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Virtual Human Who Can Evaluate Oppressed Sensation

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Abstract

Virtual human who can estimate the feeling when the virtual human's body has an oppression is developed. In this paper we present two examples to evaluate the feelings of comfortability in using a chair and a bag in virtual space by the virtual human.

A feeling when a person uses something comes from a contact surface between the person's body and the object. We try to obtain conditions on the contact surface by the simulation of the contact deformation of the virtual human's body and relate the conditions to the oppressed sensation which the person feel. We simulate only aspects of mechanical conditions, but we succeeded to suggest a way to evaluate such a feeling (oppressed sensation) in the virtual human.

For the virtual human's body an uniform non-linear elastic (Mooney model) is employed. Mooney constant of each part of the virtual human's body is converted from the measurement by a hardness tester for the each part of human body. By the simulating of hardness testing a database of relation between different Mooney constants and values of hardness are obtained. For the simulation of the hardness testing and also the contact deformation of human body, a finite element method of hyper elastic, large deformation with contact is employed. The simulated strain value or load distribution on contact surface is related to oppressed sensation by experiments for some peoples. The virtual human has the above functions and database, then it can evaluate an oppressed sensation caused by a contact with something.

Conventional virtual human can show the motion or the change of human body's shape. We advanced the idea to the large contact deformation of human body's shape and the feeling caused by the deformation. The virtual human is available to evaluate the comfort of a virtual product in the design. The virtual human also can be applied to the design of nursing care robot with special consideration of what level and distribution of forces that can be applied to a nursing care patient. Other applications include the design of bed in preventing patient soiled back, and the design of comfortable clothes.

Key words: virtual human, oppressed sensation, comfortability, human body's deformation

1. Introduction

Current practice in the design and development of a new product has utilized virtual human in evaluating motion and mechanism of the user-friendliness and ergonomics of a new product [1]. In this research we developed a virtual human who can estimate the feeling when the virtual human's body has an oppression, and in this paper we used the virtual human to evaluate the feelings of comfortability in using a chair and a bag in virtual space.

A feeling when a person uses something comes from a contact surface between the body and the object. Then we try to simulate conditions by a finite element calculation for the contact deformation of the virtual human's body and relate the simulated conditions (strain/stress value or load distribution) to the oppressed sensation. In this way we try to evaluate the oppressed sensation which a person feel by the virtual human in virtual space.

2. Virtual Human

2.1 Mechanism of Virtual Human

The virtual human we are developing in our research is going to have the following functions (mechanisms) and databases:

1) Shape data of standard human bodies of men, women, children and also fat, slender ones in their standing positions are available and the virtual human can transform itself into their human bodies.
2) When a human body changes the position, the shape of each part of the body also changes. The virtual human can express the shape conversions of body accompanied with the motion.
3) Characteristic data of body's material for each part of human body are available for the calculation of the contact deformation of body.
4) The virtual human can express the conditions of the contact deformation of the body by the simulation using a FEM.
5) Data of relation between oppressed sensation and condition of contact deformation are available and the virtual human can evaluate the oppressed feeling using the simulated condition of contact deformation.

As an example the virtual human evaluation of chair comfortablity is conceptually shown in Fig. 1. A virtual human body contacts with a virtual product, in this case a chair, and the contact deformation of the buttock with the chair is simulated, then the feeling of sitting comfort of the virtual human is evaluated.

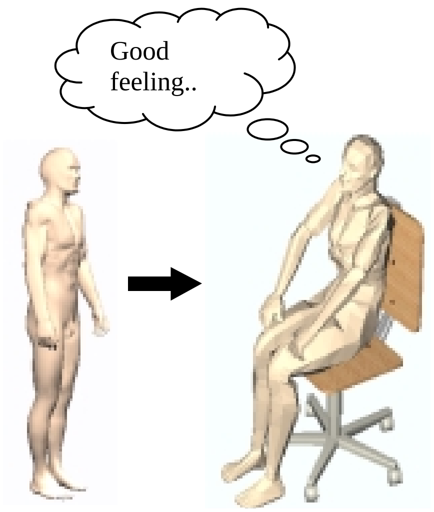


Fig. 1 Concept of a virtual human who estimates a feeling of sitting

2.2 Shape Conversion of Body Accompanied with Motion of Virtual Human

The virtual human as depicted has shape data at the standing position. Consequent changes of the body shape accompanied with the change of position must be described. In this work we tried two methods.

One is a plural chain skeleton model (named by us) by using of the functions in Softimage. The example of the representation of buttocks shape in sitting posture from one in standing posture by the plural chain skeleton model is shown in Fig.2.

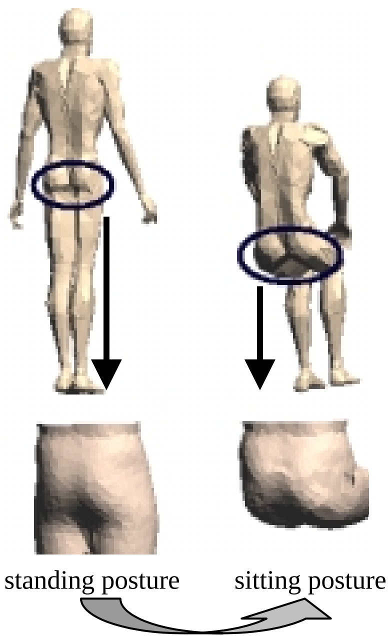


Fig. 2 Representation of buttocks shape in sitting posture from standing posture by plural chain skeleton model

The other is an anatomy based model. The example of the representation of forearm shape in bending posture from one in extended posture by the anatomy based model is shown in Fig.3.

For instance, in the simulation of contact deformation of buttocks, it is confirmed that the result of the deformation depends largely on the shape of the buttocks. Therefore, the high accurate buttocks shape in sitting posture must be obtained from one in standing posture and applied to perform the accurate simulation of contact deformation. Anatomy based model is theoretically exact model, but not practical one [2].

Then, we propose the above mentioned plural chain skeleton model in this study.

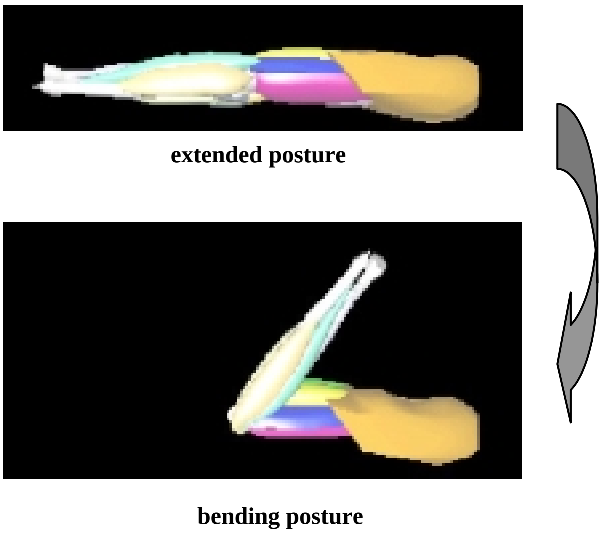


Fig.3 Representation of forearm shape in bending posture from extended posture by anatomy based model

2.3 Mathematical Modeling of Human Body and Functional for FEM Formulation [3]

The characteristics of various parts of human body, such as skin, muscle and fat are different. In this work, we are interesting in the simulation of human feeling in these body parts when subject to the contact with an object. Such feeling comes from the surface of human body, so the inside of human body is permitted as a simple model. Then, we assume human body as a homogeneous rubber and it behaves as a hyper elastic body according to Mooney model.

In the following, the mathematical modeling and its functional for the formulation of the finite element method for the large deformation of a hyper elastic body are briefly summarized. For a homogenous hyper elastic material without subject to any stress, the material possesses strain energy function W per unit mass. The change of the rate of strain energy can be expressed as

$$\dot{W} = \frac{\partial W}{\partial \gamma_{ij}} \dot{\gamma}_{ij} \tag{1}$$

where $\dot{\gamma}_{ij}$ is Green strain velocity.

The rate of change of the strain energy function W can also be expressed as

$$\dot{W} = \frac{1}{\rho_0} S_{ij} \dot{\gamma}_{ij} \tag{2}$$

where S_{ij} is Kirchhoff stress.

From Equations (1) and (2), we can obtain

$$\left\{ \frac{1}{\rho_0} S_{ij} - \frac{\partial W}{\partial \gamma_{ij}} \right\} \dot{\gamma}_{ij} = 0 \tag{3}$$

Since $\dot{\gamma}_{ij}$ is arbitrary, we have

$$S_{ij} = \rho_0 \frac{\partial W}{\partial \gamma_{ij}} \tag{4}$$

This equation is constitutive equation of a hyper elastic body. However, if $\dot{\gamma}_{ij}$ is not independent in such a case of deformation with constant volume, Equation (4) does not hold true.

The strain velocity tensor

$$\varepsilon_{ii} = \gamma_{mn} \frac{\partial X_m}{\partial x_i} \frac{\partial X_n}{\partial x_i} \tag{5}$$

must be the following condition in the deformation with constant volume.

$$\varepsilon_{ii} = \gamma_{mn} \frac{\partial X_m}{\partial x_i} \frac{\partial X_n}{\partial x_i} = 0 \tag{6}$$

Therefore, $\dot{\gamma}_{ij}$ is subject to the constraint given in Equation (6).

The terms inside { } in Equation (3) is not necessarily equal to zero, only that $(\partial X_i / \partial x_m)(\partial X_j / \partial x_n)$ are proportional. Based on the above, as the constitutive equation for an incompressible elastic body, we have

$$S_{ij} = \rho_0 \frac{\partial W}{\partial \gamma_{ij}} + h \frac{\partial X_i}{\partial x_m} \frac{\partial X_j}{\partial x_n} \tag{7}$$

where h is the static pressure, determined by boundary conditions.

From Equation (4), the strain energy function W can be expressed as a function of the three invariants, I_1, I_2, I_3:

$$\begin{aligned} I_1 &= 2\gamma_{ii} + 3 \\ I_2 &= 2\gamma_{ii}\gamma_{jj} + 4\gamma_{ii} - 2\gamma_{ij}\gamma_{ij} + 3 \\ I_3 &= \det\left[2\gamma_{ij} + \delta_{ij}\right] = \det\left[\frac{\partial x_m}{\partial X_i} \frac{\partial x_m}{\partial X_j}\right] \end{aligned} \tag{8}$$

$$W = W(I_1, I_2, I_3) \tag{9}$$

From Equation (4), Kirchhoff stress can be expressed as

$$S_{ij} = \rho_0 \left\{ \frac{\partial W}{\partial I_1}\frac{\partial I_1}{\partial \gamma_{ij}} + \frac{\partial W}{\partial I_2}\frac{\partial I_2}{\partial \gamma_{ij}} + \frac{\partial W}{\partial I_3}\frac{\partial I_3}{\partial \gamma_{ij}} \right\} \tag{10}$$

where

$$\frac{\partial I_1}{\partial \gamma_{ij}} = 2\delta_{ij}$$
$$\frac{\partial I_2}{\partial \gamma_{ij}} = 2(\delta_{ij}\delta_{rs} - \delta_{ir}\delta_{js})(2\gamma_{rs} + \delta_{rs})$$
$$\frac{\partial I_3}{\partial \gamma_{ij}} = 2\frac{\partial X_i}{\partial x_m}\frac{\partial X_j}{\partial x_m} I_3 \tag{11}$$

The above equations allow for the volume changes. For a hyper elastic material, the volume changes due to the deformation is negligibly small. In this case, the strain energy function W can ignore the third invariant, I_3. Substituting Equations (11) into Equation (7), we have

$$S_{ij} = \rho_0 \left\{ \frac{\partial W}{\partial I_1}\frac{\partial I_1}{\partial \gamma_{ij}} + \frac{\partial W}{\partial I_2}\frac{\partial I_2}{\partial \gamma_{ij}} \right\} + h\frac{\partial X_i}{\partial x_m}\frac{\partial X_j}{\partial x_m} \tag{12}$$

The strain energy equation for the case of negligible volume change due to deformation can be expressed as

$$W = C_{10}(I_1 - 3) + C_{01}(I_2 - 3) \tag{13}$$

This is Mooney model and the material follows this relation is called Mooney material.
To the equilibrium equation and the boundary condition about load, the variation δu_i of admissible displacement u_i which satisfies the relation of strain-displacement and also the boundary condition about displacement is multiplied, then integrated in the whole body comes as follows,

$$\iiint_{V_u} \left\{ \frac{\partial}{\partial X_j}\left(\frac{\partial x_i}{\partial X_m} S_{mj} \right) + \rho_0 G_{oi} \right\} \delta u_i dV_0 + \iint_{S_{0i}} \left(P_{0i} - n_{0j}\frac{\partial x_i}{\partial X_m} S_{jm} \delta u_i dS_0 \right) = 0 \tag{14}$$

By using Gauss dispersion principle, we obtained the following expression:

$$\int_{V_0} S_{ij}\delta\gamma_{ji} dV_0 = \int_{S_{nt}} P_{0i}\delta u_i dS_0 + \int_{V_u} \rho_0 G_{oj}\delta u_i \, dV_0 \tag{15}$$

Kirchhoff stress based on the above equation and the conservation of potential energy give

$$\delta\Phi = 0$$
$$\Phi = \int_{V_0} \rho_0 W dV_0 - \int_{S_{oi}} P_{oi} u_i dS_0 + \int_{V_0} \rho_0 G_{0i} u_i dV_0 \tag{16}$$

Here, Φ is the functional of all potential energy, u_i is the admissible displacement. The following third variant is excepted.

$$I_3 = 1 \tag{17}$$

Then, Equation (16) can be written as follows,

$$\Phi_p = \Phi + \int_{V_0} \lambda (I_3 - 1) dV_0 \tag{18}$$

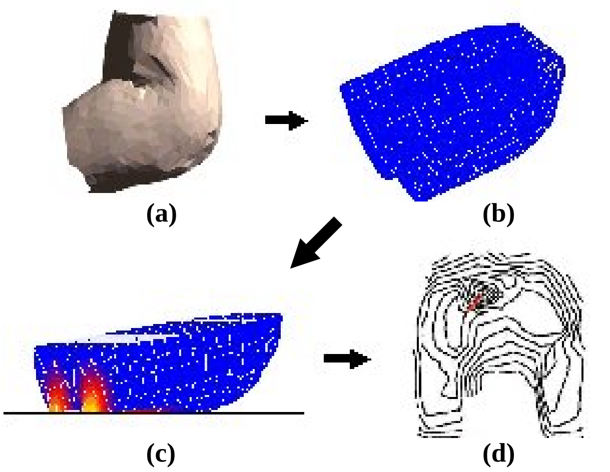
Here, λ is Lagrange multiplier.

Equation (18) is the functional. Using of the functional and the variational principle, the finite element formulation for hyper elastic material can be obtained.

2.4 Procedure of Simulation for Contact Deformation of Human Body

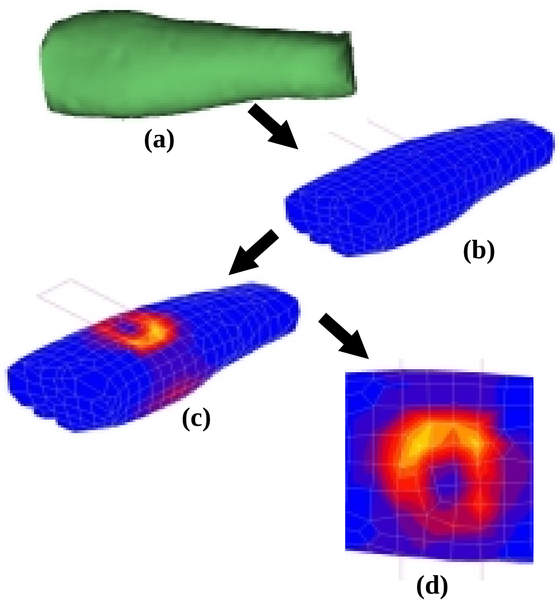
The procedure of the simulation of contact deformation, for example, on a buttocks with a chair is shown in Fig.4. First, from a shape data of buttocks in a standing posture the shape of the buttocks in a sitting posture is made by using of a plural chain skeleton model. Followed by the finite elements meshing, and the calculation for the contact deformation of the buttocks with a chair (considered as a rigid here) is performed by the above FEM for hyper elastic body. In this case, load distribution on the contact between the buttocks and the chair is obtained, and the obtained result is related to the oppressed sensation.

In Fig.5, as an other example, the simulation for large deformation of a forearm by the contact with a band handle of bag. The procedure is same to the case of buttocks. From a shape data of forearm in an extended posture the shape of the forearm in a bending posture is made by using of a plural chain skeleton model. Then the finite elements subdivision is done, and the calculation for the contact deformation of the forearm with a band-handle of bag (considered as a rigid here) is



(a) Shape of buttocks in sitting posture
(b) Finite elements subdivision
(c) Calculation of deformation of buttocks
(d) Load-distribution on the contact between buttocks and chair

Fig.4 Procedure of simulation for deformation of buttocks by the contact with chair



(a) Shape of forearm in bending posture
(b) Finite elements subdivision
(c) Calculation of deformation of forearm
(d) Equivalent strain distribution on the contact between forearm and band handle of bag

Fig.5 Procedure of simulation for large deformation of forearm by the contact with band handle of bag

performed by the FEM for hyper elastic body. In this case, equivalent strain distribution on the contact between the forearm and the band is obtained, and the obtained result is related to the oppressed sensation.

2.5 Material Characteristics of Human Body

In the simulation for the shape deformation of a certain part of human body, material characteristic is necessary. We assume a human body part is a uniform non-linear elastic (hyper elastic body according to Mooney model). Consequently, we must determine Mooney constant of each part of human body for the calculation of the contact deformation.

Soft rubber and similar soft material like sponge is measured by Asker C_2-type hardness tester. We then adopted Asker C_2-type hardness tester to obtain material characteristics of human body, and tried to convert hardness values by the hardness tester to Mooney constants. The simulation of hardness testing with Asker C_2-type hardness tester was done by the above mentioned FEM as shown in Fig.6. Database of the relation between different values of hardness and Mooney constants are obtained by the simulation.

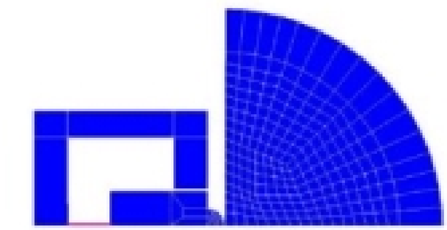


Fig.6 Simulation of hardness testing to obtain relation between hardness and Mooney constant

The measurement of each part of human body was performed by Asker C_2-type hardness tester for some persons, then the hardness values by the hardness tester were converted to Mooney constants and the results are shown in Fig.7. For example, forearm was measured at four locations on the circumference, attached number after each part of human body's name in Fig.7 means the each location.

The measured results have a dispersion naturally shown in Fig.7, because the measurements ware done for the different persons. The large dispersions comes from the location which has the harder material characteristic. For the calculation, we employ the average value of the dispersions from the data of Fig.7.

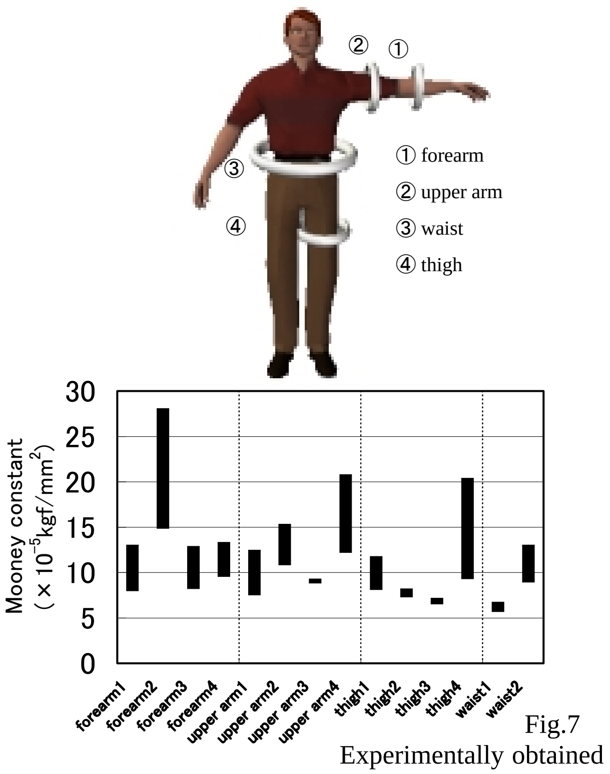


Fig.7 Experimentally obtained Mooney constants for each part of human body

2.6 Relation Between Oppressed Sensation and Contact Deformation of Body

After the result of the contact deformation of body is obtained the evaluation of oppressed sensation is followed. For the evaluation, database of the relation between oppressed sensation and contact deformation is requested.

We had the experiment to get the relation for each part of human body shown in Fig.7. As one method of the experiment, each part of the body was squeezed by a bandage with several intensity levels. We set three pain levels as follows,

Level 1 is that a person gets feeling some discomfort.
Level 2 is that a person feels a distinct pain, but the persons can endure it.
Level 3 is that a person can not endure the pain.

By the declaration of the pain level from each person who was squeezed by a bandage, strain (the amount of the squeeze) at each pain level was checked, and the relation between pain level and strain in the contact deformation of body was investigated.

Fig.8 shows the result for forearm and Fig.9 shows the result for waist. We made the experiments for each part of human body shown in Fig.7. As the results in Fig. 8 and Fig.9 show, their results have some dispersions depend on the each person. In the result of forearm (Fig.8) we can distinguish each pain level, even though it includes the dispersion. On the other hand, in the result of waist (Fig.9) we can not distinguish each pain level, especially between level 1and level 2. The case of the waist was most difficult to be distinguished for each pain level, so it is confirmed that to evaluate the oppressed sensation at the waist with a good reliability is hard, but at the forearm, upper arm and thigh are possible to evaluate the oppressed sensation.

For buttocks we can not employ the experimental method of the squeezing by bandage. Then we try to evaluate the oppressed sensation in buttocks by the load distribution on the contact surface. Chair maker has such data to estimate the relation between the load distribution (the inclination in the contour of the distribution) and the feeling of sitting.

In conclusion, when the result of strain value in the contact deformation is obtained, the virtual human can evaluate the oppressed feeling (pain level) by the database of the relation between strain and pain level for each part of body. For buttocks or other part which we can not apply the experimental method of the squeezing by bandage, the database between the load distribution on the contact surface and the oppressed feeling is prepared in the virtual human.

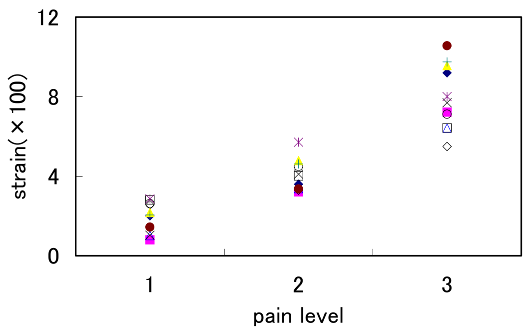


Fig.8 Relation between pain level and strain in deformation at forearm

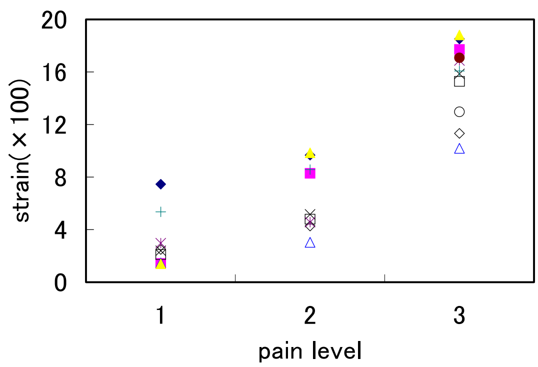


Fig.9 Relation between pain level and strain in deformation at waist

3. Simulation of Contact Deformation and Evaluation of Sensation

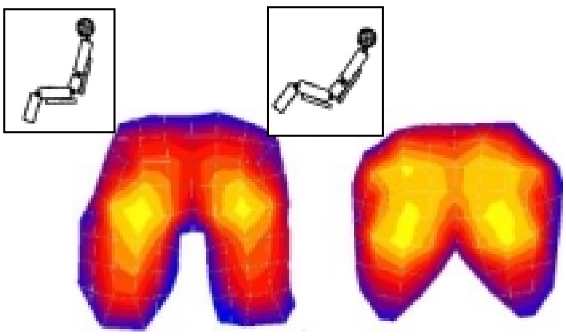
In this paper we present two examples to evaluate the feeling of comfortability in using a chair and also the feeling of pain in using a bag, in virtual space by the developed virtual human. Each procedure of the simulation of the contact deformation is shown in Fig.4 and Fig.5.

3.1 Evaluation of Comfortability in Using Chair

In this case we tried to evaluate the comfortability for two different sitting positions to a same chair. We utilized the same virtual human with two drastically different sitting positions and their corresponding load distributions are obtained as shown in Fig.10. The load distribution between the buttocks and the chair is obtained in the simulation of the contact deformation by the virtual human.

The chair maker has the data of the relation between the load distribution of the buttocks at the contact with the chair and the comfortablity of the chair experimentally. Based on the data, if overall load distribution is flat it is considered comfortable, and if the distribution has a sharp peak it is considered uncomfortable.

In case of the left in Fig.10, the virtual human sitting comfortably on a chair, the evaluation by the virtual human comes good feeling. However, in the other case of the right in Fig.10, the virtual human sitting on the inclining chair toward the back, the evaluation by the virtual human comes uncomfortable feeling. Both results of the load distribution between the buttocks and the chair by the virtual human come similar to the data of the chair maker and the evaluations of comfortability also correspond to the result of the chair maker.



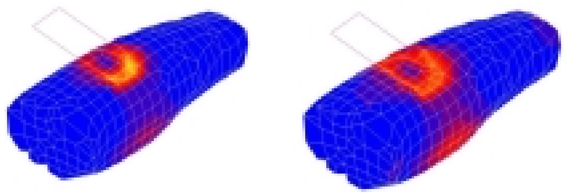
Good Bad

Fig.10 Simulation of contact deformation of buttocks by the contact with chair and evaluation of the comfortability

3.2 Evaluation of Pain Level in Using Bag

In this case we tried to evaluate the pain level for a same bag with two different weights. The same virtual human hang a band-handle of bag with two different weights on the forearm and their corresponding equivalent strain distributions are obtained as shown in Fig.11. The equivalent strain distribution between the forearm and the band-handle of bag is obtained in the simulation of the contact deformation by the virtual human.

In the case of the left in Fig.11 the evaluation of the virtual human comes pain level 1, and in the case of the right in Fig.11 the evaluation of the virtual human comes pain level 3. Such a pain level depends on the weight of the bag, also the width of the band-handle of the bag. This virtual human is available to design such a band-handle of bag.



Pain level 1 Pain level 3

Fig.11 Simulation of contact deformation of forearm by the contact with band-handle of bag and evaluation of the pain level

4. Discussion and Conclusion

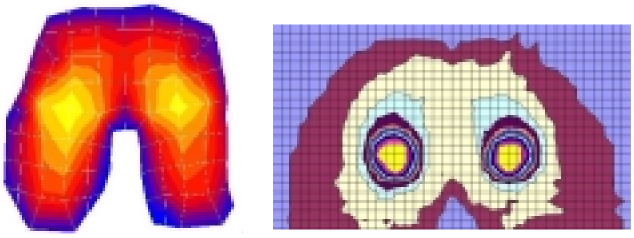
The virtual human who can evaluate oppressed sensation has been presented in this paper. In this research we are going to propose the concept of the virtual human and it's possibility. We confirmed the virtual human can evaluate oppressed sensations like comfortability and pain, but yet many challenges must be cleared.

Expression of the shape conversion of each part of the body accompanied by a motion of virtual human is very important to get the accurate condition in the contact deformation at the body part. We proposed a plural chain skeleton model for it. It is practical one, but we must prepare each different model for each part of body.

For the simulation of the contact deformation of virtual human's body we use a FEM for hyper elastic with large contact deformation. Such non-linear calculation spend much computer resource and the response time comes slow. So we are developing specialized FEM software to simulation of human body's deformation. In conventional one adopted a static implicit method, but new one employs a dynamic explicit method.

For the evaluation of oppressed sensation we adopted load distribution and strain value on the contact surface. We must examine further the relation between stress distribution and oppressed sensation, and choose a best factor.

Reliability of the simulated result is confirmed by the comparison of simulated load distribution in buttocks to the experimentally obtained result. Fig.12 shows the comparison and they have a good coincidence.



simulated result experimental result

Fig.12 Comparison of simulated result with experimental result

In this research we tried to simulate only the aspect of mechanical condition, but we succeeded to suggest a way to evaluate feelings such as comfortability and pain level one of sensibilities in a virtual human. Conventional virtual human can show the motion or the change of human body's shape. We advanced the idea to large deformation of human body's shape and the feeling caused by the deformation.

For the virtual human, we conducted the experiments to inspect the feeling of real humans. In general, the sensibility of a human varies from one person to another. The sensibilities about liking or emotion will be difficult to be treated logically. However, pain or comfort (limited from mechanical causes) can be treated logically.

In designing a new product, we attempted to establish a virtual human to evaluate the comfort of a virtual product. We further validated the proposed methods for virtual human evaluation of comfortability. The present methods can be applied to the design of nursing care robot with special consideration of what level and distribution of forces that can be applied to a nursing care patient. Other applications include the design of bed in preventing patient soiled back, and the design of comfortable clothes.

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