Motion Estimation of Elastic Articulated Objects from Image Points and Contours

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Abstract. This paper presents two new methods of elastic articulated objects modeling and motion estimation based on a new revolving conic surface. The deformation of human body surfaces can be represented by adjusting only one or two deformation parameters for each limb. Then, the 3D deformation and motion parameters are estimated by corresponding 2D image points and contours from a sequences of stereo images.

1 Introduction

Elastic articulated objects are the combination of articulated objects and nonrigid objects. Human body is a typical elastic articulated objects. In the past researches, a number of method for human deformable body modeling have been proposed. Plankers[1] developed a framework for 3D shape and motion recovery of articulated deformable objects. Smooth implicit surfaces, known as metaballs, are attached to an articulated skeleton of the human body and are arranged in an anatomically-based approximation. Sminchisescu [2] built a human body model which consists of kinematic ‘skeletons’, covered by ‘flesh’ built from superquadric ellipsoids. A typical model has 9 deformable shape parameters for each body part. Apuzzo[3] presents simplified Model of a Limb. Only three ellipsoidal metaballs are attached to each limb skeleton. Each limb has twelve deformation parameters.

Our research focuses on two major points: 3D human body modeling and its parameters determination from images. The proposed human limb model is composed of two layers: a skeleton layer and a body surface layer. The body surface layer is expressed by revolving conic surfaces. We can deform the body surface layer during animation by adjusting only one or two deformation parameters for each human limb. 3D human arm parameters determination includes the skeleton motion parameters estimation and the deformable surfaces deformation parameters determination.

2 Establishment of Revolving Conic Surfaces and Human Skeleton

A 3D conic curve can be obtained by intersecting a conic surface with a plane that does not go through the vertex of the conic surface or by intersecting two conic surfaces. Consequently, a 3D conic curve S can be specified by the system of equations

$$\begin{cases} f_1(x_s, y_s, z_s) = 0 \\ f_2(x_s, y_s, z_s) = 0 \end{cases} \quad (1)$$

Where the equation $f_1(x_S, y_S, z_S)$ is a 3D conic surface and the equation $f_2(x_S, y_S, z_S)$ is a 3D plane or a 3D conic surface.

See Fig. 1, let $P_0=(x_0, y_0, z_0)$ be a point on the 3D straight line L which can represents the skeleton of a limb. Let $e(m, n, p)$ be a non-zero vector parallel to the straight line L , then the straight line L has the canonical equation of the form

$$\frac{x-x_0}{m} = \frac{y-y_0}{n} = \frac{z-z_0}{p} = t \quad (2)$$

Let the curve S be a 3D conic curve. We can obtain a revolving conic surface by revolving the 3D conic curve S around the 3D straight line L . A revolving conic surface can represent the human body surface of a limb. It is defined as follows: Let $P(x, y, z)$ be a arbitrary point on the revolving conic surface. Let the plane U , passing through the point P and perpendicular to the straight line L . The point $P_S(x_S, y_S, z_S)$ is the intersection of the plane U and the conic curve S . The point $O(x_L, y_L, z_L)$ is the intersection of the plane U and the straight line L . Then the plane U , passing through the point P, P_S, O and perpendicular to the straight line L , has the equation of the form

$$m(x-x_S) + n(y-y_S) + p(z-z_S) = 0 \quad (3)$$

The points P, P_S, O satisfy the relation $\overline{PO} = \overline{P_S O}$, namely

$$(x-x_L)^2 + (y-y_L)^2 + (z-z_L)^2 = (x_S-x_L)^2 + (y_S-y_L)^2 + (z_S-z_L)^2 \quad (4)$$

Since the point $P_S(x_S, y_S, z_S)$ lies on the conic curve S , its coordinates satisfy the equation (1). Hence, the system of equations (1),(3),(4) are the revolving conic surface.

Fig. 1. 3D Revolving conic surface

Fig. 2. Stereo coordinate system of a 3D conic curve

The human skeleton system is treated as a series of jointed links (segments), which can be modeled as a articulated body. We describe the body as a stick model consisting of a set of fifteen joints (plus the head) connected by fourteen body segments [4].

3 Human Arm Modeling and Its Parameters Determination

3.1 Modeling from Image Points and Its Deformation Parameters Determination

A 3D conic curve S can be specified by the system of equations

$$\begin{cases} f_1(x_S, y_S, z_S) = (a_0 + a_1 x_S + a_2 y_S + a_3 z_S)(b_0 + b_1 x_S + b_2 y_S + b_3 z_S) - \rho(u_0 + u_1 x_S + u_2 y_S + u_3 z_S)^2 = 0 \\ f_2(x_S, y_S, z_S) = f_{ABC}(x_S, y_S, z_S) = a \cdot x_S + b \cdot y_S + c \cdot z_S + d = 0 \end{cases} \quad (5)$$

The first equation is a 3D conic surface. The second equation is a plane passing through the vertices A, B, C. Hence, the system of equations (3),(4),(5) are a revolving conic surface, which can represent deformable human body surface.

The input of our system of equations is (x,y,z), 3D coordinate of one arbitrary feature point on the revolving conic surface. The expected output is the parameter ρ that describes the model's deformation. Hence the deformation of one limb can also be determined with three feature points, two of them are points A, B and the third is a arbitrary point on the deformable surface. This is also a nonlinear system of equations, which can be solved by the Levenberg-Marquardt nonlinear least squares.

3.2 Modeling from Contours and Its Deformation Parameters Determination

The geometry of the stereo is shown in Fig. 2. Suppose there is a 3D conic curve S in space. Its two projections on two images are represented by two quadratic form C_1 and C_2 [5]:

$$C_i(x_i, y_i) = X_i^T Q_i X_i = 0 \quad i = 1, 2 \quad (6)$$

where $X_i = [x_i, y_i, 1]^T$. (x_i, y_i) are the 2D coordinates in two images.

Let $X_w = [x_w, y_w, z_w, 1]^T$. (x_w, y_w, z_w) is a point in the world coordinate system. Then X_i and X_w are related to each other through the following equation:

$$z_{ci} X_i = M_i X_w \quad (7)$$

Substituting the equation (7) into the equation (6), we obtain the representations of the two cones W_1 and W_2 passing through the 2D conic curve C_1 (or C_2) and the camera center o_1 (or o_2):

$$\begin{cases} W_1(x_w, y_w, z_w) = X_w^T M_1^T Q_1 M_1 X_w = 0 \\ W_2(x_w, y_w, z_w) = X_w^T M_2^T Q_2 M_2 X_w = 0 \end{cases} \quad (8)$$

The 3D conic curve S in space is the intersection curve of two cones W_1 and W_2 . Hence, the system of equations (3),(4),(8) are a revolving conic surface, which can represent deformable human body surface.

We fit one 2D conic curve to the contour of each limb in left or right images. We directly minimize the implicit form of a 2D conic curve to determine the best values of the deformation parameter ρ . We can get two deformation parameters ρ_{i-left} and $\rho_{i-right}$ of each limb at a time.

3.3 Motion Parameters Estimation of Human Skeleton

We pick up the centers of the circles that pass through the vertices of the conic curve and are tangent to the boundary of each limb. We regard the points, lying on the sticks that linking these centers, as the skeleton points. The motion of one limb can be estimated with only three skeleton points correspondences[6].

4 Experiment Results

The controlled scenes are acquired by using a stereoscopic vision system. In the experiment of modeling from image points, six paper markers have been stucked on the

body surfaces of the arm, three on the upper arm and three on the lower arm. On each limb, we detect three paper markers. The 3D coordinates of these feature points, acquired from the image planes, are used as the input data for determining the deformation parameters of two limbs. The estimated results are listed in Table 1 that describe the model’s deformation. ρ_1 and ρ_2 are the estimated deformation parameters of the two limbs respectively. In the experiment of modeling from image contours, the human arm is nicely distinguishable against the simpler background using edge detection. The estimated results are listed in Table 2 that describe the model’s deformation. Fig. 3 depicts the movement of human arm. We use OpenGL code to visualize the recovered 3D model.

Fig. 3. Left first row: original images of left camera. Left second row: estimated 3D models from image points. Right first row: corresponding target contours and conic curve fitting results. Right second row: estimated 3D model from image contours.

Table 1. Estimated deformation parameters of modeling from image points

deformation parameter	Frame1	Frame2	Frame3	Frame4
ρ_1	0.5639	0.7995	1.5288	2.3358
ρ_2	0.0727	0.1775	0.0736	0.0052

Table 2. Estimated deformation parameters of modeling from image contours

Deformation parameter	Frame1	Frame2	Frame3	Frame4
$\rho_{1,left}$ (upper arm)	81.2541	65.7300	30.2082	12.5882
$\rho_{1,right}$ (upper arm)	-41.3898	-16.4795	-9.7585	-0.2843
$\rho_{2,left}$ (lower arm)	-343.2955	-189.1445	-0.9332	-0.2642
$\rho_{2,right}$ (lower arm)	25.0255	39.0449	18.7115	14.5475

5 Conclusion

We have presented two new methods of elastic articulated objects (human bodies) modeling based on a new revolving conic surface. Our experiments have demonstrated that our model can express the deformation of human body surfaces properly.

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