# Simulation of Human Motion - Using Tissues Represented by Elastic Object Models

**Hiroshi Inaba† Shin-ya Miyazaki†† Tsuyoshi Taki†† and Jun-ichi Hasegawa††**
**†Graduate School of Computer and Cognitive Sciences, Chukyo University**
**††School of Computer and Cognitive Sciences, Chukyo University**
**Toyota City, Aichi, 470-0393, Japan**

## ABSTRACT

This paper presents generation of human motion by using a skeletal muscle and skin represented by elastic object. On the whole, human motion is associated according to the contraction of skeletal muscle. And, it results rotation and translation of skeletons that performs human motion, for example, bending of the arms or legs. Then it deforms figures of the other tissues such as fat or skin in posture. To make such a generation of motion and transformation, we use two kinds of elastic object models to make deformation of muscle and skin. The muscle consisting of the mass-and-spring model is able to generate force based on the muscle contraction and to deform the shape by shortening and expansion. The skin consists of the elastic object model based on maintaining local shapes and generates shapes by expanding and contracting around the joints. In this system, a human motion generated by modeled tissue is visualized as an animation.

**Keywords**: Human Motion, Animation, Elastic Object, Skeletal Muscle, Skin

## 1. INTRODUCTION

Recently, there has been renewal of interest in automated generation of human motion, by using a modeled human body to reconstruct a real human elaborately with a computer. Specially, if it can express a change of shape of tissues such as skeletal muscle or skin in motion, then it is promoted to understand a spatial arrangement of these tissues and a compound motion of them. The human body constructed for these purposes is called “human body model” and an experiment and an analysis by using the model is tried by a new approach. However, to express a change of shape of tissues faithfully, it is important to construct a human body, which is operated freely. So, we pay attention to a generation of motion by the muscle contraction of skeletal muscle and transformation of muscle shape and body surface expressed by elastic object. And to visualize the state of the tissue in motion is the purpose of our research.

In this paper, we propose a modeled human body consisting of rigid bones and elastic tissues such as skeletal muscle or skin for simulating of a deformation of shape in motion. The elastic component is composed of two components. The first component corresponds to skeletal muscle that generates force to shrink and starts deformation. The second component does subcutaneous tissue, which deforms according to deformation of the other tissue. An elastic object model based on the criterion of maintaining local shapes of objects is used for computation of the shape of tissue. The application of the model to leg movements is also presented.

The remainder of this paper is structured as follows: Section 2 explains an outline of this system and a method for generation of the human body model. Section 3 shows how to construct the muscle and the fatty tissue expressed by elastic object model, and describes a method for transformation of the elastic component. Section 4 shows a result that a human motion generated by modeled tissues, and visualizes to make an animation to give consideration. Section 5 shows a conclusion.

### Related Work

MusculoGraphics inc. [1] has developed an experimental environment “SIMM” for analyzing, generating and visualizing human motions. In SIMM, exercise-physiological/ biomechanical models of muscle and skeleton are used. Suzuki *et al.* [2] have proposed a system to visualize a state

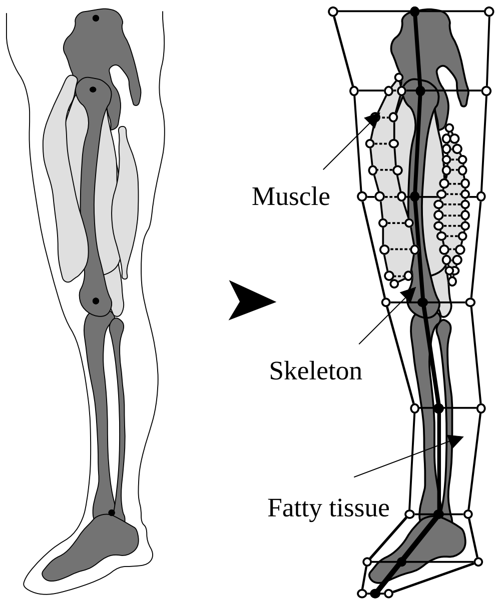



Fig 1. Human body model constructed
by skeleton, muscle and fatty tissue.

of muscle and skeleton in human motion. In this system, the virtual human body constructed from the MR image of each living body is used. In research on modeling tissues, Zajac [3] has reported in detail on modeling of skeletal muscle from the viewpoint of exercise physiology. Also, many trials for representing skin using an elastic model have been reported (for example, see [4]).

## 2. MODELING OF HUMAN BODY

### Structure of Human Body Model

The human body model for the system consists of three components; skeleton, muscle and fatty tissue (Fig 1). Each skeleton is a rigid object used as a base for positioning muscle and fatty tissue. Each muscle is an elastic object which can generate a muscle force by self-contraction. The fatty tissue is also elastic, and forms a body surface covering the skeleton and muscle. The placement of these components is decided with referring to their positional relationship in human anatomy.

### Constructing Model Components

The shape of each component in the human body model can be constructed by using slice images of a real human body (Fig 2). Basically, each component in each slice is represented by a polygon. The detail procedure for construction of the shape is as follows.
**Step 1**. Reduction of number of slices

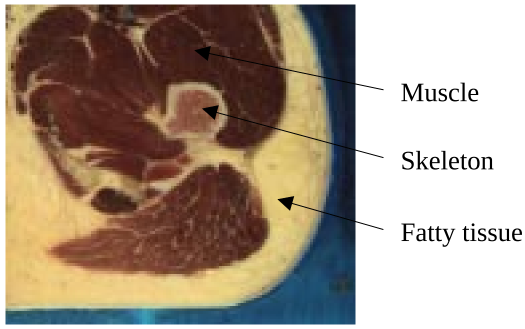
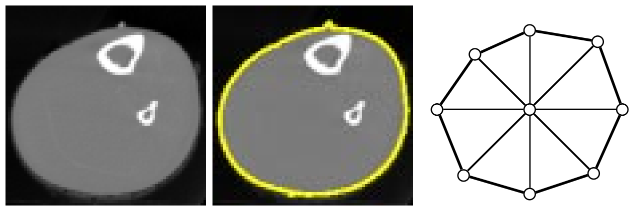



Fig 2. An example of input image.
(Visible Human dataset photograph)



(a) Input image (b) Extracted boundary (c) Constructed polygonal model

Fig 3. Construction of shapes of body tissue.

**Step 2**. Polygonal representation:
**2-1**. A border of the region corresponding to each body component is extracted from each slice (Fig 3(b)).
**2-2**. A set of intersection points of the border and lines outgoing radially from the center point of the region is obtained (Fig 3(c)). These points are vertices of a polygon representing the shape of the component.
**Step 3**. Generation of a lattice: Every pair of corresponding vertices between two adjoining slices is connected.

The shape of fatty tissue is decided based on the shapes of other components. The detail procedure to construct the shape of the fatty tissue is as follows.
**Step 1**. Selection of a reference point: The center point of the skeleton in each slice is used as the reference point.
**Step 2**. Setting of inner points: Using lines outgoing radially from the reference point, the following points are obtained:
· intersection points of the skeleton border and the lines
· intersection points of the muscle border and the lines
These are the candidate points for vertices of polygon representing shapes of skeleton and muscle, respectively (Fig 4).
If there exist two candidate points or more, only the nearest one to the reference point is remained and others are omitted.

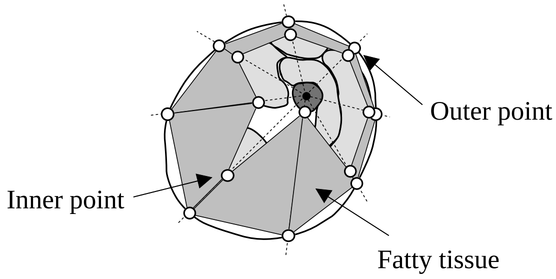



Fig 4. A section view of model.

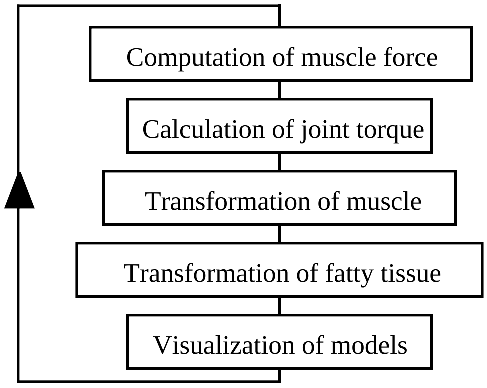



Fig 5. Procedures of motion generation.

**Step 3**. Generation of a lattice: Same as Step 3 mentioned above.

## 3. GENERATION OF BODY MOTION

### Outline of Motion Generation

Each muscle generates a muscle force based on the modeled muscle contraction. This force is transformed to a joint torque to rotate and move the skeleton. Shapes of muscle and fatty tissue are changed according to the change of posture. By performing repeatedly the above process, a human motion is generated. The results are visualized in the form of animation (Fig 5).

### Model of Muscle Contraction

In the muscle model, some mass points and springs connected in series are placed on the center axis of muscle. Additional force called “contraction force” is applied to realize muscle contraction. The contraction force $\mathbf{F}_i$ applied to mass point $i$ is given by Eq. (1).

Where $m_i$ shows a mass of point $i$. And $k$, $L$, and $D$ shows respectively, spring constant, natural length of spring, and damper. $\mathbf{r}_{ij}$ is relative vector from point $i$ to point $j$, and $\mathbf{v}_{ij}$ is relative velocity from point $i$ to point $j$. Position of mass

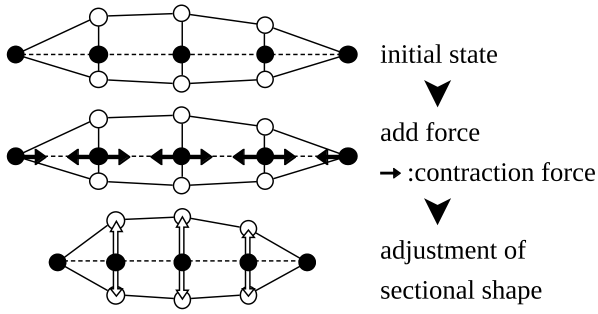



Fig 6. Model of muscle contraction.
(●: mass point, ○ : edge point, ···· : spring)

$$\mathbf{F}_i = m_i \cdot \mathbf{g} - \sum_j \left\{ k \cdot \left(1 - \frac{L}{|\mathbf{r}_{ij}|}\right) \cdot \mathbf{r}_{ij} + D \cdot \mathbf{v}_{ij} + M \cdot \frac{L}{|\mathbf{r}_{ij}|} \right\} \quad (1)$$

points are determined under the effect of the contraction force. The force applying on the mass points placed on muscle edges works directly on the skeleton. We use the criterion of keeping the volume of muscle for transformation of muscle shape, that is, thickness of muscle increases according to decrease of muscle length (Fig 6). It appears in each section of muscle lattice.

### Calculation of Joint Torque

The muscle force works to rotate a joint. Strength of joint torque is decided by the position the force applying on and vector of the force. The torque determines an angle of joint based on dynamics.

### Deformation of Fatty Tissue

**Elastic model**: To obtain a deformed shape of fatty tissue, we use an elastic object model that is suggested by our group [5]. The whole shape is constructed by a set of volume elements. This model generates proper stress for restoring the initial shape even if the object extremely deforms. The model has a feature to maintain a three-dimensional structure of the local shapes in comparison with ordinal mass-and-spring model.

Displacements of mass points in each local element are obtained as $\mathbf{r}_i$-$\mathbf{R}_i$ to satisfy the Eq. (2). Here $\mathbf{R}_i$ shows the equilibrium location of point $i$ in the local coordinate system, and $\mathbf{r}_i$ shows the current location of it. $k$ is elastic constant to decide flexibility of deformation. In fact; $\mathbf{R}_i$ is obtained to solve the Eq. (3). Where $\mathbf{Ro}_i$ shows the initial position of $\mathbf{R}_i$.

**Deformation**: The fatty tissue is passively transformed by changes of posture and transformation of the muscle. Under the constraints of muscle shape and joint angle decided

$$\sum_i \mathbf{r}_i \times k\left(\mathbf{R}_i - \mathbf{r}_i\right) = k\sum_i \mathbf{r}_i \times \mathbf{R}_i = \vec{0} \quad (2)$$

$$\mathbf{R}_i = \mathbf{M} \cdot \mathbf{Ro}_i \quad (3)$$

Where **M** shows as follows.

$$\mathbf{M} = \mathbf{uu}^T + \cos\theta\left(\mathbf{I} - \mathbf{uu}^T\right) + \sin\theta \begin{pmatrix} 0 & -u_z & u_y \\ u_z & 0 & -u_x \\ -u_y & u_x & 0 \end{pmatrix}$$

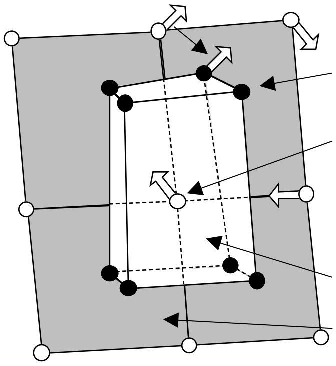



Fig 7. Deformation of non-muscle part.
(⇨ :Moving vector)

beforehand, the shape of fatty tissue is calculated. Namely, each mass point of fatty tissue is adjusted to the closest point of muscle tissue. It is a simple way to reject the fatty tissue out of the muscle tissue, and is faster than the way of collision detection between points. Motion of mass points is defined as follows:

Difference equations of the dynamic equations of motion that are established locally in each node specify the velocity $\mathbf{V}_i(T)$ and position $\mathbf{P}_i(T)$ of the point $i$ at discrete time $T$ sequentially as:

$$\mathbf{V}_i(T + \Delta T) = \mathbf{V}_i(T) + \frac{\mathbf{F}_i(T)}{m_i} \cdot \Delta T \quad (4)$$

$$\mathbf{P}_i(T + \Delta T) = \mathbf{P}_i(T) + \mathbf{V}_i(T) \cdot \Delta T \quad (5)$$

Here, $\mathbf{F}_i(T)$ means the force operating on point $i$ at time $T$. $\Delta T$ is the time step of evolution. Velocities and positions of nodes are renewed step by step in time. $\Delta T$ must be sufficiently small compared to the cycle of spring oscillation for the reliable simulation.

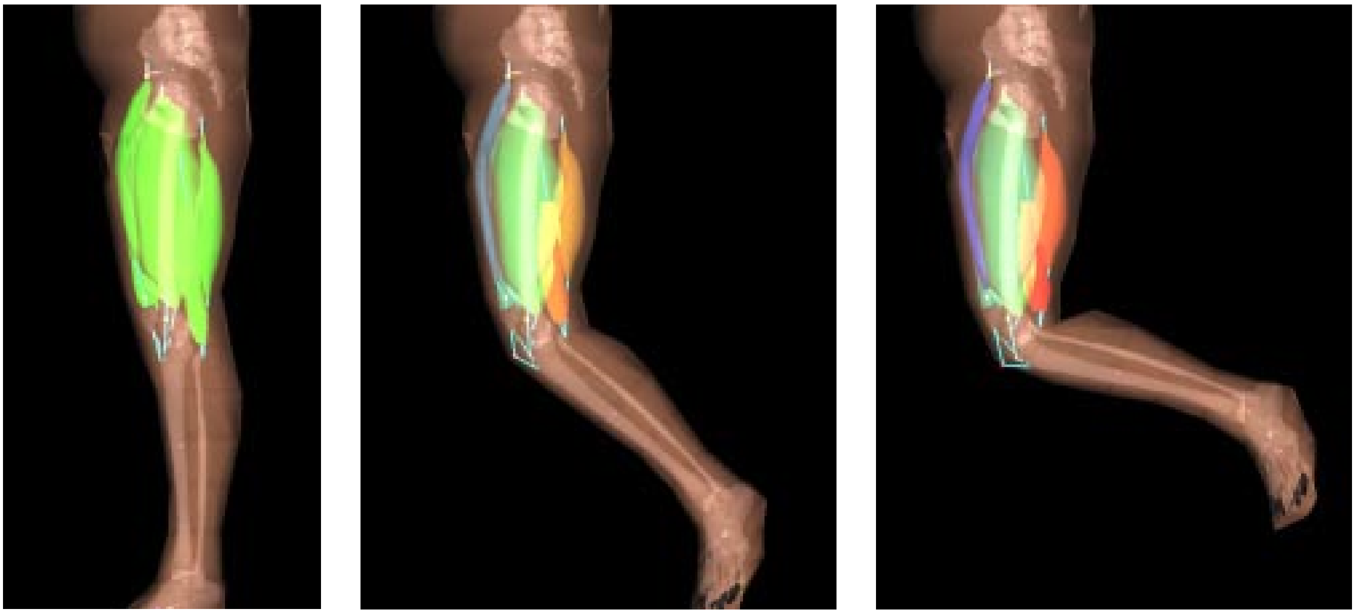
## 4. EXPERIMENTAL RESULTS

Generation and transformation results of human motion using the proposed model. In this experiment, we construct a model of the lower limbs using six muscles and try to simulate a flexion motion of knee joint. The six muscles are the biceps femoris and the quadriceps femoris. A flexion motion is generated by muscle contraction of the biceps femoris. On the other hand, the quadriceps femoris does not contract by itself, but it transforms according to a flexion motion. We extracted the shape of skeleton, muscle and fatty tissue from axial photographs of the Visible Human dataset [6] respectively. The shape of each component was extracted by semiautomatic procedure using image processing. The joint position was simply estimated from the skeletons. For parameters of the mass and the moment of inertia of bone, we referred to ref. [7]. The final results are visualized as a 3D animation. We can see the behavior of both skeleton and muscle through the fatty tissue.

Fig.8 shows an example of human motion generated by this system. We can observe the flexion motion of the knee joint by muscle contraction of the arranged muscle. Fig.9 shows the part of knee joint in the same motion. From the figure, transformation results of the both muscle and fatty tissue can be observed. Also, we found that the shape of fatty tissue was broken when the transformation became heavy or the joint angle became large. Especially, there was a tendency like this for many lattices around the joint as compare with other lattices. For this problem, we are currently trying to give the adequate elasticity for each lattice, not uniformly, or to optimize the shape of fatty tissue such as the feature of the original shape is preserved. On experimenting, we realized real-time processing for generation of human motion by using a general personal computer (Spec; Pentium III 1GHz×2, 1GB Mem, GeForce2 GTS). Table 1 shows parameters for the experiment.

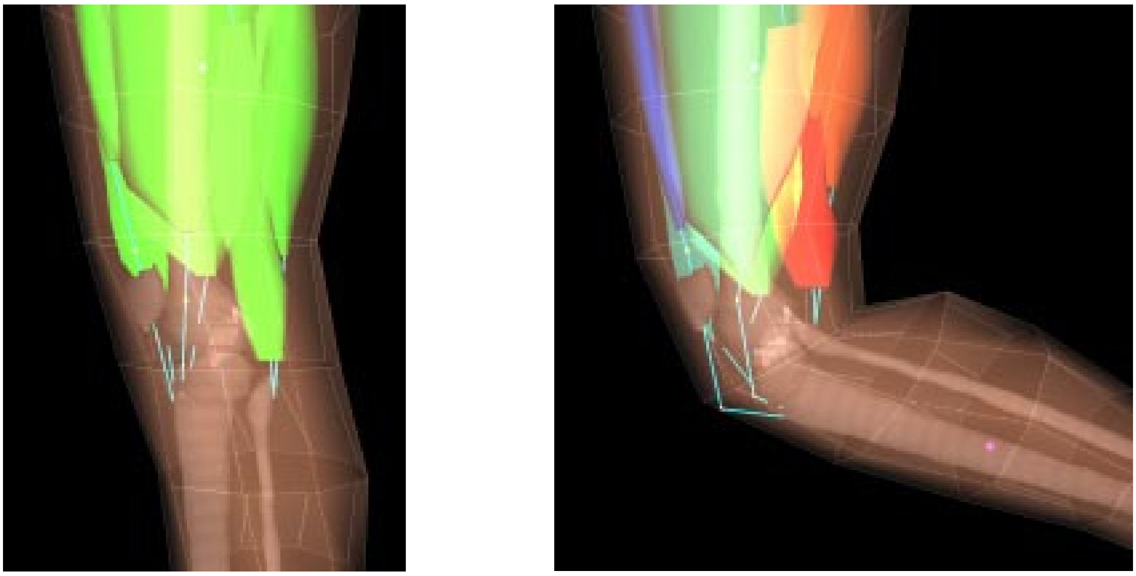
Table 1. Parameters on constrcted human body model.

| | |
|---|---|
| **Muscle part** | |
| Division level of a section shape | 12 |
| Division level of slice image | 20 |
| **Non-muscle part** | |
| Division level of a section shape | 9 |
| Division level of slice image | 20 |
| Number of elements | 270 |
| Number of points | 2160 |
| **Skeletal part** | |
| Number of polygons | 7780 |



(a) initial state (b) during moving motion (c) final state

Fig 8. Results of simulation.



(a) initial state (b) final state

Fig 9. A result of skin deformation around the knee joint.

## 5. CONCLUSIONS

In this paper, we proposed a method for the generation of human motion using skeletal muscle and skin represented by elastic object. We visualized a human motion based on muscle contraction of muscle and transformation of elastic tissue such as muscle or fatty tissue in motion. As an application of the human body model, we applied our proposed model to the lower limbs of human and generated an animation of the transformation. Our future works are a simplification of the shape of fatty tissue such as the feature of the original shape, use a model of the muscle contraction based on exercise physiology, generation of a cooperative motion by using plural muscles and so on.

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