Hand Grasping Motion Simulation for Astronauts Training

Qiang Guo and Yuqing Liu

China Astronaut Research and Training Center, Beijing 100094, China

Abstract. The objective of this paper is to find an appropriate method to realize the simulation of hand grasping motion for astronauts training. In this paper, on the basis of analysis and comparison of a variety of methods of hand grasping motion, we come up with an idea combined interpolation and inverse kinematics for hand motion simulation. An example demonstrates the method's effectiveness and practicability.

Keywords: Hand motion simulation, Interpolation methods, Inverse kinematics.

1 Introduction

In space mission, astronauts must finish a lot of operation. Before working in space, astronauts need to be trained on the ground. It's difficult to use physical methods on Earth to simulate the special space environment, such as weightlessness. Computer Simulation is developing very fast in recent years, many research institutes, Commercial Companies, Universities have done a lot of work on computer simulation and obtained great achievements. Therefore we consider using computer simulation to create virtual space working environment to assist astronauts to finish their trainings on the ground. In virtual environment virtual hand is used to substitute real hand to finish hand operation, which includes grasp, pull, push, and grip. If the operation can be realized in virtual environment, astronauts can practice their space work on the ground and finish their mission quickly and safely in space.

There are many ways of completing the simulation of hand grasping motion such as: Key frame, motion capture, kinematics and dynamics. Key frame is that the key picture which is designed by senior animator. The in-between frames are designed by assistant animator. With the development of computer graphics, the in-between frames are displaced by interpolation. Key frame depends on the skills of animator rather than the quality of animation system. Motion capture is using data glove or light mark to track people's motion. It converts the electrical signals into digital signals and inputs them into the model, and it can drive the model. But data glove has some technical problems by nature, sometimes the motion of virtual hand doesn't match with the real hand motion in practice. We may get unusual gestures. Furthermore, data glove is fragile to external interaction. Dynamics is that according to the strength and torque of the joints it can get the velocity and acceleration which conforms to physical constraints. But it will cost a lot to calculate the strength and torque. Kinematics comes from robotics[1]. People's body is regarded as rigid body. With the position and orientation of end-effector, the configuration of multibody can be obtained.

V.G. Duffy (Ed.): Digital Human Modeling, HCII 2007, LNCS 4561, pp. 101–109, 2007.

In this paper, we come up with an idea combined interpolation and inverse kinematics for hand motion simulation. During the period of real grasping, we use data glove to sampling several frames as key frames. To simulate the motion of hand grasping, we need 24 frames data of every joint in 1 second at least. The data of key frame is not enough for simulating the whole process of grasping. Therefore, we use interpolation to get the position of fingertip in-between frames, then calculate the joint angles of every joint in-between frames by Inverse kinematics solution. When we get the joint angles of all joints of the whole process, we can simulate the whole action of hand grasping.

2 Hand Structure Description

2.1 Skeleton Description of Human Hand

The proposed hand model is composed of a skeletal model. We describe the posture of a hand with the position of the bones and the joints in it. We model the hand skeleton with rigid links and joints.

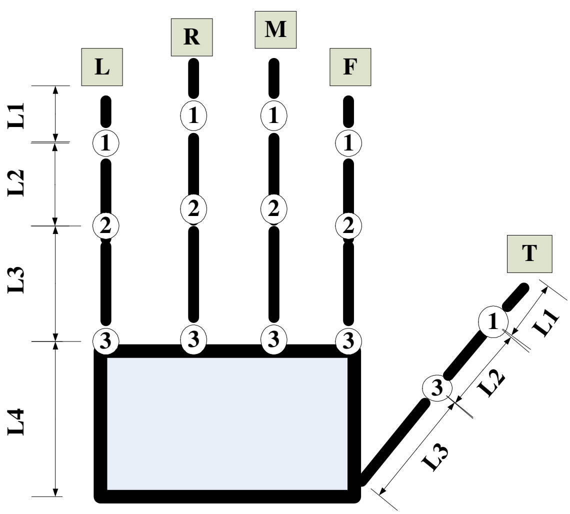


Fig. 1. Diagram for the hand skeleton

Fig.1 illustrates the hand skeleton[2]. We model the skeleton of human hand with a hierarchical structure that consists of rigid body links and joints.
T=Thumb, F=First finger, M=Middle finger,
R=Ring finger, L=Little finger.
1, 2, 3 represents the joints of distal phalange, middle phalange, proximal phalange.
L1=the length of distal phalange,
L2=the length of middle phalange,
L3=the length of proximal phalange,
L4=the length of metacarpal
The proportion of length of L1:L2:L3:L4=2:3:5:8

2.2 The Motion of Single Finger

Fig.2 shows the side view of single finger[3]. Letter A represents the position of the finger tip. Letter B represents the position of the joint of distal phalange. Letter C represents the position of the joint of middle phalange. Letter D represents the position of the joint of proximal phalange. The local reference frames of X_1BY_1、X_2BY_2、X_3BY_3 are based on the points of B, C, D. is the angle between L_1 and Y_1, is the angle between L_2 and Y_2 , is the angle between L_3 and Y_3 , is the angle between L_4 and Y.

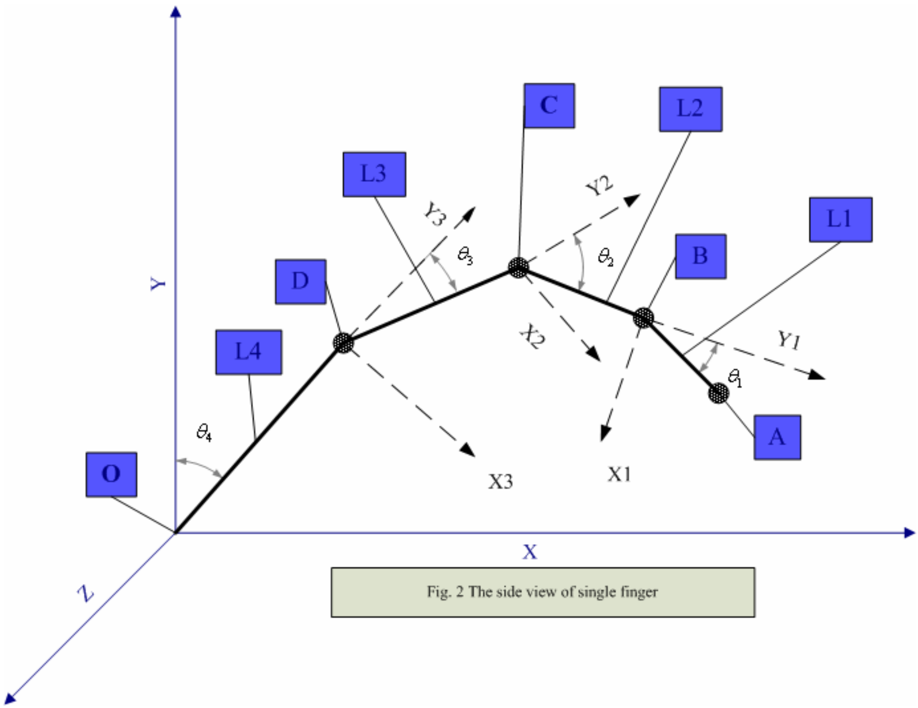


Fig. 2 The side view of single finger

2.3 Equation of Hand Motion

According to Fig.2, we get the equation of hand motion of hand tip. As follow:

$$\begin{bmatrix} X_A \\ Y_A \\ Z_A \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\theta_4 & \sin\theta_4 & 0 & L_4\cos\theta_4 \\ -\sin\theta_4 & \cos\theta_4 & 0 & L_4\sin\theta_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\theta_3 & \sin\theta_3 & 0 & L_3\cos\theta_3 \\ -\sin\theta_3 & \cos\theta_3 & 0 & L_3\sin\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\theta_2 & \sin\theta_2 & 0 & L_2\cos\theta_2 \\ -\sin\theta_2 & \cos\theta_2 & 0 & L_2\sin\theta 2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} L_1\cos\theta_1 \\ L_1\sin\theta_1 \\ 0 \\ 1 \end{bmatrix}$$

$$\begin{cases} X_A = L_1\sin(\theta_1+\theta_2+\theta_3+\theta_4) + L_2\sin(\theta_2+\theta_3+\theta_4) + L_3\sin(\theta_3+\theta_4) + L_4\sin(\theta_4) \\ Y_A = L_1\cos(\theta_1+\theta_2+\theta_3+\theta_4) + L_2\cos(\theta_2+\theta_3+\theta_4) + L_3\cos(\theta_3+\theta_4) + L_4\cos(\theta_4) \end{cases}$$

X_A, Y_A, Z_A is the position vector of the coordinate A. Because we just simulate the planar motion of single finger, so we set Z_A=1 in the matrix.

3 Interpolation and Inverse Kinematics

3.1 Interpolation Methods

In order to get the position of finger tip (A) in-between frame in Fig.2, we adopt interpolation methods. First, we get the value of X (A). Then, according to different interpolation methods, we get the value of Y (A). In this paper, we compare these interpolation methods such as Linear interpolation, Lagrange interpolation, Newton interpolation [4]. Linear interpolation is a basic method which it can obtain linear relationship between two sampling points to get the interpolation function. For example: the sampling point is $(x_0,y_0),(x_1,y_1)$, so the interpolation function is

$$L(x) = y_0 + \frac{y_1 - y_0}{x_1 - x_0}(x - x_0) \tag{1}$$

Lagrange interpolation polynomial is

$$L_n(x) = y_0 l_0(x) + y_1 l_1(x) + \cdots y_n l_n(x) \tag{2}$$

$$l_k(x) = \frac{(x - x_0)\cdots(x - x_{k-1})(x - x_{k+1})\cdots(x - x_n)}{(x_k - x_0)\cdots(x_k - x_{k-1})(x_k - x_{k+1})\cdots(x_k - x_n)} \tag{3}$$

Newton interpolation polynomial is

$$N_n(x) = a_0 + a_1(x - x_0) + a_2(x - x_0)(x - x_1) + \cdots + a_n(x - x_0)(x - x_1)\cdots(x - x_{n-1}) \tag{4}$$

Newton method divides into Difference Method[4] and Difference Quotient Method[3]. Difference Method is suitable for the condition of equidistant point $x_k = x_0 + kh$. When the sampling points are not equidistant point, we adopt Difference Quotient Method.

To compare Newton interpolation with Lagrange interpolation, Newton interpolation doesn't need to recalculate when adding a new point. According to the interpolation polynomials uniqueness theorem, Lagrange interpolation polynomial and Newton interpolation polynomial are the same interpolation polynomial. In order to make the calculation cost litter, we select Newton interpolation. In a word, we select Linear interpolation or Newton interpolation to get the value of Y.

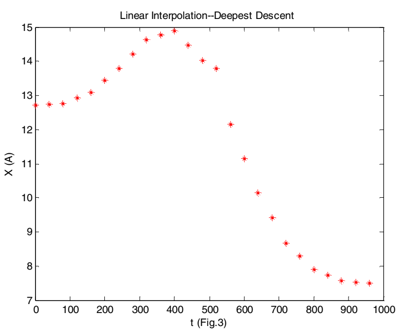
3.2 Inverse Kinematics Methods

After getting the data of finger tip (A), we can calculate the positions of B, C, D in-between frames. In order to get the data of B, C, D, we use Inverse dynamic solution. Inverse kinematics solution comes from robots. With the position of articulation link's tip, it gets other joints' data. In this paper, we compare three Inverse kinematics methods. They are Steepest descent Method, Newton Method, Quasi-Newton Method[5]. Steepest descent Method is that it starts from a point, selecting the orientation to make the object function f(x) decline quickly and converge at minimizer point fast. Newton Method is that to get the optimal solutions by iterative computations along Newton orientation $d = -\nabla^2 f(x)^{-1} \nabla f(x)$. It has many advantages: the speed of convergence is quickly; it can find the global optimal solution. But it has some shortcoming at the same time, such as if the initial point is far from minimize point, this method can not converge to the optimal point . In order to conquer this shortcoming, people proposed Quasi-Newton Method. Quasi-Newton Method is that to substitute the $\nabla^2 f(x)$'s inverse matrix with a matrix which doesn't has second derivative matrix. According to different construction matrix, there are many Quasi-Newton Methods. In this paper, we adopt DFP method.

4 Experiments and Analysis

In order to decide which methods of interpolation and inverse kinematics are suitable to this research, we conduct the following experiments. For the sake of predigesting the experiments, we just simulate planar motion of single finger. Here we assume that first finger, middle finger, ring finger, and little finger are in the same length. We take grasping motion for example. And the grasped object is not considered in this research. The period of motion is 1 second and sampling the data of key frames every 80 ms. The bound of $\theta_1, \theta_2, \theta_3, \theta_4$ is $0 \le \theta_1 \le 80^\circ$, $0 \le \theta_2 \le 95^\circ$, $0 \le \theta_3 \le 60^\circ$, $\theta_4 = 45^\circ$. To make the image smoothly, we need 24 frames of image. For the sake of getting 24 frames of image, firstly we use Linearity interpolation to get the value of X of A, then using Newton interpolation or Linear interpolation to get the value of Y of A, finally comparing the result. After getting the data of finger tip, we can calculate the data of B, C by Inverse kinematics solution. In this paper, we compare these three methods as follow: Steepest descent, Newton, Quasi-Newton.

Hardware platform: CPU Inter Core Cuo2 1.83G, Memory 1G. Software platform Windows XP, Matlab 7.1 and Visual C++ 6.0.



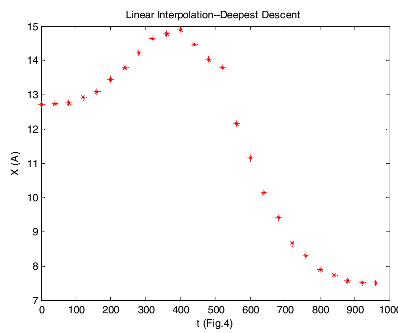
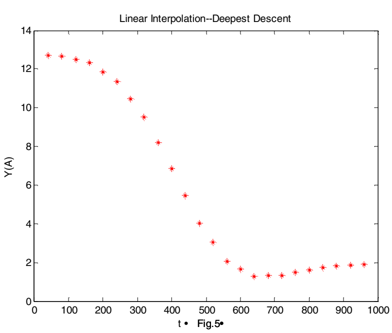
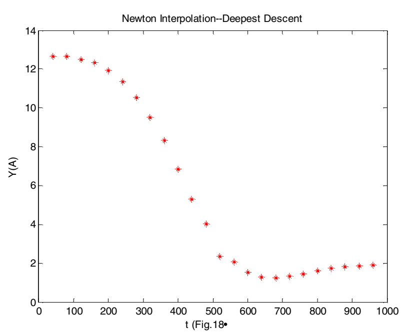
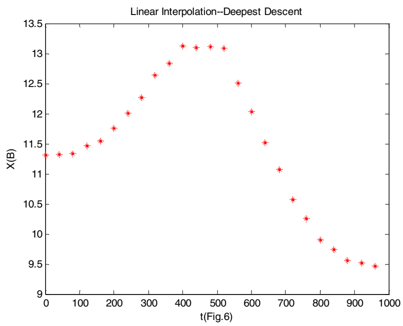
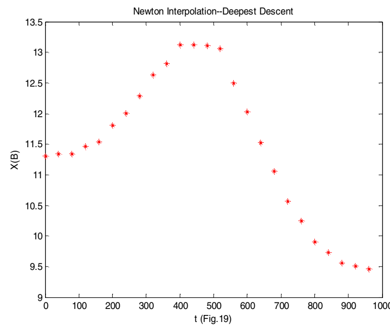


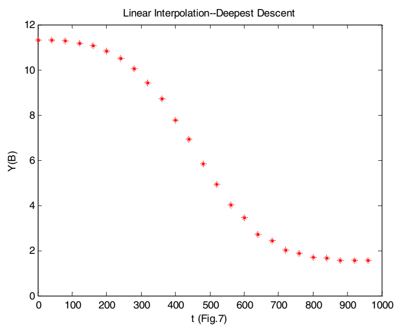
Fig.3 and Fig.4 is obtained by Linear Interpolation. They show the relationship of X between insert point(X, Y) and key frame point(X_0, Y_0), (X_1, Y_1). $X=(X_0+X_1)/2$.

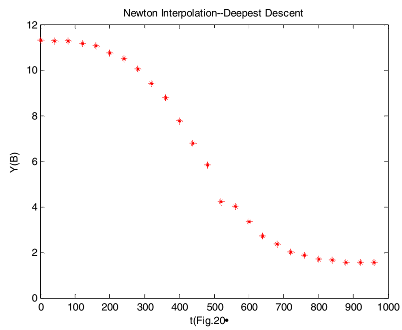


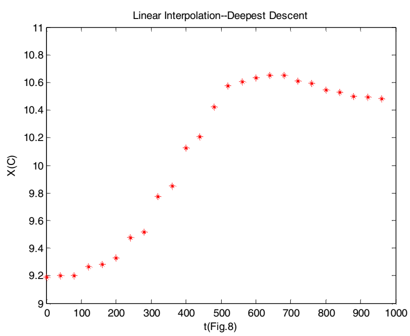


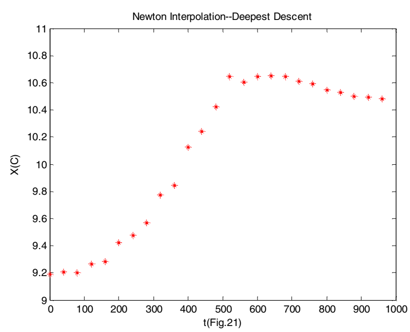

Linear Interpolation--Deepest Descent
X(B)
t(Fig.6)

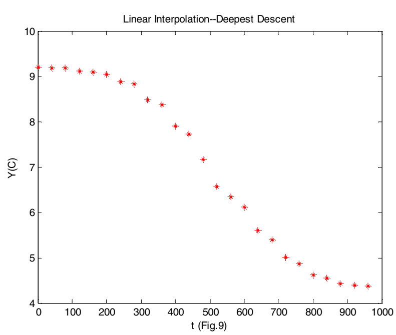

Newton Interpolation--Deepest Descent
X(B)
t (Fig.19)

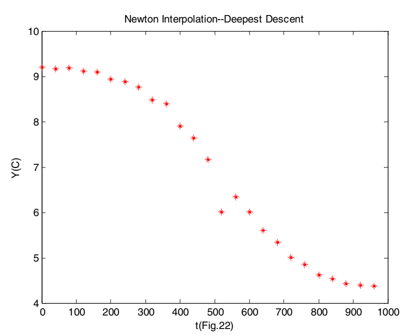

Linear Interpolation--Deepest Descent
Y(B)
t (Fig.7)


Newton Interpolation--Deepest Descent
Y(B)
t(Fig.20•

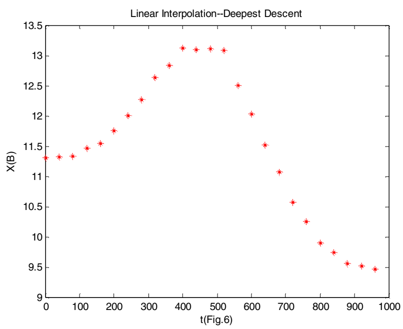

Linear Interpolation--Deepest Descent
X(C)
t(Fig.8)

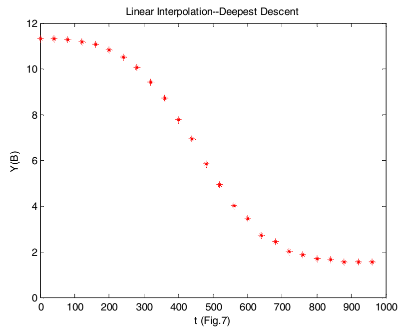

Newton Interpolation--Deepest Descent
X(C)
t(Fig.21)

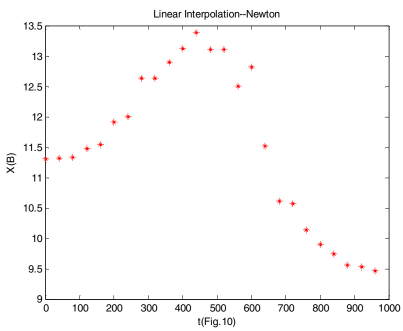

Linear Interpolation--Deepest Descent
Y(C)
t (Fig.9)

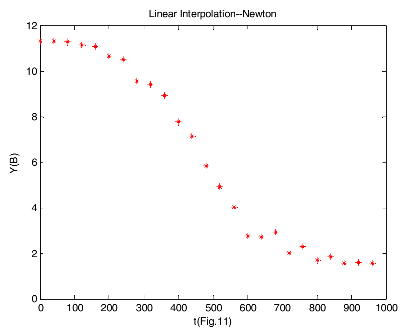

Newton Interpolation--Deepest Descent
Y(C)
t(Fig.22)

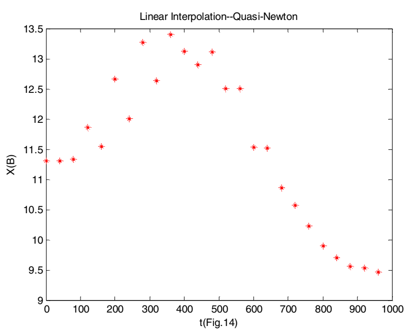
In order to get the value of Y, Fig.5 adopts Linear Interpolation and Fig.18 adopts Newton Interpolation. In Fig.6-Fig.9 the data of B and C is obtained by Deepest Descent Method which is based on the data of A in Fig.3 and Fig.5. In Fig.19-Fig.22 the data of B and C is also obtained by Deepest Descent Method which is based on the data of A in Fig.4 and Fig.18 .To compare these pictures, we find the result of Linear Interpolation and Newton Interpolation which is based on Deepest Descent Method has little difference.











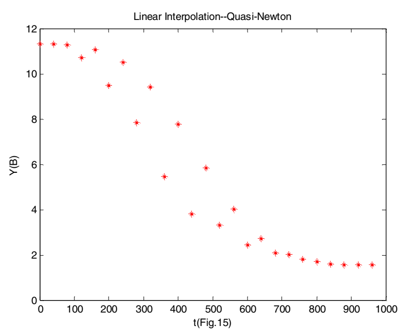
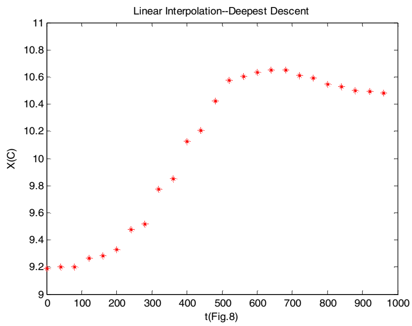
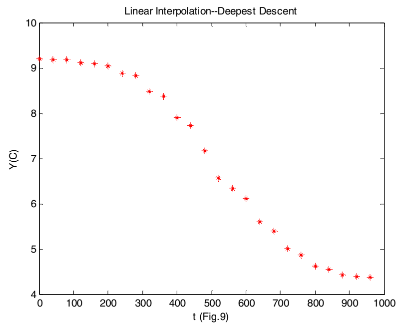
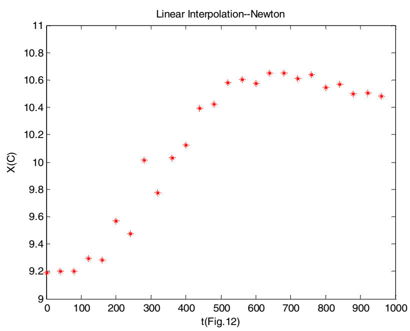
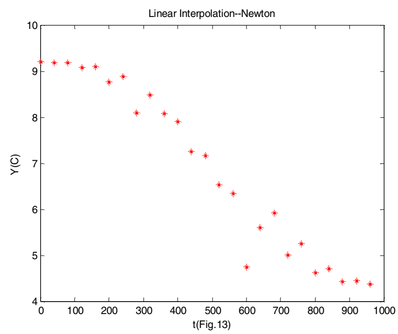


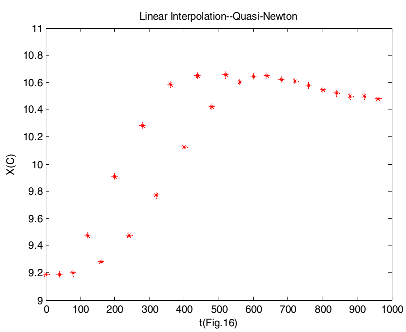
Fig.6-Fig 17 is based on the data of A which is obtained by Linear interpolation. With the image we conclude that the data of Steepest descent Method is accurate, the image is smooth. But the data of Newton Method, Quasi-Newton Method is unstable and has many fluctuations. The reason why the Newton Method doesn't work very

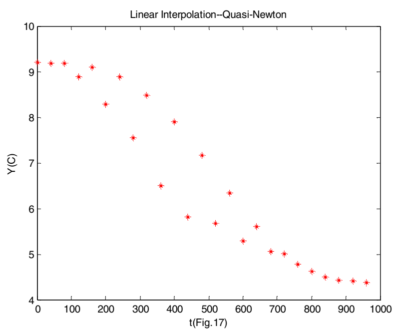






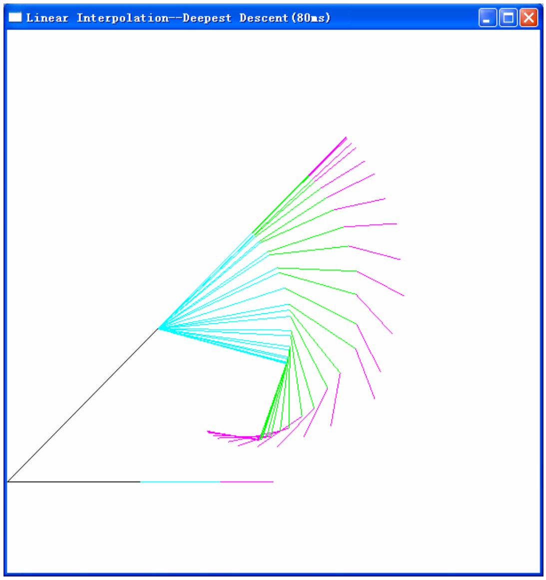






well is that Newton orientation is not descendent orientation. Furthermore, although the object function is descending, the result is not the optimal solution along Newton orientation. When the initial point is far from the target point, the result with Newton Method, Quasi-Newton Method is not good. To make the result better, let the initial point get close to the target point.

The picture is drawed by the data of Linear Interpolation—Deepest Descent. It reflects the process of hand grasping motion. From the picture, we find it has a little difference with real hand grasping motion. This means we could use this method to simulate the real action in some areas. The methodology proposed in this paper is effective and practically.



5 Conclusion

The example demonstrates that interpolation methods affect the result a little, but the Inverse kinematics methods affect the result a lot. If you select different methods, the result is different. Steepest descent Method is suitable for hand grasping motion and iterative calculation cost a little. Quasi-Newton's Method iterative calculation also cost a little, but the result is not good .Newton Method's iterative calculation cost a lot and the result is not good, it depends on many conditions such as Newton orientation and the position of initial point. The methodology proposed in this paper is effective and practically.

References

1. Cai, Z.: Robotics, Qing Hua publishing company (2000)
2. Yasumuro, Y., Chen, Q.: Three-dimensional modeling of the human hand with motion constraints. Image and Vision Computing 17, 149–156 (1999)
3. Yang, Q., Zhang, L.: Research on the rule of the process of human finger grasping. China Mechanism Engineering 2004-15-13
4. Burden, R.L., Douglas Faires, J.: Numerical Analysis, 7th edn. Higher Education Press (2005)
5. Chen, B.: Optimization Theory and Algorithm, Qing Hua publishing company (2005)