ESTABLISHING A 3D HUMAN GAIT AND KNEE MODEL

Ying Zhu **Jim X. Chen**

Computer Science Department

George Mason University

4400 University Drive, Fairfax

VA 22030, U.S.A.

Email: yzhu1@gmu.edu, jchen@cs.gmu.edu

ABSTRACT

This paper presents a system interactively simulating the human gait cycle and knee joint. The goal of the system is to help understanding and analyzing the knee behavior during gait cycle. We establish a model of the lower half of the human body. The model can simulate human gait with quite high realism. Moreover, users can manipulate the model to demonstrate various normal or abnormal gait behavior. A 3D knee joint model is reconstructed from knee intersection images. This model gives highly realistic and more detailed simulation of the behavior of human femur and tibia during gait cycle. The model is physically-based as well as biomechanically-based.

Keywords: computer graphics, simulation, human model, gait, knee joint

1. OVERVIEW

Today's graphic software can generate highly realistic images. Rendering human figure and simulating human activities are still one of the most challenging issues in computer graphics. The difficulty of simulating humans comes from three research fields: computer graphics, biomechanics, and robotics. However, simulation of humans also has a large variety of applications in these areas.

This paper describes a system simulating the lower half of human body. The goal of the system is to simulate the human gait under normal condition as well as illness, and at the same time simulate the situation of knee joint. The various forces and pressures are analyzed and graphically demonstrated. The user can interactively manipulate the various parameters of the human body. This system can help doctors analyze the illness of knee joint and plan a surgery. It can also be used by patients to preview the effect of knee surgery.

The system is consisted of three parts: the simulation of human gait, the simulation of human tibia and femur, and the analysis of forces and pressures. The system is developed on Silicon Graphics workstation using OpenGL graphics library.

2. BACKGROUND

The simulation of human figures in computer graphics can be traced back to more than 20 years ago. The 3D human figure models arose independently from at least six different applications: [Badle93]

1) Crash simulation
2) Motion analysis
3) Workplace assessment
4) Dance or movement notation
5) Entertainment
6) Motion understanding

Beside those traditional applications, today virtual environments are becoming more and more useful in the areas such as training, education, etc. Simulating human motion is one of the most complicated topic in virtual environments. Therefore, a good human model is highly demanded in this area

In the area of medical visualization, volume visualization software is widely used to visualize the medical image obtained via radiology equipment. Such images can help doctors diagnose the diseases and plan certain surgeries. With the technology of virtual environment, a virtual surgery can be established to simulate the real surgery process. Such an environment will be highly useful in preparing complicated and sometimes dangerous surgeries. In such an environment, the model of certain body parts or certain organs rather than the complete human model is needed. Moreover, the partial model here requires more detailed and realistic visualization than general application.

When simulating human, there are three basic issues must be dealt with:

1) modeling,
2) rendering,
3) control.

The modeling concerns with how to represent human body. Normally the virtual human model is broken down into geometric segments. A segments can be 3D polygon comprised of points, edges, and faces of its surfaces. The segments of the figure are linked together. There are other representations of the segments, such as parametric descriptions.

A human model should looks like human. That is, the model must be visually realistic. Accurate skin models are difficult to build because the enfleshment of a figure is so dependent on individual physiology, muscle tone, muscle/fat ratio, and gender[Badle93]. The problem becomes worse when rendering human organs because the surface of different organs is more variable than skin. In addition, simulating human facial expressions is especially hard because expressions are very hard to describe.

A human model should also behave like human. This means that the visual human model should not only be physically-based but also biomechanically-based. This goal is also difficult to reach because such a model must allow interpolation and extrapolation. What we have now is a generic mechanism that incorporates possible empirical data up to the degree of error permitted for the task.

Several research efforts have been made to establishing realistic human models.

Jack is an interactive, programming graphics platform built by Department of Computer and Information Science, University of Pennsylvania [Badle93]. Jack is used for the definition, manipulation, animation, and human factors performance analysis of virtual human figures. The system allows the positioning of the body through an interactive program and has several built-in behaviors including balance, reaching and grasping, and a walking behavior that uses a simplified dynamic model and motion capture data. More importantly, Jack can be accessed by high level task control, various knowledge bases, task definitions and natural language instructions. Thus human activities can be visualized from high level task understanding and planning as well as by interactive specification.

Animation Lab of Georgia Institute of Technology develop a control of a simulated three-dimensional model of a human runner[Hodgi95]. The rigid body model has seventeen segments and thirty controlled degrees of freedom. The dynamic parameters of the simulation were computed using data measured from humans to produce a model that is biomechnically realistic within the constraints of a rigid body approximation. The locomotion control algorithms are developed to allow the model to run at a variety of speeds and to turn to face in an arbitrary direction on the plane.

Biomechanics Research lab of Johns Hopkins University is conducting several projects in biomechanic simulation and modeling. Among them, a discrete three-dimensional surface model of a cadaveric thorax is constructed using CAT scan images. Using the motion data obtained from electromagnetic tracking sensors, they can animate any passive motion of the shoulder girdle, and determine the relative locations and displacements of each of the shoulder structures.

Zona Japan Inc. developed a program (OASIS) which builds a Rigid Body Spring Model and analyzes the leg axial alignment, knee joint forces and knee pressure distribution, the collateral ligamentous tension, the involved leg loading axis and length, etc., in order to seek for the optimal knee corrective osteotomy. However, OASIS analysis is based on 2D graphical modeling rather than 3D modeling.

3. MODELING HUMAN GAIT

First, we establish a stick model to represent the lower extremity of the human model. The stick model consists of 15 parts:

1) Right Metatarsal Head V
2) Right Heel
3) Right Lateral Malleolus
4) Right Tibial Tubercle
5) Right Femoral Epicondyle
6) Right Greater Trochanter
7) Right ASIS
8) Left Metatarsal Head V
9) Left Heel
10) Left Lateral Malleolus
11) Left Tibial Tubercle
12) Left Femoral Epicondyle

13) Left Greater Trochanter
14) Left ASIS
15) Sacrum

Parts are linked together with lines. The initial animation data is obtained by attaching a marker to each part of a real human and tracking the movement of the marks. The data obtained are digitalized to series of 3D coordinators. Using these data, a stick human model is rendered in a 3D environment. The initial model can be animated to show the normal human gait cycle. See Figure 1.

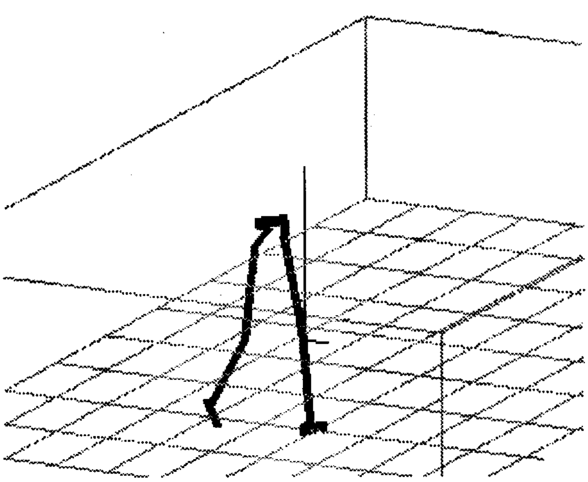

Figure 1. Stick Model in 3D environment

After the stick model is established, the next step is to build a system to analyze the force interactions during the gait cycle. The force interactions is very complicated and hard to measure during human gait cycle. So first we have to use certain level of simplification. The major force that push human to move is the ground reaction force. A major assumption is that the combination ground reaction force should be balanced by the body weight and muscle reaction. The detail of the analysis is left out for another paper. In general, we consider only the muscle around knee joint. The parameters we consider include body weight, body height, ground reaction force, and muscle reaction force, etc. The goal is to keep the body balanced. To achieve this, the mass center must be kept to a certain range while the model is in motion. The mass center should be right above the center point of the two foot when the model stands still. While the model is walking, the mass center are moving around that center point according to the gait cycle. Certain constraints are applied. While the mass center is moving, the body weight is distributed accordingly to two legs. The body weight distribution will also be used to calculate the pressure on the surface of tibia during the gait cycle.

With the analysis, we can calculate and show the forces on the knee in three dimensions during gait cycle. Besides, the dynamic distribution of the pressure on the tibia surface is also shown on a 2D image of the intersection of knee. These analysis, though primitive, can help understand the behavior of knee joint in various gait stages. For example, we can see which part of the tibia surface is enduring most pressure at certain gait stage. See Figure 2 and 3.

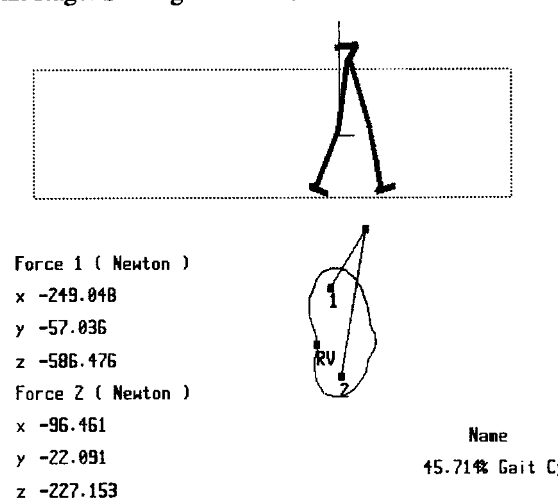

Figure 2 Analyzing forces on the knee

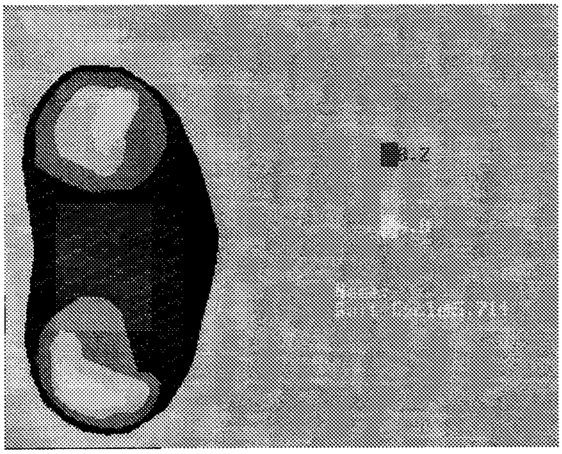

Figure 3 The pressure on the tibia surface

Several parameters of the human model can be manipulated by the user to demonstrate different body features. Users can interactively change the body weight, the length of femur, the length of tibia, and so on. More importantly, users can simulate different abnormal situation of knee which frequently happened to overweighted person. That is, user can change the angle between the of femur and tibia and simulating the consequent gait cycle by animating the human model. This simulation can also be used to see the result of surgery that corrects the angle between the femur and tibia.

4. SIMULATING KNEE JOINT

To analyze the situation of human knee joint during gait cycle, we need a more detailed and more realistic model of knee joint. There are several "raw" knee databases on the Internet, some are MRI image and some are intersection image, etc. However, it is hard to find a constructed 3D knee model. What we have to do is to reconstruct a 3D knee model from the raw knee database.

We use about 50 knee (vertical) intersection GIF images to reconstruct our knee model. By detecting the edge of the femur and tibia, we obtain series of points representing the edges of each intersection. After several smoothing process, we construct the corresponding points into polygons which represent the surfaces of the femur and tibia. The normal of each polygon is also calculated for shading purpose. Therefore, we reconstructed a 3D knee model with about 200 polygons. See Figure 4.

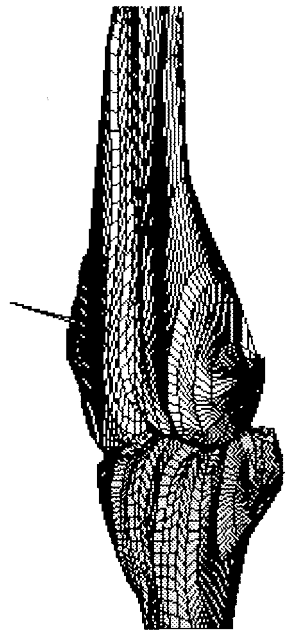

Figure 4 The 3D model of knee joint

The animation of the knee joint model should go with the simulation of gait cycle and the force/pressure analysis mentioned above. Again, we have to use some assumptions and simplifications. For example, we assume that both femur and tibia will rotate around the center of the space between femur and tibia. This may not be true at the real world, but at present stage, it is a reasonable way to show the behavior of the knee joint.

More realistic modeling of the knee joint behavior will need finite element methods which seek to reduce the continuous problem with an infinite number of degrees of freedom to a discrete problem possessing a finite number of degrees of freedom represented by a system of algebraic equations. Further research need to be done in the future for this ongoing research.

5. CONCLUSION

We present a system interactively simulating the human gait cycle and knee joint. The goal of the system is to help understanding and analyzing the knee behavior during gait cycle. We establish a model of the lower half of the human body. The model can simulate human gait with quite high realism. Moreover, users can manipulate the model to demonstrate various normal or abnormal gait behavior. A 3D knee joint model is reconstructed from knee intersection images. This model gives highly realistic and more detailed simulation of the behavior of human femur and tibia during gait cycle. The model is physically-based as well as biomechanically-based. Further research efforts are focused on making highly realistic appearance and behavior.

REFERENCES

[Badle93] Badler, N, Phillips, C, and Webber, B: *Simulating Humans, Computer Graphics Animation and Control*, Oxford University Press, New York, 1993

[Brude89] Bruderlin, A, Calvert, T: Goal-Directed, Dynamic Animation of Human Walking, *Computer Graphics*, Vol. 23, No. 3, pp. 233-242, 1989

[Hodgi95] Hodgins, J, Wooten, W, Brogan, D, O'Brien, J: Animating Human Athletics, *Siggraph'95*, 1995

[McMah84]McMahon, T: *Muscles, Reflexes, and Locomotion*, Princeton University Press, Princeton, 1984