

Gait Volume : Spatio-Temporal Analysis of Walking

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Abstract

This paper describes a new approach for identifying a person from a spatio-temporal volume which consists of sequential images of a person walking in an arbitrary direction. The proposed approach employs an omnidirectional image sensor and analyzes three dimensional frequency properties of spatio-temporal volume, because the sensor can capture a long image sequence of person's movements in all directions and their walking patterns have some cycles. Spatio-temporal volume data, called as "gait volume", contain information not only spatial individuality such as features of body and face, but also movement of their body within unique rhythm. The three dimensional fourier transform is applied to the gait volume for obtaining unique frequency in each person's walking. This paper also evaluates availability of three dimensional frequency analysis of the gait volume, how much is the difference in people's frequency patterns while walking.

1. Introduction

The need for automated person identification is growing with many applications such as surveillance, access control, and smart interfaces. It is well-known that biometrics is a powerful tool for reliable automated person identification. Many biometric-based identification techniques are already established such as fingerprints, and iris and face identification. Gait is also an important biometric data for person identification. Previous researches have concluded that it is possible to identify a person from their gait [1], [2], [3], [4], [5].

When walking, people move their torso, arms, and legs in a unique way. Hence the rhythm of a gait should be different among individuals. Since gait can be observed at a distance, gait recognition has advantages for surveillance system recognition. Our approach employs an omnidirectional image sensor for capturing an image sequence of people walking. The merit is that it can observe a 360-degree of field of view at one time. The proposed approach analyzes the three dimensional frequency properties of spatio-temporal volume, because walking patterns have some cycles. Spatio-temporal volume data, here called "gait volume", contain information of not only spatial individuality such as features of torso and face, but also the movement of their body with its unique rhythm. Three dimensional fourier transform is applied to the gait volume to obtain a unique frequency for each person's walking pattern.

2. Proposed Approach

One significance of our proposed approach is the ability to use various appearances of humans for person identification without specifying the view of the observations. An overview of the approach of our proposal is shown in Fig. 1.

2.1 Gait Volume

To analyze the characteristics of walking, the proposed approach is to create a gait volume. By aligning the center of the bodies on the azimuth and registering images of human bodies by frame, gait volume is constructed. Fig. 2 shows an isosurface of a silhouette that is extracted from the volume data with a walk-

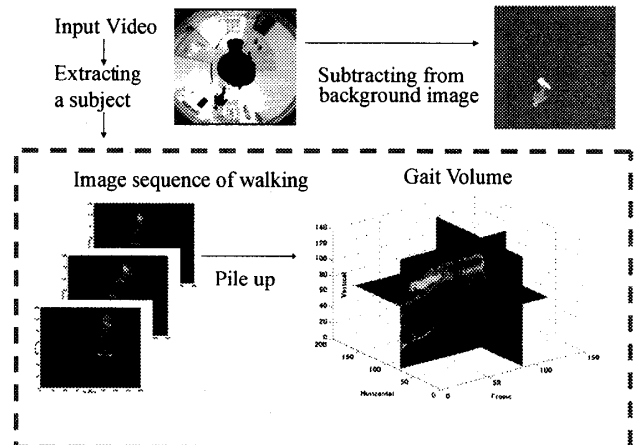


Figure 1: Overview of a proposed approach

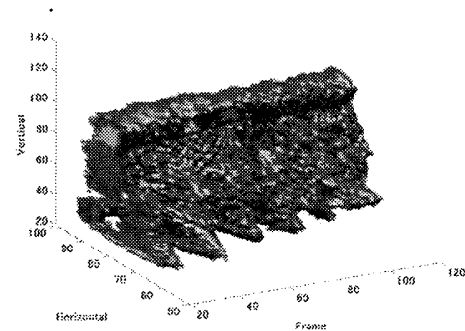


Figure 2: Gait volume

ing sequence. Gait volume includes both spatial and temporal information.

From gait volume, it is possible to acquire information about how a human moves his/her body while walking. Fig. 3 (a) and (b) shows a horizontal slice of gait volume. Fig. 3 (a) shows a horizontal slice of gait volume at a plane which includes line I shown in Fig. 3, and Fig. 3 (b) shows a horizontal slice of gait volume at a plane which includes line II shown in Fig. 3.

The cycles of patterns in Fig. 3 (a) shows unique movements of arms when a person is walking. The width of a band shown in Fig. 3 (a) describes a width of a human's body from a top point of view. Small repeating changes of the width of the band shown in Fig. 3 are generated by horizontal movements while walking. Fig. 3 (b) shows a horizontal slice of gait volume around the legs. A single cycle in waves shown in Fig. 3 (b) are generated when a person takes a single stride of the gait. Form and length of a single cycle or waves shown in Fig. 3 (b) represent movement, speed, and rhythmicity of the legs in the gait.

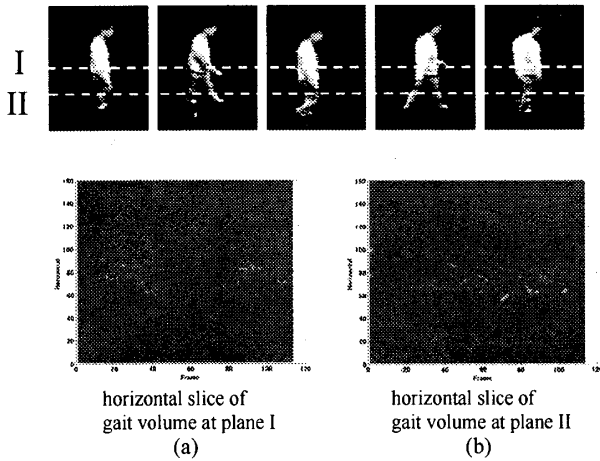


Figure 3: A horizontal slice of the gait volume

2.2 Fourier Transform of Gait Volume

On a slice of the gait volume such as in Fig. 3, there are some iterations of cycles and changes of the texture of the gait volume. Therefore by three dimensional fourier transform, and horizontal, vertical, and temporal transforms, it is possible to expose the characteristic frequency of a person walking. In this paper, the proposed approach takes three dimensional fourier transform of the gait volume.

By three dimensional fourier transform of the gait volume, it is possible to express spatio-temporal frequency. Fig. 4 shows an example of a frequency domain of the gait volume (FDGV). In Fig. 4, dark spots mean a large power spectrum caused by fourier transform in FDGV, and in turn, the light spots contain the small spectrum of fourier transform. At center of FDGV, an orthogonal frequency is described. Since areas of a body that generate changes of texture by walking are so small for all areas of the body, most of the contents in the gait volume don't change toward any spatio-temporal axis. Thus, the largest power spectrum concentrates at the center of FDGV. But spectrum at orthogonal frequency have no relationship to the frequency generated by the gait; such that it is useless and so is ignored for recognition.

Fig 4 (a) describes FDGV from the point of view I, Fig 4 (b) describes FDGV from the point of view II shown in Fig. 4. Fig. 4 (a) shows a vertical-temporal plane of FDGV, Fig. 4 (b) shows a vertical-temporal plane of FDGV. A vertical-temporal plane can represent features caused by vertical movements and swings, and a horizontal-temporal plane can represent features caused by horizontal movements and swings while walking. Since orthogonal frequency is not important for observing gait, in the case of vertical-temporal FDGV shown in Fig. 4 (a), dark patterns of FDGV on areas enclosed between temporal 1Hz - 2Hz and vertical DC component - 7Hz are generated by the person's walking. In the case of Fig. 4 (b) the same as that of Fig. 4, because the spectrum around the orthogonal frequency has not been caused by gait, patterns of spectrum on FDGV around the orthogonal frequency can be ignored. Therefore, the dark patterns of FDGV on areas enclosed between temporal 1Hz - 2Hz and horizontal DC component - 5Hz are generated by

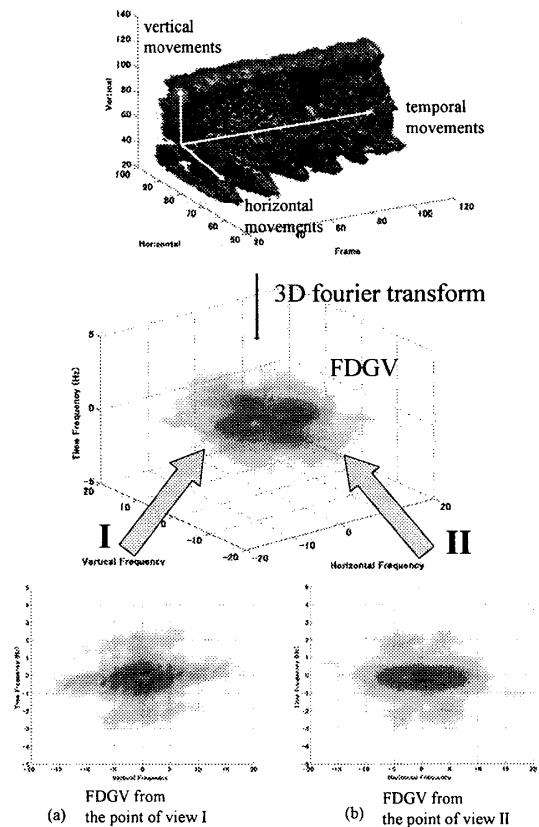


Figure 4: 3D fourier transform of the gait volume

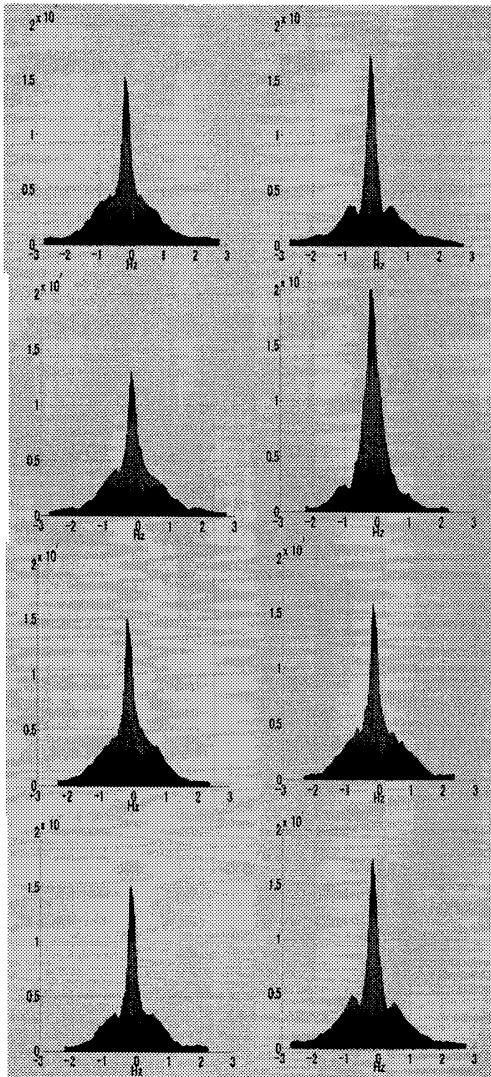


Figure 5: FDGV sliced at single axis

the person's walking. Like shown in Fig. 4 (a) and Fig. 4 (b), by representing a person's gait as FDGV, it is possible to analyze and evaluate from any spatio-temporal view point.

3. Experiments

We gathered gait data in indoor environments with the same background. Subjects were asked to walk at their normal speed and stride. All subjects walk the same route and passed through beside the omnidirectional sensor with a video camera that was placed at 1.7m and perpendicular to the ground. We captured all images at 30 frames per second. Each walking sequence consists of about 150 images. From the video images, human regions are extracted, and all human regions are aligned by the center azimuth of the body. Also, the height of the body is normalized by the length from top to bottom of the extracted body.

We then applied the proposed approach to each sequence, and Fig. 5 shows the fourier transform results for all subjects. First, in order to analyze whether

there are differences on FDGV from each person, and if FDGV can be available for discrimination of people, we examined differences about a single axis in FDGV. Therefore a single axis needs to be defined, and the axis must be useful for evaluating differences among individuals. In this paper, the axis is decided when the widest range of patterns of frequency are contained on the axis among all axis in 3D FDGV. Fig. 5 shows frequency patterns for 8 subjects at the decided axis. Each figure in Fig. 5 corresponds to a pattern of frequency. In Fig. 5, horizontal axis means frequency, and vertical axis indicates the power of the spectrum. From Fig. 5, there are obviously different patterns between DC component and 2Hz from each person.

For the experiment with cross-correlation, we gathered 5 people's gait data, 2 men and 3 women, and had them walk 10 times on the same route. We made experiments for 10 patterns on each subject, and computed cross-correlation for every subject. These patterns of cross-correlation were selected from the sequences for each of the subjects.

In 46 of 50 patterns, the correct person had the top value of cross-correlation of 5 subjects. But in the case of the subject No.3, the values of cross-correlation are less than those of other subjects' cases. Because subject No.3 is wearing a cloth with complicated textures, the small differences on each sequence would generate the large differences of the frequency which don't relate to the features of his gait.

4. Conclusions and Future Work

This paper aimed to discriminate people from their gait. To capture images of a person walking in an arbitrary direction, an omnidirectional image sensor was utilized. The center of the human body could be aligned on the azimuth. The volume data was taken by fourier transform of the walking sequence for gait recognition, which was a registered image of human bodies by frame. The proposed method didn't need to specify the part of the body, but was effective by taking the fourier transform of volume data from the whole of the walking sequence.

From the experimental results, it was seen that each subject had different frequency patterns from their fourier transform results, which suggested that it was possible to recognize people from their gait by applying fourier transform.

In future studies we will apply our proposed approach to many walking patterns, which will include many patterns of clothes, various types of appearance, and in different lighting conditions. Also we must investigate and specify which frequency especially affects discrimination of individual people.

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