

# Extracting Gait Signatures based on Anatomical Knowledge

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## 1. Introduction

As a biometric, human gait may be defined as a means of identifying individuals by the way they walk [1]. Using gait has many advantages over other biometrics such as fingerprints, most notably that it is non-invasive. The human gait is a pattern of locomotion and can be described by kinetic or kinematic characteristics [2]. The gait signatures are the most effective and well-defined representation method for kinematic gait analysis. In the past, gait motion measurement systems have used markers that represent the observed movement in the form of 3D trajectories that translate into kinematic variables [3]. However, using markers needs intrusive and expensive specialized hardware.

This study aims to generate gait signatures by computer vision and to extract kinematic features for recognizing people. To achieve this, we propose a new method for extracting the body points by topological analysis and linear regression guided by anatomical knowledge. A 2D stick figure model is used to represent the human body, and joint angles and angular velocities are calculated to describe the gait motion. The trajectory-based kinematic features are extracted from image sequences for recognizing people. Results show that the new approach works successfully, in comparison with medical data acquired by a marker system, and should therefore prove suited to the suggested application domains.

## 2. Human Gait and Properties of Body Segments

Human gait is a form of periodic motion, especially when walking laterally; hence we can predict human movement in a gait cycle. Murray [4] considers human gait as “a total walking cycle” - the action of walking can be thought of as a periodic signal. This assumes that the pattern of the gait motion is approximately sinusoidal in nature. However, the human gait in kinematic analysis is usually characterized by the joint angles between body segments and their relationships to the events of the gait cycle [5]. The joint angles are more commonly expressed as flexion and extension. Fig. 1 shows the mean and standard deviations, by medical data from anatomical markers in limb segment [6], for joint angle of the thigh and knee motion during one gait cycle.

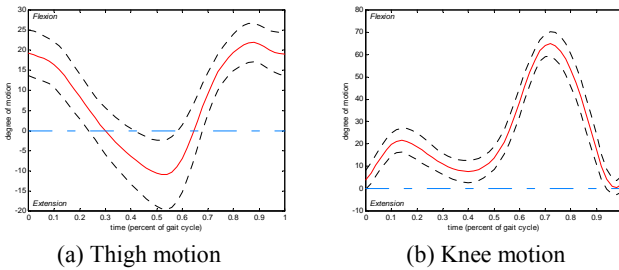


Figure 1. Normal Range during Free Walking

One the other hand, the analysis of human motion often requires knowledge of the properties of body segments. The dimensions of various body segment-links callipered from cadavers were extensively studied [5,7]. Their literature pre-

sented a stick figure in which the lengths were shown as a percentage of body height. The results of this study have been used in dynamic models for animating human motion. The mean dimensions of body height can be used to determine topological position of each body part in human figures.

## 3. Extracting Human Body Points and Leg Angles

To extract the body points, the vertical position of the neck, shoulder, chest, pelvis, knees, and ankles for a body height  $H$  was estimated by study of anatomical data [5] to be  $0.870H$ ,  $0.818H$ ,  $0.720H$ ,  $0.285H$ , and  $0.039H$ , respectively. In the upper body region including head, neck, shoulder, and chest, the horizontal coordinate is calculated from two border points as

$$x_{center} = x_s + (x_l - x_s) / 2 \quad (1)$$

where  $x_s$  and  $x_l$  represent the horizontal position of the first and the last pixels on the scan line respectively. The waist and pelvis coordinate is calculated by interpolation from the coordinates of the shoulder and chest as

$$x_{waist} = x_{pelvis} = x_{chest} + \frac{(x_{chest} - x_{shoulder})}{(y_{chest} - y_{shoulder})} (y_{waist} - y_{chest}). \quad (2)$$

Finding the knees and ankles require a more sophisticated algorithm than finding the upper body components. These points can be determined by the leg angles extracted from border data of the body contour by linear regression analysis. To extract the border data, the expected vertical position of the pelvis, knees, and ankles is again derived from anatomical data. The knee position is determined by the distance from the  $x$ -axis. Fig. 2(a) shows the expected joint positions and extracted border pixels from the body contour determined by our new approach. Fig. 2(b) shows the extracted border data with lines selected by least-squares analysis superimposed. Data near joint positions is masked from these calculations.

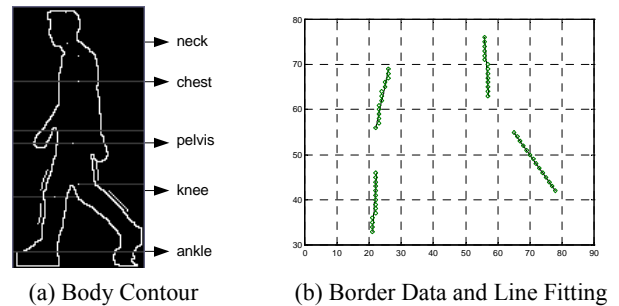


Figure 2. Extracting Gait Angles by Least Squares

The thigh and shin angles can be calculated by linear regression using the border data. The angles  $\theta_{jnt,k}$  of joint  $jnt$  at image frame  $k$  can be approximated by the slope of the lines in linear regression equation as [8]

$$\theta_{jnt,k} = \frac{\sum_{i=1}^n (y_i - \bar{y})(x_i - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2} \quad (3)$$

where  $n$  is the number of the points and  $jnt \in \{thigh, shin, knee\}$ . Also, a certainty factor (CF)  $\gamma_{jnt,k}$  of the angle  $\theta_{jnt,k}$  can be

determined by the correlation coefficient as

$$\gamma_{jnt,k} = \left| \frac{\sum_{i=1}^n (y_i - \bar{y})(x_i - \bar{x})}{\sqrt{\sum_{i=1}^n (y_i - \bar{y})^2 \sum_{i=1}^n (x_i - \bar{x})^2}} \right|. \quad (4)$$

In general, a segmented image is highly susceptible to noise in the object boundary, and the border data can include spurious pixels. Therefore, a weighted moving average is employed to reduce the influence of angles measured in noisy frames as

$$\theta_{jnt}(n) = \frac{\sum_{k=n-q}^{n+q} (\gamma_{jnt,k} \cdot \theta_{jnt,k})}{\sum_{k=n-q}^{n+q} \gamma_{jnt,k}} \quad (5)$$

where  $q$  is a size of moving window, here set to 2.

To determine the lower body points, knee and ankle points are calculated by

$$x_{ka}, y_{ka} = \left[ x_i + L_s \cos(\theta_{jnt} + \phi) \quad y_i + L_s \sin(\theta_{jnt} + \phi) \right] \quad (6)$$

where  $\phi$  is the phase shift,  $x_i$  and  $y_i$  are the joint coordinate of a higher rank such as pelvis, and  $L_s$  is the length of the thigh or shin guided by known properties of body segments.

#### 4. Human Gait Signatures and Kinematic Features

There are nine coordinates (body points) determined by topological analysis and linear regression in human body:  $(x_{head}, y_{head})$ ,  $(x_{neck}, y_{neck})$ ,  $(x_{shoulder}, y_{shoulder})$ ,  $(x_{waist}, y_{waist})$ ,  $(x_{pelvis}, y_{pelvis})$ ,  $(x_{knee1}, y_{knee1})$ ,  $(x_{knee2}, y_{knee2})$ ,  $(x_{ankle1}, y_{ankle1})$ , and  $(x_{ankle2}, y_{ankle2})$ . Figs. 3(a) and (b) show the body signature obtained by connecting the nine coordinates and the graphical demonstration of the joint angles used in the gait signature.

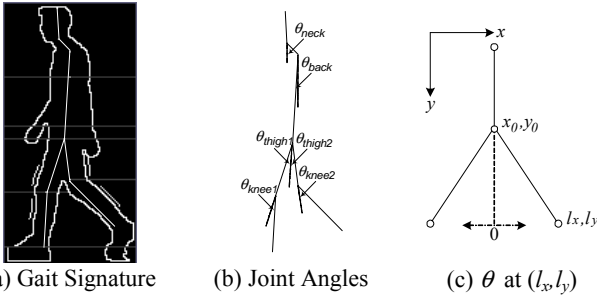


Figure 3. Gait Signature and Joint Angles

In motion analysis of human gait, kinematic characteristics include linear and angular position, their displacements and the time derivatives, notably the linear and angular velocities and accelerations. These kinematic characteristics can be well represented by trajectory-based features. Now we can calculate the six angles which are associated with these joints:  $\theta_{neck}$ ,  $\theta_{back}$ ,  $\theta_{thigh1}$ ,  $\theta_{thigh2}$ ,  $\theta_{knee1}$ , and  $\theta_{knee2}$ . In general, the angle  $\theta_{l,k}$  of location  $(l_x, l_y)$  at frame  $k$  is calculated by

$$\theta_{l,k} = \tan^{-1} \left( (l_x - x_c) / (l_y - y_c) \right). \quad (7)$$

The angular velocities  $\omega_{l,k}$  at frame  $k$ , given an inter-frame time  $\Delta t$  (1/25 sec, for Fig. 4), are

$$\omega_{l,k} = (\theta_{l,i} - \theta_{l,k-1}) / \Delta t. \quad (8)$$

Also, the gait velocity  $v_k$  at frame  $k$  is calculated by

$$v_k = (x_k - x_{k-1}) / \Delta t. \quad (9)$$

#### 5. Results

In the experiments, three different humans with around 32 consecutive images of each sequence are used for analyzing gait data. A set of the gait data extracted from image sequences provides potentially valuable time-dependent patterns as a gait time series. Figs. 4(a), (b) and (c) show the gait

signature, the relative angles of thigh and knee during a gait cycle. These are consistent with medical data of Figs. 1(a) and (b) and differ between subjects. In figure (d), we can find a periodicity of human gait motion. We can also predict a gait motion by using the phase-space portrait.

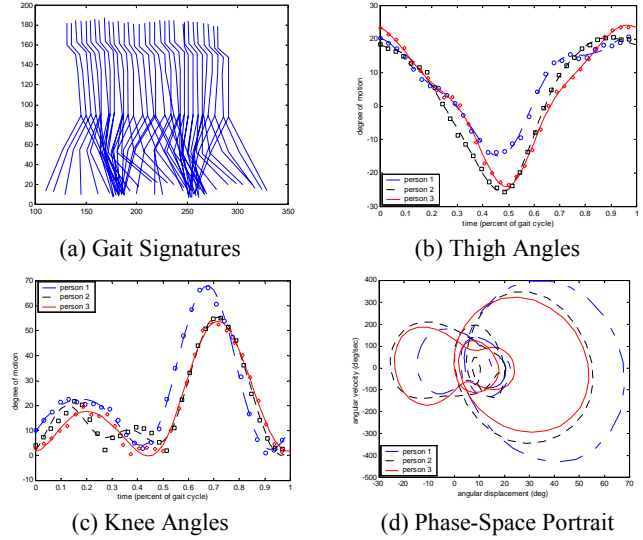


Figure 4. Experimental Result

To recognize human by gait motion, an enhanced back-propagation algorithm is employed as a classifier, and a small number of gait features are used as input data. We have mainly used kinematic features selected based on heuristic knowledge. The features are extracted from the image sequence during a time periodic. Though the recognition rate here was 100% we have used a very small set of data for classification, thus making meaningful comparisons of recognition performance impossible. Naturally we seek to extend the analysis in future.

#### 6. Conclusions

We have described a new method for extracting the gait signature and kinematic features for analyzing the gait motion and recognizing people, guided by known anatomy. As such, this new approach appears to recognize the body's structure and its motion. In future we seek to clarify the technique in terms of application capability as well as analyzing a larger database of subjects.

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