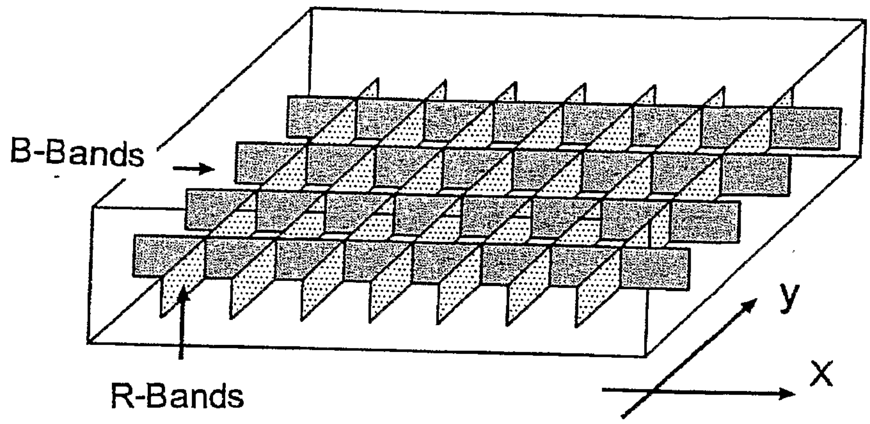
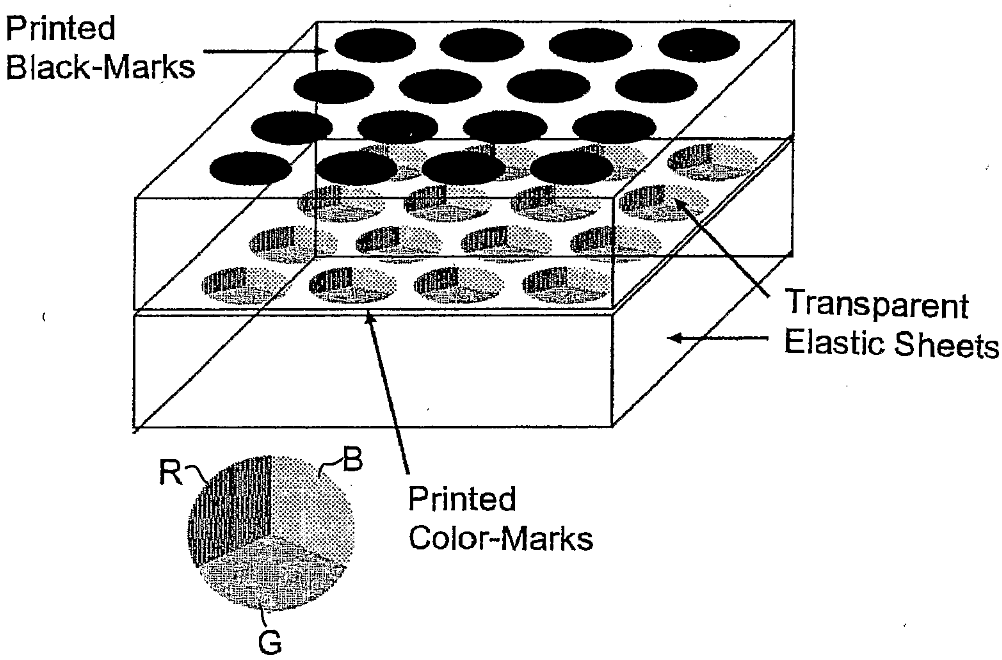

B-Bands
R-Bands
y
X

FIG. 13


Printed
Black-Marks
Transparent
Elastic Sheets
R
B
G
Printed
Color-Marks

VIII-5-1	**Declaration: Non-prejudicial disclosure or exceptions to lack of novelty** Declaration as to non-prejudicial disclosures or exceptions to lack of novelty (Rules 4.17(v) and 51bis.1(a)(v)): Name (LAST, First)	in relation to this international application TOUDAI TLO, Ltd. declares that the subject matter claimed in this international application was disclosed as follows:
VIII-5-1(i)	Kind of disclosure:	other
VIII-5-1(ii)	Date of disclosure:	23 May 2003 (23.05.2003)
VIII-5-1(iii)	Title of disclosure:	JSME ROBOMEC 2003 Conference in Hakodate
VIII-5-1(iv)	Place of disclosure:	Hakodate-shi, Hokkaido, Japan
VIII-5-1(v)	This declaration is made for the purposes of:	all designations

26. 1. 2006

NOTIFICATION OF CHANGE OF ADDRESS

To : Commissioner of the Patent Office

1. Identification of the International Application
   PCT/JP2004/007285

2. Applicant
   Name : TOUDAI TLO, Ltd.
   Address : 3-1, Hongo 7-chome, Bunkyo-ku, Tokyo 113-0033 Japan
   Country of nationality : Japan
   Country of residence : Japan

3. Person Changing Address
   Relationship to the International Application : Applicant and Inventor
   Name : MIZOTA, Terukazu
   Former address : c/o TOUDAI TLO, Ltd., 3-1, Hongo 7-chome, Bunkyo-ku, Tokyo 113-0033 Japan
   New address : c/o Nitta Corporation Nara Factory, 172 Ikezawa-cho, Yamatokohriyama-shi, Nara 639-1085 Japan
   Country of nationality : Japan
   Country of residence : Japan

4. Agent
   Name : (10313) INABA, Shigeru
   Signature Shigeru Inaba
   Address : NARUSE, INABA & INAMI
   Hanabishi Imas Hirakawacho Building 4th Floor,
   2-3-11, Hirakawacho, Chiyoda-ku, Tokyo 102-0093 Japan

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2004/007285

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl[7] G01L5/16, G01L1/04, G01L1/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl[7] G01L5/16, G01L1/04, G01L1/24

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Japanese Utility Model Gazette 1922-1996, Japanese Publication of Unexamined Utility Model Applications 1971-2004, Japanese Registered Utility Model Gazette 1994-2004, Japanese Gazette Containing the Utility Model 1996-2004

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 1321753 A1(Center for Advanced Science and Technology Incubation,Ltd.) 2003.06.25,all pages, all figures & WO 02/18893 A1 & US 2003-0178556 A1 & AU 8254901 A & CA 2419252 A	1-29
Y	JP 11-118625 A(TOYOTA Central R&D Labs.,Inc.) 1999.04.30,all pages,all figures(Family:none)	1-29
Y	JP 11-108630 A(Shiseido Co.,Ltd.) 1999.04.23, all pages, all figures(Family:none)	1-29
A	EP 872719 A1(TOKAI RUBBER INDUSTRIES,LTD.) 1998.10.21,all pages,all figures & JP 10-249768 A & US 6037703 A1 & DE 69800176 T	1-29

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24.08.2004	14.9.2004

Name and mailing address of the ISA/JP
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan

Authorized officer
HISAO MATSUURA 2F 9613
Telephone No. +81-3-3581-1101 Ext. 3215

2538008
06/03/06

Copy for the designated Office (DO/CA) PCT/JP2004/007285

PATENT COOPERATION TREATY

3

PCT

From the INTERNATIONAL BUREAU

To:

INABA, Shigeru
Naruse, Inaba & Inami
Hanabishi Imas Hirakawacho
Building 4th Floor
3-11, Hirakawacho 2-chome
Chiyoda-ku, Tokyo 102-0093
Japan

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

Date of mailing (day/month/year) 22 February 2006 (22.02.2006)	
Applicant's or agent's file reference CAR04008	**IMPORTANT NOTIFICATION**
International application No. PCT/JP2004/007285	**International filing date** (day/month/year) 21 May 2004 (21.05.2004)

1. The following indications appeared on record concerning:

[X] the applicant [X] the inventor [ ] the agent [ ] the common representative

Name and Address	State of Nationality	State of Residence
MIZOTA, Terukazu c/o Toudai TLO, Ltd. 3-1, Hongo 7-chome Bunkyo-ku, Tokyo 113-0033 Japan	JP	JP
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[ ] the person [ ] the name [X] the address [ ] the nationality [ ] the residence

Name and Address	State of Nationality	State of Residence
MIZOTA, Terukazu c/o Nitta Corporation Nara Factory 172, Ikezawa-cho Yamatokohriyama-shi, Nara 639-1085 Japan	JP	JP
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[ ] the International Preliminary Examining Authority
[X] the designated Offices concerned
[ ] the elected Offices concerned
[ ] other:

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No. (41-22) 338.70.10	Authorized officer Arounni WETZLER (Fax 338 7010) Telephone No. (41-22) 338 8359

Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2538008 A1 2005/03/31

(21) 2 538 008

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 2004/05/21
(87) Date publication PCT/PCT Publication Date: 2005/03/31
(85) Entrée phase nationale/National Entry: 2006/03/06
(86) N° demande PCT/PCT Application No.: JP 2004/007285
(87) N° publication PCT/PCT Publication No.: 2005/029028
(30) Priorité/Priority: 2003/09/16 (JP2003-322624)

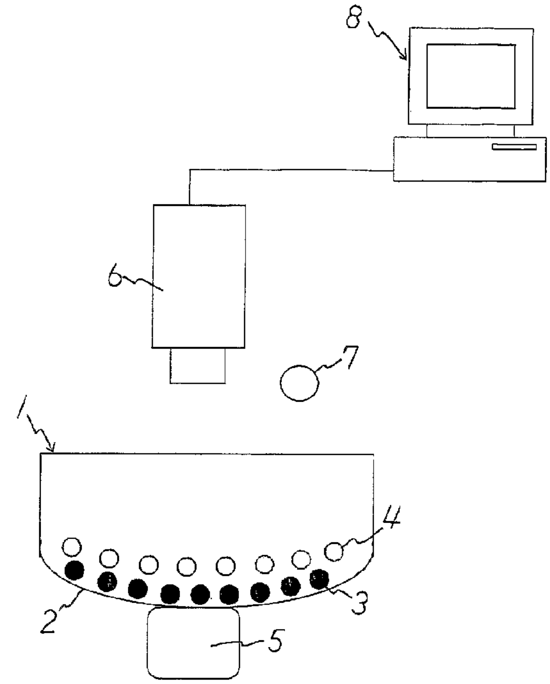
(51) Cl.Int./Int.Cl. *G01L 5/16* (2006.01), *G01L 1/24* (2006.01), *G01L 1/04* (2006.01)
(71) Demandeur/Applicant:
TOUDAI TLO, LTD., JP

(72) Inventeurs/Inventors:
MIZOTA, TERUKAZU, JP;
KAMIYAMA, KAZUTO, JP;
KAJIMOTO, HIROYUKI, JP;
KAWAKAMI, NAOKI, JP;
TACHI, SUSUMU, JP

(74) Agent: SMART & BIGGAR

(54) Titre : CAPTEUR TACTILE OPTIQUE ET PROCEDE DE RESTITUTION DE LA REPARTITION D'UN VECTEUR DE FORCE AU MOYEN DU CAPTEUR

(54) Title: OPTICAL TACTILE SENSOR AND METHOD OF RECONSTRUCTING FORCE VECTOR DISTRIBUTION USING THE SENSOR



(57) Abrégé/Abstract:
The invention relates to a tactile sensor capable of obtaining information for a plurality of degrees of freedom at each point on a surface. An optical tactile sensor is provided with a sensing part and a photographing device, the sensing part comprising a transparent elastic body and a plurality of groups of markers provided inside the elastic body, each marker group being made up of a number of colored markers, with markers making up different marker groups having different colors for each group. The elastic body has an arbitrary curved surface. The behavior of the colored markers when an object touches the curved surface of the elastic body is obtained as image information of markers by photographing device. The sensor further comprises a force vector distribution reconstructing device for reconstructing forces applied to said surface from information as to the behavior of markers that is obtained from said image information of markers.

SP063402

[19] 中华人民共和国国家知识产权局

[51] Int. Cl.
G01L 5/16 (2006.01)
G01L 1/04 (2006.01)
G01L 1/24 (2006.01)

[12] 发明专利申请公开说明书

[21] 申请号 200480026715.9

[43] 公开日 2006 年 10 月 25 日

[11] 公开号 CN 1853093A

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[30] 优先权
[32] 2003. 9.16 [33] JP [31] 322624/2003
[86] 国际申请 PCT/JP2004/007285 2004.5.21
[87] 国际公布 WO2005/029028 英 2005.3.31
[85] 进入国家阶段日期 2006.3.16

[71] 申请人 株式会社东京大学 TLO
地址 日本东京都
[72] 发明人 沟田晃一 神山和人 梶本裕之
川上直树 馆 暲
[74] 专利代理机构 北京市柳沈律师事务所
代理人 陶凤波 侯 宇

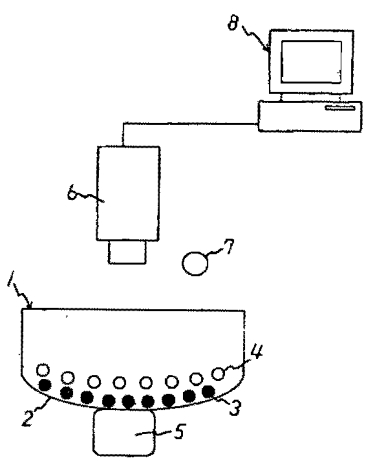
权利要求书 4 页 说明书 16 页 附图 7 页

[54] 发明名称

光学式触觉传感器和使用该传感器的力矢量分布再构成法

[57] 摘要

提供一种具备由自由曲面构成的触觉部的光学式触觉传感器。其是具备触觉部和摄影手段的光学式触觉传感器，该触觉部由透明弹性体(1)和设置在该弹性体内的多个标志组构成，各标志组分别由多个有色标志构成，构成不同标志组的标志的每组具有相互不同的颜色，该弹性体的表面(2)是自由曲面，该标志组沿该自由曲面配置。在物体接触到了该弹性体时由摄影手段对该有色标志的动作进行摄影。触觉传感器其理想的是指型触觉传感器。



(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Veröffentlichungsnummer:
(11) Publication number:
(11) Numéro de publication:

EP 1 664 710 A0

Internationale Anmeldung veröffentlicht durch die Weltorganisation für geistiges Eigentum unter der Nummer:

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International application published by the World Intellectual Property Organisation under number:

WO 2005/029028 (art. 158 of the EPC).

Demande internationale publiée par l'Organisation Mondiale de la Propriété sous le numéro:

WO 2005/029028 (art. 158 de la CBE).

(19)대한민국특허청(KR)
(12) 공개특허공보(A)

(51) 。Int. Cl.
G01L 1/04 (2006.01)
G01L 1/24 (2006.01)
G01L 5/16 (2006.01)
G06F 3/00 (2006.01)

(11) 공개번호 10-2006-0076293
(43) 공개일자 2006년07월04일

(21) 출원번호 10-2006-7005121
(22) 출원일자 2006년03월13일
번역문 제출일자 2006년03월13일
(86) 국제출원번호 PCT/JP2004/007285
국제출원일자 2004년05월21일
(87) 국제공개번호 WO 2005/029028
국제공개일자 2005년03월31일

(30) 우선권주장 JP-P-2003-00322624 2003년09월16일 일본(JP)

(71) 출원인 가부시키가이샤 도쿄다이가쿠 티엘오
일본국 도쿄도 분쿄쿠 혼고 7쵸메 3-1

(72) 발명자 미조다 데루가즈
일본국, 나라 639-1085 야모토고히리야마시 이게자와쬬 172,니타코퍼레이션 나라공장내
가미야마 가즈토
일본국, 군마 3710847 마에바시시 오오도모마찌 3-21-1
가지모토 히로유키
일본국, 가나가와 2440815 요코하마시 토츠가구 시모구라타쬬828-362
가와가미 나오키
일본국, 도쿄 1120001 분쿄구 학산 2-35-2 맨션 다치바나2층
다찌 스스무
일본 이바라키 3050045 쯔꾸바시 우메조노 2-31-14

(74) 대리인 김영환

심사청구 : 없음

(54) 광학식 촉각센서 및 그 센서를 이용한 힘벡터 분포 재구성방법

요약

본 발명은 표면의 각 점에서 복수의 자유도에 관한 정보를 얻는 것이 가능한 촉각센서에 관한 것이다. 광학식 촉각센서에는 센서부와 촬영장치가 구비되며, 상기 센서부는 투명탄성체와 투명탄성체 내부에 설치된 다수의 마커로 구성되고, 각 마커군은 다수의 유색마커로 구성되며, 마커들은 마커군들 사이에 서로 다른 색을 띤다. 탄성체는 자유곡면으로 이루어진 표

РОССИЙСКАЯ ФЕДЕРАЦИЯ

(19) **RU** (11) **2 358 247** (13) **C2**

(51) МПК
G01L 5/16 (2006.01)
G01L 1/14 (2006.01)
G01L 1/24 (2006.01)

ФЕДЕРАЛЬНАЯ СЛУЖБА
ПО ИНТЕЛЛЕКТУАЛЬНОЙ СОБСТВЕННОСТИ,
ПАТЕНТАМ И ТОВАРНЫМ ЗНАКАМ

(12) ОПИСАНИЕ ИЗОБРЕТЕНИЯ К ПАТЕНТУ

(21), (22) Заявка: **2006108381/28, 21.05.2004**

(24) Дата начала отсчета срока действия патента:
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(30) Конвенционный приоритет:
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(56) Список документов, цитированных в отчете о поиске: **EP 1321753 A1, 25.06.2003. JP 11118625 A, 30.04.1999. JP 11108630 A, 23.04.1999.**

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(86) Заявка PCT:
JP 2004/007285 (21.05.2004)

(87) Публикация PCT:
WO 2005/029028 (31.03.2005)

Адрес для переписки:
129090, Москва, ул. Б.Спасская, 25, стр.3, ООО "Юридическая фирма Городисский и Партнеры", пат.пов. Ю.Д.Кузнецову, рег.№ 595

(72) Автор(ы):
МИЗОТА Теруказу (JP),
КАМИЯМА Казуто (JP),
КАДЗИМОТО Хироюки (JP),
КАВАКАМИ Наоки (JP),
ТАТИ Сусуму (JP)

(73) Патентообладатель(и):
ТОУДАИ ТЛО, ЛТД. (JP)

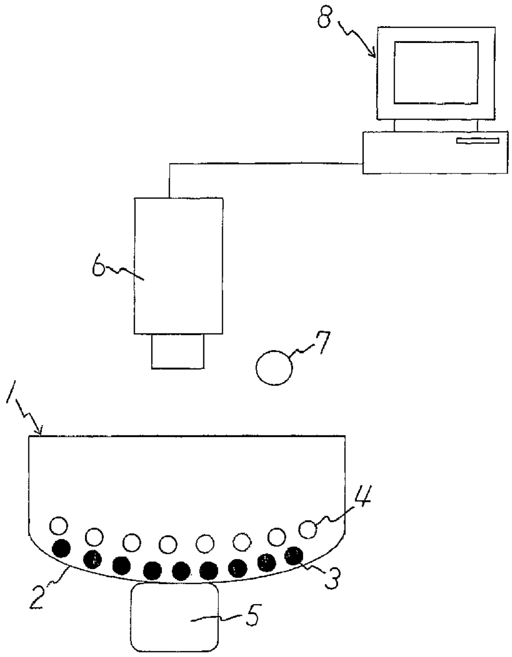
RU 2358247 C2

(54) ОПТИЧЕСКИЙ ТАКТИЛЬНЫЙ ДАТЧИК И СПОСОБ ВОССТАНОВЛЕНИЯ РАСПРЕДЕЛЕНИЯ ВЕКТОРА СИЛЫ С ИСПОЛЬЗОВАНИЕМ УКАЗАННОГО ДАТЧИКА

(57) Реферат:

Изобретение относится к устройству и способу определения вектора силы и может быть использовано в тактильном датчике для руки робота. Оптический тактильный датчик содержит чувствительную часть и фотографирующее устройство, при этом чувствительная часть содержит прозрачный гибкий корпус и множество групп маркеров, расположенных внутри гибкого корпуса. Каждая группа маркеров содержит множество окрашенных маркеров, при этом маркеры, составляющие различные группы маркеров, имеют различную окраску в каждой группе. Гибкий корпус имеет произвольную искривленную поверхность. Поведение окрашенных маркеров, когда объект касается искривленной поверхности гибкого корпуса, получается как информация о маркерах в виде изображения с помощью фотографирующего устройства. Датчик дополнительно содержит устройство для восстановления распределения вектора силы, предназначенное для восстановления сил, приложенных к поверхности, на основе информации о поведении маркеров, которая получается на

основе указанной информации о маркерах в виде изображения. Технический результат заключается в возможности создания оптического тактильного датчика с произвольной искривленной поверхностью, позволяющего измерять трехмерное распределение вектора силы, который возможно использовать как тактильный датчик для манипулятора (руки робота). 5 н. и 21 з.п. ф-лы, 13 ил.



ФИГ.3

RU 2358247 C2

RU 2358247 C2

US007420155B2

(12) **United States Patent**
Mizota et al.

(10) **Patent No.: US 7,420,155 B2**
(45) **Date of Patent: Sep. 2, 2008**

(54) **OPTICAL TACTILE SENSOR AND METHOD OF RECONSTRUCTING FORCE VECTOR DISTRIBUTION USING THE SENSOR**

(75) Inventors: **Terukazu Mizota**, Yamatokohriyama (JP); **Kazuto Kamiyama**, Maebashi (JP); **Hiroyuki Kajimoto**, Yokohama (JP); **Naoki Kawakami**, Tokyo (JP); **Susumu Tachi**, Tsukuba (JP)

(73) Assignee: **Toudai TLO, Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 28 days.

(21) Appl. No.: **10/571,576**

(22) PCT Filed: **May 21, 2004**

(86) PCT No.: **PCT/JP2004/007285**

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Primary Examiner—Georgia Y. Epps
Assistant Examiner—Brian J Livedalen
(74) *Attorney, Agent, or Firm*—Ladas & Parry, LLP

(57) **ABSTRACT**

The invention relates to a tactile sensor capable of obtaining information for a plurality of degrees of freedom at each point on a surface. An optical tactile sensor is provided with a sensing part and a photographing device, the sensing part comprising a transparent elastic body and a plurality of groups of markers provided inside the elastic body, each marker group being made up of a number of colored markers, with markers making up different marker groups having different colors for each group. The elastic body has an arbitrary curved surface. The behavior of the colored markers when an object touches the curved surface of the elastic body is obtained as image information of markers by photographing device. The sensor further comprises a force vector distribution reconstructing device for reconstructing forces applied to said surface from information as to the behavior of markers that is obtained from said image information of markers.

27 Claims, 7 Drawing Sheets