Using B-Spline Curves for Hand Recognition

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Abstract

The B-Spline curve and surface provide an accurate tool to record object shape. We present a biometric identification system through hand geometry measurements by using B-Spline curves. We use 4 B-Spline curves to fit with fingers (except thumb) from a single hand image for a single person. Then we store these 4 curves as well as other geometry measurements of the hand as the “signature” of that person into the database. By computing the differences between the curves from database hand images and the curves from the query hand image using the point projection method, we are able to verify/identify the person by locating the closest database hand image to the query hand image.

1. Introduction

A biometric system is able to identify an individual based his physiological traits such as fingerprint, iris, hand and face or behavioural traits such as gait, voice and handwriting. Various biometric techniques have been described in the literature and many of them have been commercialised. Among them, the most popular ones are fingerprint identification and face recognition. However, all of these biometric techniques have own advantages and disadvantages according to user acceptance, cost and performance [1]. Biometric system using hand geometry measures is easy and cheap to set up and does not cause anxiety for user like fingerprint and iris systems. These are the major superiorities to other biometric systems.

A limited amount of research has addressed the method of hand recognition using geometric measurements. Anil et al. [2] and Sanchez-Reillo et al. [3] proposed various geometric features of the hand such as width and length of fingers, hand size, and height profile. These two methods have some constraints for the user to place his/her hand on the platform. The user has to place his/her fingers between fixation pegs (figure 1). Cenker Oden et al. [4] presented an improved method to use implicit polynomials to model the finger, which removed the constraints of needing special hand placement. All of these methods only measure features on fingers and do not record the shape of fingers. Although it saves the store space for the system, it may lose important geometric information about the fingers. For example, if someone has a distorted finger, then it may become a unique verification/identification feature for him/her. Furthermore, some features (widths of a single finger) from one person do not guarantee to correspond the same features from the other person. Therefore, we propose to use B-Spline curves to record the shape of fingers. B-Spline curves as well as other geometric features of the hand (hand size, and height profile) are stored into a database as the signatures of individuals.

The B-Spline curve has become popular in computer vision and pattern recognition in recent years. For example, cubic B-Spline curves have been used in edge detection schemes [5]. This technique achieves good noise immunity and preserves accurate localization. Cham [6] proposed an automatic B-Spline curve fitting technique for the representation of object boundaries in 2D images. Unser [7] even claimed that splines and wavelets provide a new perspective for pattern recognition. All these results encourage us to employ the B-Spline curves for hand recognition.

In this paper, we present a novel hand recognition system that not only removes fixed-pegs for image acquisition but also represents fingers as B-Spline curves. The rest of the paper is organized as follows. In section 2, we present the details of preprocessing and B-Spline curve fitting. In section 3, we give the algorithm of
computing the difference between two hand images from two individuals. In section 4 we report our experimental results (up to 100% of success in identification) and proposed future works.

2. Preprocessing and B-Spline fitting

Hand images are obtained with a CCD color digital camera, placed a fixed distance above the platform, where the user’s hand is placed. Because there are no fixed pegs, the user has greater freedom to place the hand as long as each finger is separate.

2.1 Preprocessing

The original images are color. They are transformed into black and white binary images through thresholding (figure 2a), since there is a clear distinction in intensity between the hand and the background by design. A border following algorithm is applied to locate the boundary of the binary image [8]. After the extraction of boundary, the binary images are enhanced into a single-pixel-width boundary of the hand (figure 2b).

2.1 Non-uniform B-Spline curve fitting

A non-uniform B-Spline curve is defined as

\[ C(t) = \sum_{i=0}^{n} N_{i,p}(t)P_i \]  

where \( \{P_i\} \) are the control points for the B-Spline curve and \( \{N_{i,p}\} \) is the pth B-Spline basis functions defined as

\[ N_{i,p} = \frac{t-t_{i-1}}{t_{i+p}-t_{i-1}} + \frac{t_{i+p}-t}{t_{i+p}-t_{i+1}} \]  

\[ N_{i,1} = \begin{cases} 1 & \text{if } t_{i-1} \leq t \leq t_{i+1} \\ 0 & \text{otherwise} \end{cases} \]  

where \( \{t_0, t_1, ..., t_{n+p}\} \) is a non-uniform knot vector. We choose a non-uniform B-Spline curve because it is more flexible and can reduce the fitting errors [6]. We assign the value of a knot vector according to the normalized arc-length distances between a pair of neighboring control points. There are two steps for the calculation of a knot vector.

- We first generate an auxiliary vector \( \{\tilde{t}_i\} \), whose dimensionality is equal to the number of control points. It can be calculated as

\[ \tilde{t}_i = t_i = \tilde{t}_{i-1} + \frac{\|P_i - P_{i-1}\|}{\sum_{j=0}^{i} \|P_j - P_{j-1}\|} \]  

\[ = \begin{cases} 0 & \text{if } i = 0 \\ \frac{\|P_i - P_{i-1}\|}{\sum_{j=0}^{i} \|P_j - P_{j-1}\|} & \text{if } 0 < i < n \\ 1 & \text{if } i = n \end{cases} \]  

where \( \|*\| \) means the Euclidean distance computation.

- We generate the non-uniform knot vector \( \{t_i\} \) from \( \{\tilde{t}_i\} \) use Eq. (5)

\[ \begin{align*}
  t_0 &= \ldots = t_p = 0 \\
  t_{j+p} &= \frac{1}{p} \sum_{i=j}^{j+p-1} t_i, \quad j = 1, ..., n-p \\
  t_{m-p} &= \ldots = t_m = 1
\end{align*} \]  

The most common B-Spline curve used in computer graphics is the cubic B-Spline curve, where the degree of B-Spline basis function is 3 \( (p=3 \text{ in Eq. (2) (3)(4)(5))} \). We use cubic B-Spline curves to fit the finger contours. We already have finger boundary points on the B-Spline curves; the next step is to obtain the control points for
defining the B-Spline curve. By using an auxiliary vector \( \mathbf{\tilde{t}_k} \) from Eq. (4) (5), we calculate the control points by rearranging the Eq. (2) as

\[
Q_k = C(\mathbf{\tilde{t}_k}) = \sum_{i=0}^{n} N_{i,p}(\mathbf{\tilde{t}_k})P_t
\]

By solving the \((n+1) \times (n+1)\) system of linear equations, we eventually can obtain all control points. An example of a cubic non-uniform B-Spline fitting with the contour of middle finger and errors of fitting are given in figure 3.

Finally, we fit all fingers with B-Spline curves. Because the geometric features of thumb are not reliable [3], we only measure the length of thumb. We store four B-Spline curves (one for each finger) as well as length of thumb, width of hand into database. An illustration of geometric features used in this paper is given in figure 4.

3. Computing the differences

We use just one hand image from an individual to extract the geometric features and store them into the database. We propose that one sample from an individual is enough for future identification or verification unless this individual has a large change of hand shape.

After we establish the hand image database, we can identify or verify the person by computing the differences between the query hand image and database hand images. We carry out the same procedures for the query hand image to extract geometric features as the database hand images. The differences of the length of thumb and the width of hand are easy to calculate. It is more difficult to compute the differences between two B-Spline curves. There are two steps for the calculation of the differences.

3.1 B-Spline curve registration

Two B-Spline curves have to be aligned to remove the orientation differences. We first remove angle difference by aligning both curves along the \( y \) axis. A directional vector is the average of two edge vectors (figure 5). Then we calculate the angle between the directional vector and the \( y \) axis and rotate the curve toward \( y \) axis using the rotation equation:

\[
\begin{bmatrix}
x_{\text{new}} \\
y_{\text{new}}
\end{bmatrix} = \begin{bmatrix}
\cos \theta & \sin \theta \\
-\sin \theta & \cos \theta
\end{bmatrix} \begin{bmatrix}
x \\
y
\end{bmatrix}
\]

Finally, we coincide the fingertips of two fingers and correct the offset along \( x \) axis to guarantee that the \( y \) axis is in the middle of the finger (figure 6a). If one of finger is distorted, we only correct the offset along \( x \) axis to guarantee \( y \) axis is in the middle part of the finger (figure 6b).
3.2 Point projection for difference computation

Point projection is a standard technique for finding the minimum distance between a point and a geometric object (figure 7a). We have developed a robust point projection method for a B-Spline curve or surface in [8]. Using this technique, we project six points, which are on one of B-Spline curves, to the other B-Spline curve. The six points are all outside the fingertip region and finger bottom region. Half of them are on the left side and the other half are on the right side (figure 7b).

\[ \text{Diff}_k = \sum_{i=1}^{n} L_{1,k} + h_k \quad k = 1,2,3,4 \quad (8) \]

where \( L_{1,k} \) is the minimum distance between a point and a B-Spline curve and \( h \) is the height of the finger. \( k \) is the index of finger (except thumb).

4. Experimental results and future works

In first stage, we tested our method on a public sample database that can be downloaded from www.csr.unibo.it (including 8 images from 9 persons). In our method, no training is involved and just one image from one individual is used for feature extraction so that 63 (7x9) images remains for testing. We first use only four B-Spline curves (four fingers) to compute the overall difference \( \sum_{k=1}^{4} \text{Diff}_k \). The identification rate is 100% (only using four fingers). The maximum difference between two hand images from the same person is 20. The minimum and maximum difference between two hand images from different peoples is 35 and 285, respectively. In second stage, we tested our method on our own database, which includes 6 images from 20 persons. We use the overall difference of four fingers and the differences of the length of the thumb and the width of the hand. The identification rate is 97% (total 5x20 test images, 20 images for the feature extraction). The error rate in verification is 5% (5 images).

In this paper, non-uniform B-Spline curves have been proposed for recognizing hand shapes. B-Spline curves can accurately record the shape of fingers and the point projection method provides an accurate way to evaluate the difference between two B-Spline curves. The proposed technique achieves high rate of identification and verification. Proposed future works include a more extensive test performed on a larger database collected over a period of time.

5. References


