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3D Face Recognition Using Quadrics With Perturbations

This paper presents a method for 3D face reconstruction into a limited number of analytical perturbation functions from stereo images. From a depth map, we generate a 3D model of the face. This model enables us to improve the quality of 3D face recognition using set-theoretic operation of subtraction.

Key words: Three-dimensional recognition, images, voxelization, voxels

Introduction

Three-dimensional (3D) recognition is one of the most progressive methods [1]. The essence of the method can be briefly described as follows. Lines are projected onto the face, and a 3D model of the face is reconstructed on the basis of these lines. In this model, special points, which form a feature vector, are identified. The method offers the following advantages: continuous and secret identification of the object; it is impossible to use a fake object; twins can be distinguished; weak dependence on head turning (the range of head deflection is substantially increased); weak dependence on external illumination, hair, and face turgidity in the case of a correct choice of the light range. Three-dimensional identification can be used in darkness, and it remains effective even in the case with head turning up to 90◦. The drawbacks of the method are the necessity of using special equipment and high computational requirements (hardware implementation of algorithms), which increases the cost of the system. The recognition system performs a number of actions during the identification process. The face image can be obtained by means of digital scanning of an existing 2D picture or by using a video image. When the face is detected, its "alignment" is performed, i.e., the system determines the head size and position. As was already mentioned, the face can be recognized with head turning angles up to 90◦, while the greatest angle of head turning for 2D identification is 35◦. During face measurements, the system calculates the curves with a scale smaller than one millimeter and generates a reference sample, and then a special program converts the reference sample into a digital code. Thus, each face is finally presented in a digital form. After that, the images are compared. All faces have some specific features, humps and dimples, which make all faces unique. The key features are registered as nodal point (each human being has approximately 80 nodal points on the average). The distances between these points are used by the program to compare different faces. The most relevant distances are the distance between the eyes, nose width, depth of eye pits, shape of cheek bones, and length of the jaw line.

This paper describes the method of face recognition with the use of analytical perturbation functions [2] and the set-theoretic operation of subtraction.

Description of method

A calibrated stereo pair is used for calculating 3D points on the face (Fig. 1). Let us assume that we have two projective matrices Mi

$$\begin{pmatrix} u_i s_i \\ v_i s_i \\ s_i \end{pmatrix} = M_i \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \qquad (1)$$

where x, y, z are three-dimensional coordinates of the point, ui and vi are their projections in the image i, and si is the scale factor. The stereo pair is characterized by the following parameters: the points of the image planes E1 = (u1, v1) and E2 = (u2, v2), and the point of the world coordinate system P = (x, y, z). Using the calibrated stereo pair for the face, we calculate the depth map (Fig. 2) by the correlation algorithm. There are two basic types of algorithms for calculating 3D data on the basis of stereo images: feature-based and area-based algorithms [3, 4], Feature-based algorithms detect various elements of interest (ribs, segments, and contours) in the images and find such elements for two or more points of observation. These algorithms ensure fast operation and use a moderate number of pixels. However, these algorithms cannot guarantee successful search for chosen primitive elements.

Therefore, in this work we use an area-based algorithm with correlation of image intensity levels [4]:

Here I1 and I2 are the intensities of the left and right images, ‾I1 and ‾I2 are their mean values, dx and dy are the displacements along the epipolar line, and s = max(0.1 − c) is the correlation estimate.

There are two images of the stereo pair (see Fig. 1); scanning of these images provides information about the depth buffer (depth map) in accordance with Eq. (2) and the algorithm described in [4].

$$s=\frac{\sum_{i,j}\left((A(i,j)-B(i,J)\right)^2}{\sqrt{\left(\sum_{i,j}(A(i,J))^2\right)\left(\sum_{i,j}(B(i.j))^2\right)}} \qquad (2)$$

$$A(i,J)=(I1(x+i,y+j)-\vec{I}1),$$
$$B(i,j)=(I2(x+dx+i,y+dy+j)-\vec{I}2$$

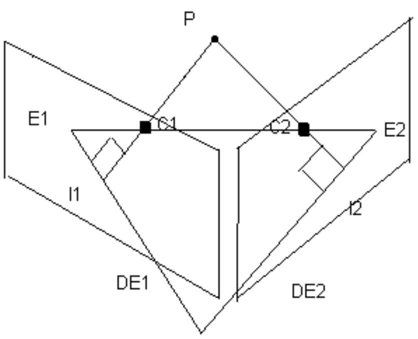


Figure 1. Stereo pair

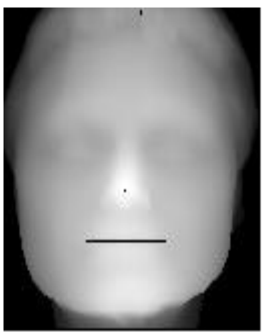


Figure 2. Depth map

Then the surface based on perturbation functions are calculated by using the data from the depth buffer.

Conversion to functionally based objects

Quadric's equation is

$$Q=\begin{pmatrix} q_{xx} & \frac{q_{xy}}{2} & \frac{q_{xz}}{2} & \frac{q_x}{2} \\ \frac{q_{xy}}{2} & q_{yy} & \frac{q_{yz}}{2} & \frac{q_y}{2} \\ \frac{q_{xz}}{2} & \frac{q_{yz}}{2} & q_{zz} & \frac{q_z}{2} \\ \frac{q_x}{2} & \frac{q_y}{2} & \frac{q_z}{2} & q \end{pmatrix} \qquad (3)$$

Value of function according to (3) in arbitrary point $P[x,y,z]$ will be:

$$Q(P[x,y,z])=q_{xx}x^2+q_{yy}y^2+q_{zz}z^2+q_{xy}xy+ \\ +q_{xz}xz+q_{yz}yz+q_x x+q_y y+q_z z+q \qquad (4)$$

Since value Q on surfaces is zero, for finding of coefficients of quadric using 9 $P_1[x_1,y_1,z_1]\div P_9[x_9,y_9,z_9]$ points, get single-line equation system.

$$\begin{cases} Q(P_1)=0 \\ Q(P_2)=0 \\ \dots \\ Q(P_i)=0 \\ \dots \\ Q(P_9)=0 \end{cases} \qquad (5)$$

By (4) we have:

$$\begin{cases} q_{xx}x_1^2+q_{yy}y_1^2+q_{zz}z_1^2+q_{xy}x_1y_1+q_{xz}x_1z_1+ \\ q_{yz}y_1z_1+q_x x_1+q_y y_1+q_z z_1+q=0 \\ \\ q_{xx}x_2^2+q_{yy}y_2^2+q_{zz}z_2^2+q_{xy}x_2y_2+q_{xz}x_2z_2+ \\ +q_{yz}y_2z_2+q_x x_2+q_y y_2+q_z z_2+q=0 \\ \dots \\ q_{xx}x_i^2+q_{yy}y_i^2+q_{zz}z_i^2+q_{xy}x_iy_i+q_{xz}x_iz_i+ \\ +q_{yz}y_iz_i+q_x x_i+q_y y_i+q_z z_i+q=0 \\ \dots \\ q_{xx}x_9^2+q_{yy}y_9^2+q_{zz}z_9^2+q_{xy}x_9y_9+q_{xz}x_9z_9+ \\ +q_{yz}y_9z_9+q_x x_9+q_y y_9+q_z z_9+q=0 \end{cases} \qquad (6)$$

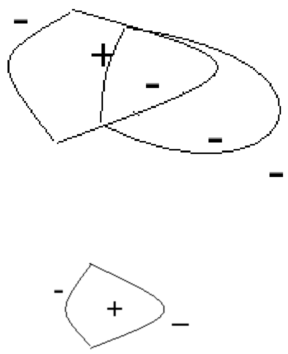
$$([T]\cup[B])\begin{bmatrix} q_{xx} \\ q_{yy} \\ q_{zz} \\ q_{xy} \\ q_{xz} \\ q_{yz} \\ q_x \\ q_y \\ q_z \end{bmatrix} = \begin{bmatrix} K \\ K \\ K \\ K \\ K \\ K \\ K \\ K \\ K \end{bmatrix} (7)$$

$$T = \begin{bmatrix} x_1^2 & y_1^2 & z_1^2 & x_1y_1 \\ x_2^2 & y_2^2 & z_2^2 & x_2y_2 \\ x_3^2 & y_3^2 & z_3^2 & x_3y_3 \\ x_4^2 & y_4^2 & z_4^2 & x_4y_4 \\ x_5^2 & y_5^2 & z_5^2 & x_5y_5 \\ x_6^2 & y_6^2 & z_6^2 & x_6y_6 \\ x_7^2 & y_7^2 & z_7^2 & x_7y_7 \\ x_8^2 & y_8^2 & z_8^2 & x_8y_8 \\ x_9^2 & y_9^2 & z_9^2 & x_9y_9 \end{bmatrix}$$

$$B = \begin{bmatrix} x_1z_1 & y_1z_1 & x_1 & y_1 & z_1 \\ x_2z_2 & y_2z_2 & x_2 & y_2 & z_2 \\ x_3z_3 & y_3z_3 & x_3 & y_3 & z_3 \\ x_4z_4 & y_4z_4 & x_4 & y_4 & z_4 \\ x_5z_5 & y_5z_5 & x_5 & y_5 & z_5 \\ x_6z_6 & y_6z_6 & x_6 & y_6 & z_6 \\ x_7z_7 & y_7z_7 & x_7 & y_7 & z_7 \\ x_8z_8 & y_8z_8 & x_8 & y_8 & z_8 \\ x_9z_9 & y_9z_9 & x_9 & y_9 & z_9 \end{bmatrix}$$

Solution of equation system (7) with free member q (it will equal -K) under given $P_1[x_1, y_1, z_1] \div P_9[x_9, y_9, z_9]$ will be 9 sought coefficients $q_{xx}, q_{yy}, q_{zz}, q_{xy}, q_{xz}, q_{yz}, q_x, q_y, q_z$.

Given a 3D poins from depth map, we convert the data to a volumetric representation to use as a base for creating the function-based surface by means of strict mathematical calculation without iterations [5].



G1: f1(X) >=0

Figure 3. Set-theoretic operation of subtraction

As a result, we obtain a 3D mask of the face (see Fig. 3). Using three anthropomorphic points, we construct a coordinate system that ensures a possibility of superposition of the tested masks; finally, certain parts are cut off by a clipping plane for equalization of the volumes.

Applying the set-theoretic operation of subtraction (Fig. 3)

$$F(x,y,z) = F_1(x,y,z) \setminus F_2(x,y,z) (8)$$

we determine the set of 3D points (voxels) belonging to the object

$$G_1 : f_1(x,y,z) \geq 0$$

$$G_2 : f_1(x,y,z) \geq 0$$

$$G_3 = \Phi_i(G_1, G_2)$$

To find 3D points, voxelization of the remaining part of the volume after the subtraction is needed. Based on this fact, we assume that the observer looks along the Z axis. We have to obtain the projection of the remaining part onto the XY plane, which should be the final set of values. Therefore, the entire cube is divided into "bars" so that each bar corresponds to a pixel in the image. Each bar is divided along the Z axis, thus, forming a set of voxels. Binary division of the bar along the z coordinate is performed (let us call it the upper-level voxel). The voxel at the ith level is divided into two identical parts (into two voxels of the nest detail level). After that, each part is recursively divided for the purpose of searching for voxels that belong to the remaining part being considered. The vector of the nearest voxel end to the observer is equal to the half-sum of the vectors of the near and far ends of the voxel of the previous level of division, and the vector of the far end of the voxel is equal to the vector of the far end of the voxel of the previous level of division:

$$P_{ni}^1 = P_{ni-1}, P_{fi}^1 = (P_{ni-1} + P_{fi-1})/2 \quad (9)$$

$$P_{ni}^2 = (P_{ni-1} + P_{fi-1})/2, P_{fi}^2 = P_{fi-1}.$$

$$V_i^1 = \{P_{ni}^1, P_{fi}^1\}, V_i^2 = \{P_{ni}^2, P_{fi}^2\},$$

Here V 1 i and V 2 i are the voxels of the ith level of recursion (the nearest voxel to the point and the farthest voxel from the observation point, respectively); P1 ni and P2 f i are the coordinates of the near and far ends of the voxel at the ith level of recursion.

The smaller the number of voxels left, the greater the similarity of the tested objects.

Conclusions

A method of face recognition based on scalar perturbation functions and the set-theoretic operation of subtraction is proposed. Three-dimensional masks were used for face recognition. This method differs from available 3D methods by the fact that it involves not only all points of the surface in the recognition procedure, but also the volume of the tested mask. The method offers the following advantages: manual initialization of the process is not needed; three-dimensional morphing solves the problem of face recognition on the basis of different facial expressions; face recognition on the basis of only some part of the image is possible; face reconstruction is completely automated. The computation time is approximately 900 ms with a resolution of 640 × 480 pixels with the use of the Intel Core i7-2700K processor (8 MB cache memory, 3.90 GHz).

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У статті запропоновано метод 3D-реконструкції обличчя шляхом використання аналітичних функцій збурення від стереозображень. 3D-модель обличчя створюється з карти висот. Ця модель дозволяє покращити якість 3D розпізнавання обличчя з використанням теоретико-множинних операцій віднімання.

Ключові слова: 3-D розпізнавання, зображення, вокселізація, воксель

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В статье предложен метод 3D-реконструкции лица путем использования аналитических функций возмущения от стереоизображений. 3D-модель лица создается по карте высот. Данная модель позволяет улучшить качество 3D распознавания лица с ипользованием теоретико- множественных операций вычитания.

Ключевые слова: 3-D распознавание, изображение, вокселизация, воксель