A Liveness Detection Method for Face Recognition Based on Optical Flow Field

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***Abstract*— It is a common spoof to use a photograph to fool face recognition algorithm. In light of differences in optical flow fields generated by movements of two–dimensional planes and three-dimensional objects, we proposed a new liveness detection method for face recognition. Under the assumption that the test region is a two–dimensional plane, we can obtain a reference field from the actual optical flow field data. Then the degree of differences between the two fields can be used to distinguish between a three-dimensional face and a two–dimensional photograph. Empirical study shows that the proposed approach is both feasible and effective.**

***Keywords*— Liveness Detection, Face Recognition, Optical Flow Field, Anti-spoofing, Plane**

I. Introduction

Face recognition, as a biometric identification technology, has developed rapidly in recent years. Compared with other biometric identification systems such as fingerprints, irises, voices, face recognition is more direct, user-friendly and convenient. It has therefore been widely applied to attendance and security systems. Face recognition system in general can't distinguish between 'live' face and 'not live' face, which is not secure enough. For example, it is an easy way to spoof face recognition system by facial pictures such as using a portrait photographs A secure system needs a liveness detection function in order to guard against spoofing. Generally, liveness detection for face recognition is performed according to the facial expression change or movement. According to the sequential images of face movement, the system is able to analyze face parts' movements or facial expressions, especially the movement of lips and eyes such as blinking, to detect fake faces [1], [2]. Kollreider used optical flow field to detect facial organ motion information to perform the liveness detection [3]. The method proposed in this paper is different from those anti-spoofing methods which emphasize on the characteristics of facial motions. Instead, it analyzes the difference in characteristics of the optical flow field generated by a planar object and the flow field generated by a three-dimensional object to decide whether the test region is a picture or a real face.

II. Background

A. Optical Flow Field

Optical flow is the instantaneous speed of a moving spatial object's pixel movements on the projection plane. The research of optical flow is to use the time-domain change and correlation of pixel intensity in image sequences to determine the 'movement' of each pixel's location, that is, to study the relationship between the intensity change by time and the object's structure and movement in the scene. The instantaneous change rate of intensity on specific point in projection plane is defined as optical flow vector. Optical flow field means apparent movement of image intensity pattern, which is a two-dimensional vector field. It contains information of instantaneous velocity vector of each pixel, and pixel's velocity vector can be seen as the corresponding point in spatial object mapping to projection plane. So actually it's a map from the object velocity field. The optical flow algorithm includes gradient based methods, region based matching methods, energy based methods, phase based methods, etc [4].

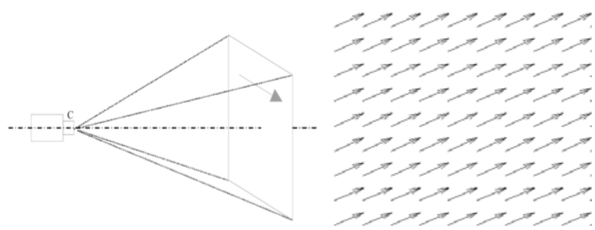
B. Phase Based Method

The optical flow algorithm adopted in this paper employed the phase based approach proposed by Fleet and Jespon [5]. The algorithm defines component velocity in terms of the instantaneous motion normal to level phase contours in the output of band-pass velocity-tuned filters. Band-pass filters are used to decompose the input signal according to scale, speed and orientation. After a series of comparative experiments [4], it is obvious that the phase based method has a good overall performance.

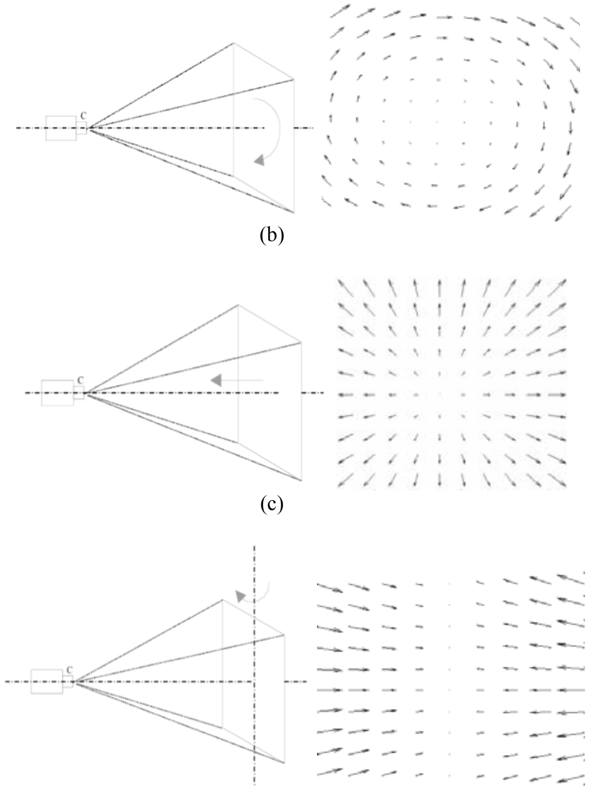
III. Model and Deduction

A. Four Basic Types of Optical Flow Fields

The relative motion between a two-dimensional plane and an observer (camera) can be divided into four basic types: translation, rotation, moving forward or backward and swing. All other movements are combinations of these four basic motion types. The four motion types can generate different optical flow field, which is shown in Fig. 1. Similarly, any planar object's optical flow field can be represented as a linear combination of these four basic types with regularity.



(a)



(b)

(c)

(d)

Fig. 1 Optical flow fields generated by four basic types of relative motions. (a) Translation (b) Rotation (c) Moving forward or backward (d) Swing

However, face is an irregular three-dimensional object, which means the optical flow field generated by head motion object and facial expressions are irregular. The first three basic types of optical flow field generated by two-dimensional and three-dimensional objects are quite similar. The fourth type of optical flow field generated by two-dimensional and three-dimensional objects have more differences, which means shaking, raising or lowering head gives rise to a better differentiation.

B. Optical Flow Field Calculation

We need some quantifiable characteristics to distinguish between real facial optical flow and the fake one. As we know, the transformation from space object to projection plane is perspective projection transformation, which means a straight line through the perspective projection transformation is still a straight line. Therefore, any change rate along the straight line in the optical flow field is constant, lest the straight line after transformation will be distorted. It is certain that the straight line speed change rate will also be constant along a particular horizontal or vertical direction. Let v_x, v_y be the horizontal and vertical direction component of the vector of a specific point in the optical flow field, we have

$$\frac{\partial v_x}{\partial \mathrm{x}} = C_1(\mathrm{y}), \quad \frac{\partial v_y}{\partial \mathrm{x}} = C_2(\mathrm{y}) \tag{1}$$

$$\frac{\partial v_x}{\partial \mathrm{y}} = C_3(\mathrm{x}), \frac{\partial v_y}{\partial \mathrm{y}} = C_4(\mathrm{x}) \tag{2}$$

So for the ideal case, the two-dimensional object's optical flow field can be presented as

$$\mathrm{v_x} = a_1 \mathrm{x} + b_1 \mathrm{y} + c_1, \tag{3}$$

$$\mathrm{v_y} = a_2 \mathrm{x} + b_2 \mathrm{y} + c_2. \tag{4}$$

We need to judge whether an optical flow field is in line with the planar object's optical flow field. Under the assumption that it is an ideal optical flow field of planar object, we deduce backwardly to get a reference field, which can be represented by coefficients a_1, b_1, c_1, a_2, b_2 and c_2. Then we compare the two fields to determine whether the test region is planar.

Let the m×n matrix U and V represent the horizontal and vertical component of the optical flow field respectively. Then a_1 can be written as

$$a_1 = \frac{U_{right} - U_{left}}{\lceil m/2 \rceil}, \tag{5}$$

where U_{left} and U_{right} are the horizontal component's arithmetic mean of the optical flow field's left and right half respectively.

$$U_{left} = \frac{\sum_{i=1}^{\lfloor m/2 \rfloor} \sum_{j=1}^{n} U_{ij}}{n \lfloor m/2 \rfloor}, \quad U_{right} = \frac{\sum_{i=m}^{m-\lceil m/2 \rceil} \sum_{j=1}^{n} U_{ij}}{n \lfloor m/2 \rfloor}. \tag{6}$$

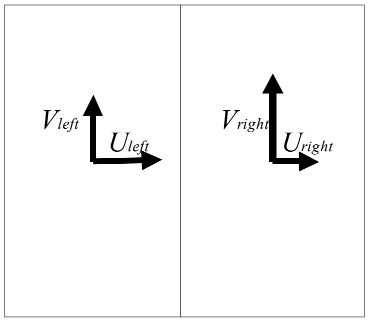


Fig. 2 The left and right half of an optical flow field

Coefficient b_1 is given by

$$b_1 = \frac{U_{upper} - U_{lower}}{\lceil n/2 \rceil}, \tag{7}$$

where U_{uppert} and U_{lower} are :

$$U_{upper} = \frac{\sum_{j=1}^{\lfloor n/2 \rfloor} \sum_{i=1}^{m} U_{ij}}{m \lfloor n/2 \rfloor}, \quad U_{lower} = \frac{\sum_{j=n}^{m-\lceil n/2 \rceil} \sum_{i=1}^{m} U_{ij}}{m \lfloor n/2 \rfloor}. \tag{8}$$

We can get the coefficients a_2 and b_2 by the same way.

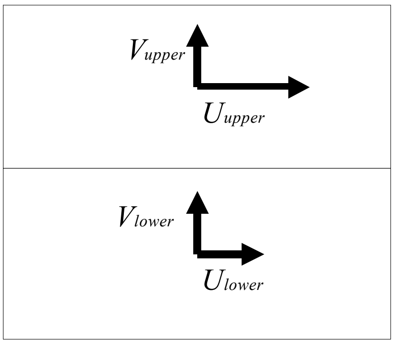


Fig. 3 The upper and lower half of an optical flow field

$$V_{left} = \frac{\sum_{i=1}^{\lfloor m/2 \rfloor} \sum_{j=1}^{n} V_{ij}}{n \lfloor m/2 \rfloor}, \quad V_{right} = \frac{\sum_{i=m}^{m-\lceil m/2 \rceil} \sum_{j=1}^{n} V_{ij}}{n \lfloor m/2 \rfloor}, \tag{9}$$

$$a_2 = \frac{V_{right} - V_{left}}{\lceil m/2 \rceil}, \tag{10}$$

$$V_{upper} = \frac{\sum_{j=1}^{\lfloor n/2 \rfloor} \sum_{i=1}^{m} V_{ij}}{m \lfloor n/2 \rfloor}, \quad V_{lower} = \frac{\sum_{j=n}^{m-\lceil n/2 \rceil} \sum_{i=1}^{m} V_{ij}}{m \lfloor n/2 \rfloor}, \tag{11}$$

$$b_2 = \frac{V_{upper} - V_{lower}}{\lceil n/2 \rceil}. \tag{12}$$

We can see that among the four basic types of optical flow fields, the arithmetic mean of all but the one generated by translation is 0 and the optical flow in the geometric center is 0. Therefore, by calculating the test region's arithmetic average, we can get its optical flow field generated by the translation component of the motion. In theory, the optical flow vector equals to the optical flow vector of region's geometric center.

$$U_{center} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} U_{ij}}{mn}, \tag{13}$$

$$V_{center} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} V_{ij}}{mn}. \tag{14}$$

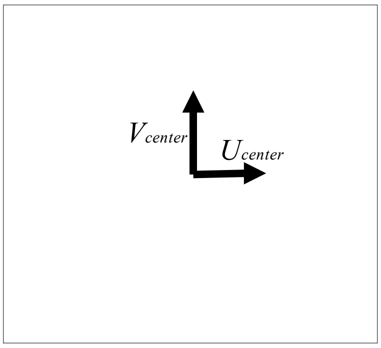


Fig. 4 V_{center} and U_{center} are the arithmetic means of an optical flow field's horizontal and vertical component respectively

And then we can get the other two coefficients c_1 and c_2:

$$c_1 = U_{center} - a_1 n/2 - b_1 m/2 \tag{15}$$

$$c_2 = V_{center} - a_2 n/2 - b_2 m/2 \tag{16}$$

C. Difference Degree Calculation

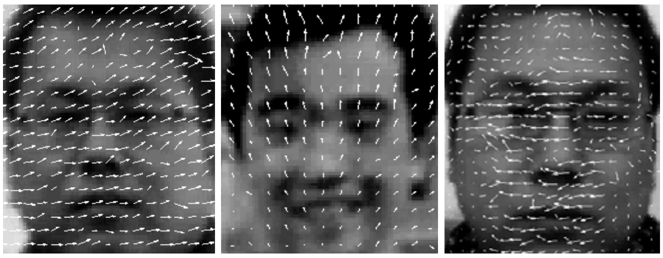
We used the functions above to calculate the coefficients a_1, b_1, c_1, a_2, b_2 and c_2, and employed the optical flow field with these coefficients as the reference and compared with the test region optical flow field. We used D to represent the difference between the two optical flow fields:

$$D = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \sqrt{(a_1 i + b_1 j + c_1 - U_{ij})^2 + (a_2 i + b_2 j + c_2 - V_{ij})^2}}{\sum_{i=1}^{m} \sum_{j=1}^{n} \sqrt{U_{ij}^{\ 2} + V_{ij}^{\ 2}}} \tag{17}$$

The greater D is, the more likely it is a real face. Set a threshold T, when D > T we conclude that it is a real face, otherwise it needs more detection.

IV. Evaluation

We conducted experiment on 3 groups of sample data. For the first group, we printed 100 face pictures, and randomly translated, rotated and turned it in front of the camera. For the second group, we folded and curled the pictures before shown to the camera, to make their surfaces not completely smooth. The third group was a real face experiment, with people facing the camera, doing random gestures like shaking, swinging, raising or lowering head. Ten people participated the experiment in turn, with a total of 10 turns. Fig. 5 shows some of the optical flow field result obtained in this experiment.



(a) (b) (c)

Fig. 5 Examples of the optical flow fields. (a)Group 1 (b) Group 2 (c) Group 3

The time duration of these experiments were 10 seconds. The camera used in the experiment had a sampling rate at 30 frames per second. The system made a calculation every 10 frames and then produced a report. In assessment T was set to 0.2, 0.4, 0.6 and 0.8 respectively. The following table is the ratio of successful detection in each of the three experiments.

TABLE I
EXPERIMENTAL RESULTS

Group	**T**			
	0.2	0.4	0.6	0.8
1st	0.54	0.83	0.86	0.92
2nd	0.45	0.80	0.85	0.89
3rd	1.00	1.00	0.94	0.86

As is shown in the Fig. 6, the greater T is, the higher the ratio of successful detection is. But at a certain point the ratio will drop. The testee needs to amplify his gestures to pass the detection, making the system less user-friendly. Comparing the first and second groups of data, we can also see that mild roughness of the test region has no observable impact on the test result.

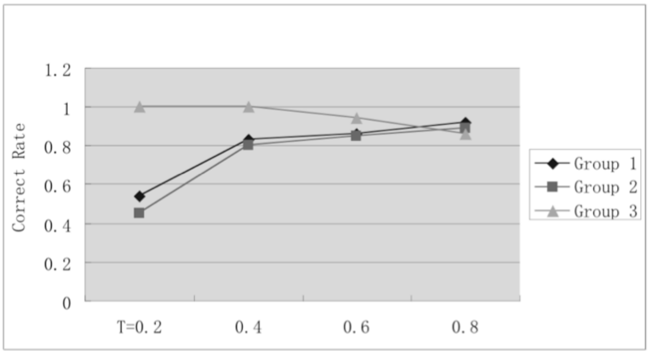


Fig. 6 Experiment comparison

V. CONCLUSION

By analyzing the optical flow field to detect real face, the liveness detection face recognition method proposed in the paper showed good performance in experiment. However, this method relies on the precise calculation of the optical flow field, so illumination change will have an impact on the result. To address this problem, further research is needed. In addition, this method is working under the assumption that the fake face is on a plane. It won't work on the three-dimensional face model or some seriously bended or folded face images. So in practice, it should be combined with other liveness detection methods to increase the rate of successful detection.

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