

Invited Paper

Characterization of object shapes by singular points: with an application to the feature extraction of human facial expressions

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ABSTRACT

The surface singular points of a function defined on an object surface represents the topological structure of the object. This paper proposes and reports the implementation and testing of a new method to characterize the facial expressions by extracting the singular points of the face. As the input, the surface normals of human faces obtained by the lighting switch photometry method are used. An averaging filter is used to reduce the noise in the raw data. The experimental results demonstrate the usefulness of the proposed method to characterize facial expressions.

INTRODUCTION

The importance of human face recognition as a new means of human-machine communications has been increasing rapidly. There are two main subjects in this field; One is the identification of persons [13, 6] and the other is the analysis of human facial expressions [11, 2].

Most of the researches on the analysis of facial shapes have been based on the two-dimensional (2D) data; characteristic regions such as a nose, eyes and a mouth are extracted from 2D facial images and their shapes, locations and lengths are analyzed [9, 15, 16]. Such 2D methods can analyze faces quickly. The results, however, are influenced by the orientation of the face and the illumination. For this reason, the 2D methods cannot extract

stable information from the facial images.

Recently, research on the analysis of 3D data has begun. The methods extract and trace the characteristic points and regions such as the top of a nose [14], the markers attached to a face [1, 7, 8], the isodensity maps [10] and the surface curvature for face identification computed from the Moiré topography [4]. However, the number of characteristic points obtained by these methods is small and hence it has been impossible to analyze detailed facial shapes such as the wrinkles on the cheeks.

To analyze the detailed shapes, the Lighting Switch Photometry method [3] is used to obtain the data in this paper. This method provides the normal vectors at each point on the face. Using the normal vectors, we compute the singular points and use them for representing the characteristics of the facial expressions. This enables us to characterize subtle changes in the facial expressions.

FACIAL SHAPE CHARACTERIZATION BY THE SINGULAR POINTS

In the case of manufactured objects, their shapes can be represented by using combinatorial topology in terms of vertices, edges and faces. In the case of a human face, we cannot find such characteristics to describe the shape. For this reason, contemporary methods use characteristic points such as the top of the nose or marks attached to the face as is described previously. Recently, Shinagawa, Kergosien and Kunii [17] have proposed the characteristics that can be used instead of vertex-edge-face description: the singular points of a Morse function defined on the surface.

First of all, we define a height function on the object surface (see Figure 1). The singular points of this function are the peaks, saddle points and pits. The pits and peaks are to be understood as points of the surface at which the height function h has a local minimum and maximum. At a saddle point, h has a minimum when viewed from one direction and a maximum when viewed from another direction. At the singular points, the surface normals are parallel to the axis of the height function.

According to Morse theory, there is a one-to-one correspondence between a primitive called a cell and a non-degenerate singular point of a Morse function defined on the object surface that is a C^2 2-manifold. When we consider an object surface, there are 0D, 1D and 2D cells. Simply speak-

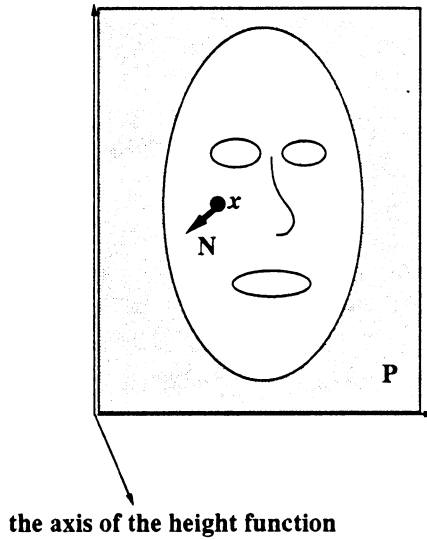


Figure 1: The height function

ing, a 1D cell is a point, a 2D is a chip of a string and a 2-cell is a patch of a surface. The object surface can be reconstructed by pasting the cells corresponding to the singular points of the function. A peak corresponds to a 2-cell, a saddle point to a 1-cell and a pit to a 0-cell. (A description of Morse theory can be found, for example, in [5].) Therefore, the singular points determine the topological structure of the object surface.

The singular points are important for object recognition. For example, we recognize the terrain by the peaks, pits and saddle points. When we consider the energy potential surface, the peaks, pits and the saddle points represent the equilibrium states. As can be seen from these examples, the singular points play significant roles when we characterize the object.

For these reasons, we characterize the shapes of the faces corresponding to various facial expressions by the singular points. The lighting switch photometry method [3], which is summarized in the next section, outputs the surface normals of an object surface. The singular points of the surface can be directly computed from the data.

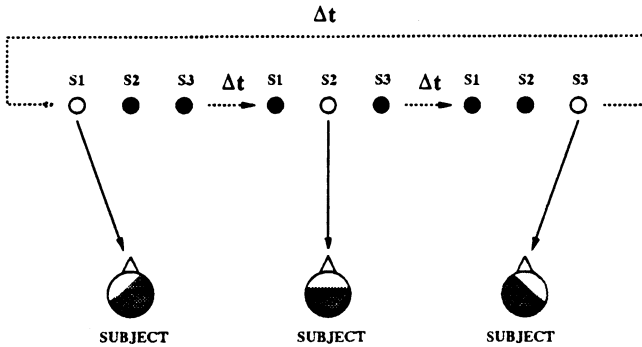


Figure 2: Light Switching

LIGHTING SWITCH PHOTOMETRY METHOD

The lighting switch photometry (LSP) method uses multiple light sources and one video camera as in the case of the photometric stereo method [12]. The three light sources are switched rapidly in turn and the images are obtained using a video camera when the subject is illuminated by one of the light sources (see Figure 2). For each light source, the images obtained when it illuminates are interpolated to obtain the intermediate images at a given instant. Three images with different light sources are computed for each instant. Assuming the Lambertian reflectance, the normal vector at each point on the face at a given instant is computed from the intensity of the corresponding pixels of the three images. The 3D shape of the face at each instant is reconstructed from these normal vectors using integration iteratively. Even if the human face moves, the detailed shapes such as the wrinkles on the face can be extracted by this method.

COMPUTATION OF SINGULAR POINTS FROM THE NORMAL VECTORS

The singular points on the surface of a face are detected using the normal vectors as follows.

Let us denote the surface of a face by A . First of all, we consider a plane P perpendicular to the axis of the height function. We define a map

Π that projects the normal vectors at each point to the plane P . The result of this mapping forms the “needle map”.

For a point x on the face, we consider a closed curve that goes around x counterclockwisely. Let us denote the curve by $c : [0, 1] \rightarrow A$ where $c(0) = c(1)$. Points on this curve are designated by $c(s)$, $s \in [0, 1]$. Figure 3 shows the relationship between the singular points on the surface and the needle map.

Let $t(s)$ be the tangent vector of the curve c at the point $c(s)$, and $n(s)$ be the normal vector of the face at the point $c(s)$. Now $\alpha(s)$ is defined as the angle between $\Pi(t(s))$ and $\Pi(n(s))$ on the plane P (see Figure 4). If the projected normal vector $\Pi(n(s))$ is directed to the interior of the curve $\Pi(c)$, $\alpha(s)$ takes the negative value. Otherwise, $\alpha(s)$ takes the positive value.

The value of $\alpha(s)$ varies as we trace the curve c . We can classify x by the change in the value of $\alpha(s)$; The point x is a *peak* if $\alpha(s)$ is always positive, a *pit* if $\alpha(s)$ is always negative and a *saddle point* if the sign of $\alpha(s)$ changes four times. Figure 5 shows the variations of $\alpha(s)$ for the peak, pit, pass, and other cases. Here, we assume that the surface is smooth enough so that the classification of x does not depend on the choice of the curve c if c is small enough.

The LSP method provides one normal vector per pixel. The data is hence discretized. We consider a pixel as a square region with four vertices (Figure 6). $\Pi(x)$ is discretized and is located at a vertex. The curve $\Pi(c)$ is defined as the square passing through the centers of the four pixels containing $\Pi(x)$ as one of its vertices. $\alpha(s)$ is defined as the angle between $\Pi(t(s))$ and $\Pi(n(s))$ at the centers of the four pixels.

The original data of normal vectors is noisy. To reduce the noise, an averaging filter is used. A certain number of pixels are merged to form a region of equal size. The direction of the normal vector of each region is the average direction of the normal vectors in that area. Applying the above procedure to each region, we can find the singular points on the surface.

In our experiment, the normal vectors are obtained for 640×480 pixels. By the averaging process, the original image is partitioned into 40×30 areas. As is stated previously, the surface is assumed to be smooth enough so that we can classify x correctly by the curve c of this size. When the person is not viewed in full face by the video camera, it is necessary to rotate the obtained normal vectors so that the facial expression is seen in full face.

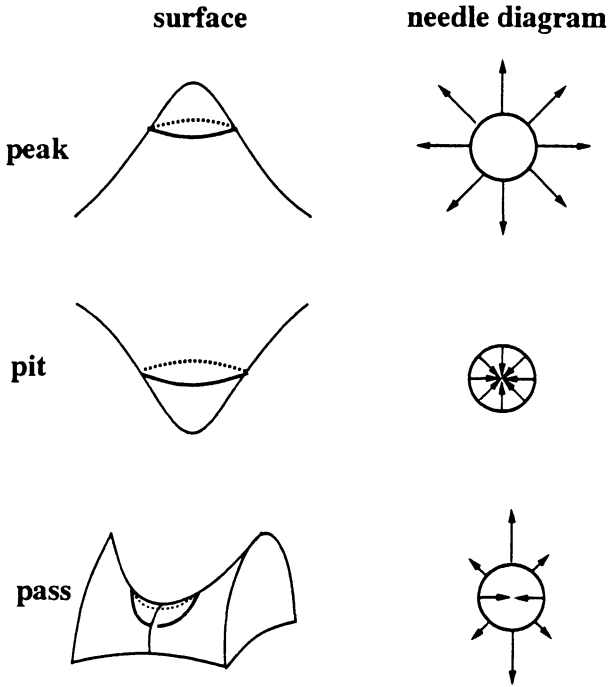


Figure 3: The singular points and the needle diagrams

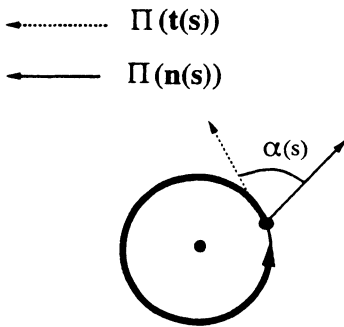


Figure 4: The angle α

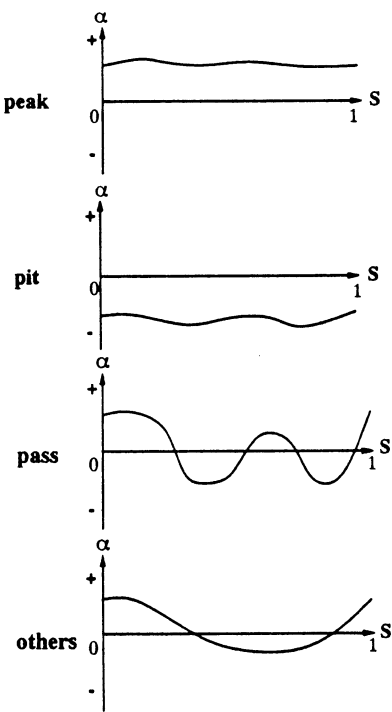


Figure 5: The change in α on the curve c

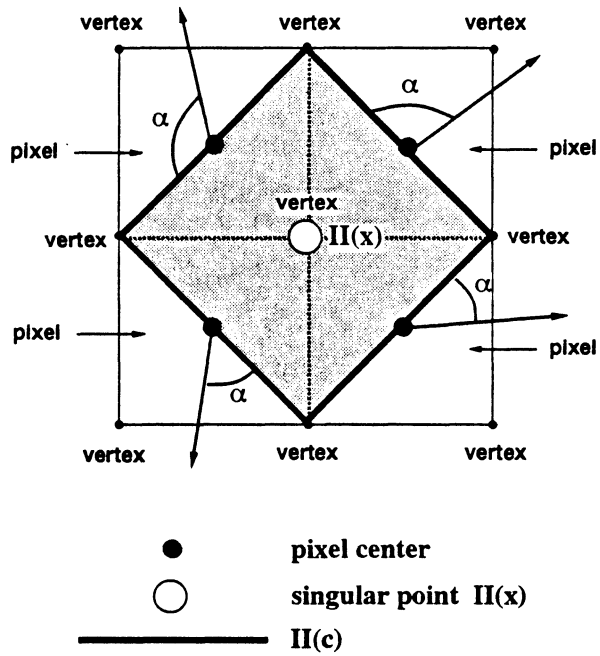


Figure 6: Discretization of the curve c and $\alpha(s)$

EXPERIMENTAL RESULTS

Figure 7 shows the change in the locations of the singular points on the needle diagram of a laughing face. A square stands for a pass, a black circle for the peak and a white circle for a pit. On the neutral face (Figure 7(a)), there are three peaks and two saddle points. When the face begins to laugh, the number of singular points increases (see Figure 7(a) and (b)). It can be also seen that the newly generated singular points are on the upper part of the face and the cheeks. Figure 8 shows the corresponding face images. Figure 9(a) shows the singular points of another person's laughing face.

Figure 9(b) shows the singular points of an angry face. Singular points are found between the eyes. There are, however, none on the cheeks. Figure 9(c) shows the singular points of a sad face. Figure 10 shows the corresponding face images.

It is hard to discriminate the sad face (Figure 9(c)) from the laughing face (Figure 9(a)) just looking at the singular points. This is because the both faces have similar wrinkles. To discriminate between the two, we need additional information such as the shape of the eyes and the mouth.

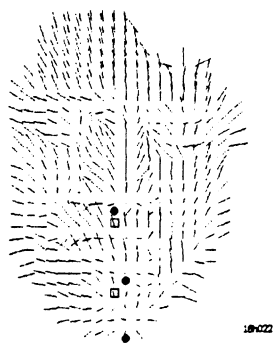
The distribution of the singular points characterizes the facial expressions as can be seen in these examples.

CONCLUSIONS AND FUTURE WORK

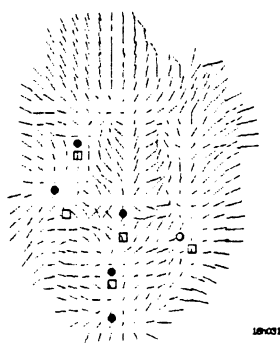
We have presented a method to characterize the facial expressions by the singular points. Automatic recognition of facial expressions is a future application of our method. Using additional information such as the shape of the eyes and the mouth to reinforce the information of the singular points is another extension we have in mind. Elimination of the noise in the data obtained by the LSP method is one of the future research. As another possible improvement of the system, we are considering the use of infra-red light sources to avoid the influence of the lights to the facial expressions.

ACKNOWLEDGEMENTS

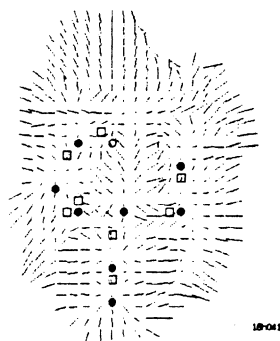
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(a)

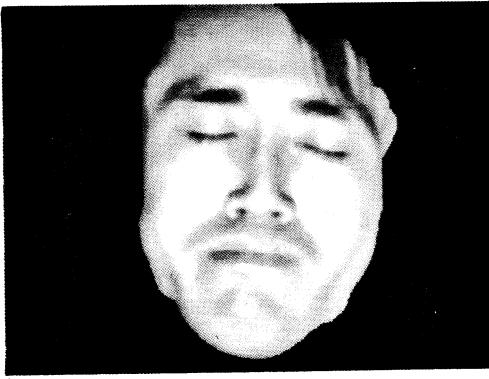


(b)



(c)

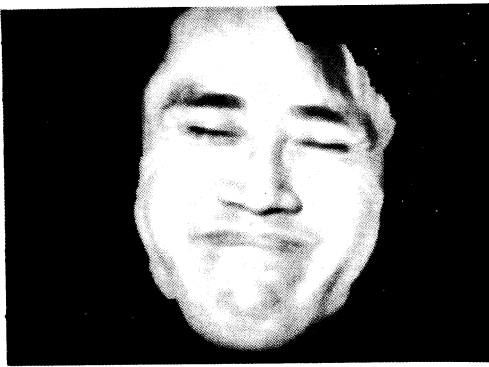
Figure 7: The distribution of the singular points when a person begins to laugh



(a)

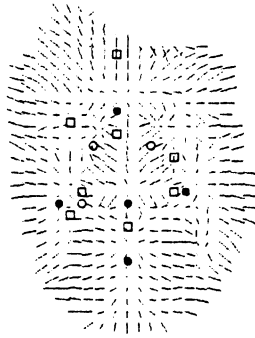


(b)

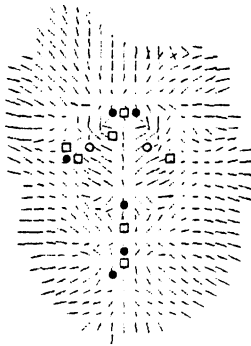


(c)

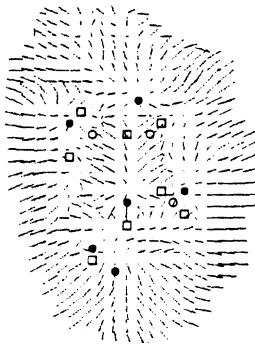
Figure 8: The images corresponding to Figure 7



(a)

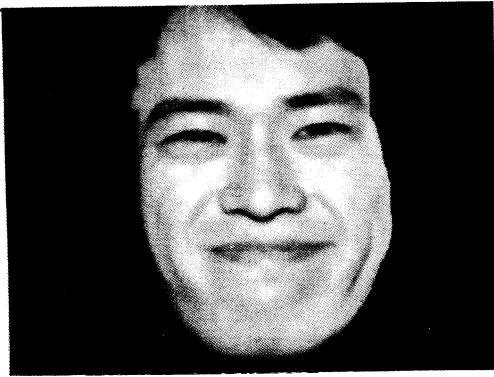


(b)

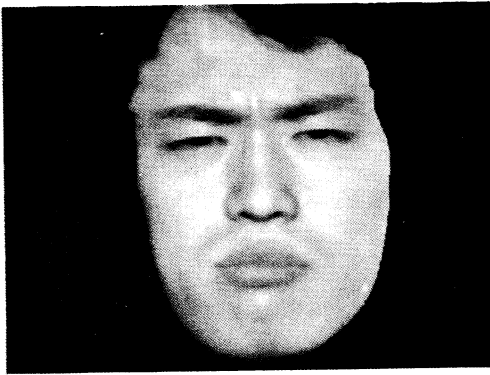


(c)

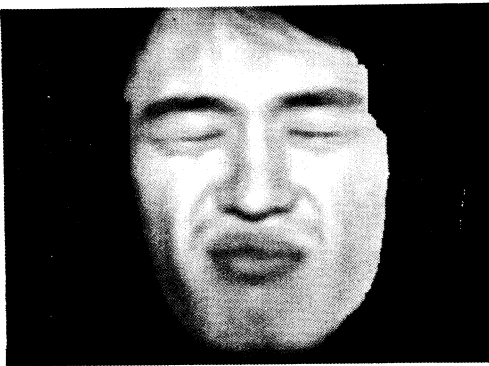
Figure 9: The distribution of the singular points on (a) a laughing face, (b) an angry face (c) and a sad face



(a)



(b)



(c)

Figure 10: The images corresponding to Figure 7

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