Viewpoint Invariance in Automatic Gait Recognition

Nicholas M. Spencer, John N. Carter
Image, Speech and Intelligent Systems
University of Southampton, UK
{nms00r | jnc}@ecs.soton.ac.uk

1. Introduction

Biometrics are not perfect and many suffer from social and practical problems. One may need to make physical contact with systems, for example fingerprinting, or suffer social embarrassment when interrogating a voice recognition system. Biometrics that need no physical contact such as face recognition are more acceptable to users but can be limited by practical issues such as face visibility. Gait is one of the newest biometrics and has potential of overcoming many problems. It requires no contact, is not easily concealed and uses the body as a more accessible target which is why it attracts much interest and research for possible application in identification at a distance. There is a rich literature, including medical and psychological studies, indicating the potential for gait in personal identification[4]. Early medical studies suggest that if all gait movements are considered then gait is unique. Murrays[3] work indicates that gait contains 24 different components giving it the richness necessary for a successful biometric.

Hip rotation can be modeled as a simple pendulum, whose motion is approximately described by simple harmonic motion and can be expressed as a Fourier series[1]. This has also been extended to include the lower leg by using a bilaterally symmetric and coupled oscillator model[5], where the signature is created from the phase-weighted magnitude of the lower order Fourier components of both the thigh and lower leg rotations.

Carter and Nixon[2] use a model based perspective technique to correct measured gait angles from geometrically marked limb positions transformed under oblique trajectory angles to the observer. They show that gait signatures based on phase and high order amplitude measurements are independent of pose.

We generalise further on this model by including camera elevation angle. We analyse the effects of different trajectories and elevation angles for multiple periods of synthetic gait and show that subject position is important. We develop a new technique and experimentally confirm that angles can be successfully corrected which shows promise in normalising multiple periods of human gait under similar conditions.

2. Gait Signatures and Pose

We consider a model based technique to correct measured angles under simple pin hole perspective geometry. Angles defined between two points, say the hip and knee positions or knee and ankle, are deformed by the perspective transformation, motion trajectory angle, and camera elevation angle. Previous work[2] on viewpoint invariance shows that human gait measured along varying trajectory angles θ to the camera can not be simply cosine corrected for the trajectory angle, but that the angle of the plane of the leg swing α, with respect to the vertical, must be taken into account.

$$\tan\phi = \frac{\tan\psi}{\cos\theta} - \tan\alpha\tan\theta \qquad (1)$$

Equation 1 describes the true thigh angle ϕ in terms of the measured angle ψ, the trajectory θ, and the inclined thigh α angles under simple pin hole perspective geometry. This implies that the true hip angle can be calculated directly from the measured angle and that the correction is simply a linear scaling with an offset dependant on trajectory and hip inclination angles. The equation also suggests that if $\tan\phi$ is used instead of the angle ϕ itself as a measure, then a biometric can be extracted without knowledge of the trajectory and hip inclination angles.

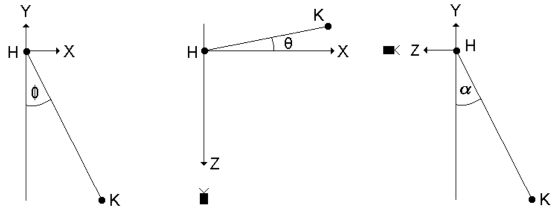
$$\tan\phi = A_0 + A_1\left[\sin(\omega+\theta_1) + \sum_{n=2}^{N}\left(\frac{A_n}{A_1}\right)\sin(n\omega+\theta_n)\right] \qquad (2)$$

Equation 2 is a modified Fourier series where the amplitudes of the higher harmonics have been normalised by the amplitude of the fundamental. Combining the angle correction, equation 1, and equation 2 suggests that phase and high order amplitude ratios form a gait signature that is independent of pose.

3. Simple Angle Correction

The true thigh angle ϕ, is defined by the angle between the hip and knee points, H and K respectively. We assume that people walk periodically in straight lines along a trajectory θ degrees to the X axis, with a small inclined hip angle α and the camera elevated by β degrees from the ground plane.

In a simple projective camera system, measured gait angle ψ is computed from the projected positions of the pose transformed hip, and knee points, H' and K' respectively for a camera C with focal distance f.



(a) Front View (b) Plan View (c) Side View

Figure 1: Front view shows the true gait angle ϕ, measured relative to the Hip (H) and Knee (K) positions. The plan view shows the trajectory angle θ, corresponding to the direction of motion and the side view shows the thigh inclination angle α from the vertical.

$$\tan\psi = \frac{\left[\frac{fK'_x}{C_z - K'_z} - \frac{fH'_x}{C_z - H'_z}\right]}{\left[\frac{fH'_y}{C_z - H'_z} - \frac{fK'_y}{C_z - K'_z}\right]} \tag{3}$$

The pose transform is defined by rotating the hip and knee points by the trajectory θ and elevation β angles then translating along the direction of motion. If the camera is assumed to be far away from the subject the depth values $C_z - H'_z$ and $C_z - K'_z$ are much greater than the components of position so the x, y translational components can be neglected and the true angle equation can be expressed in terms of the measured and rotation angles.

$$\tan\phi = \frac{\tan\psi\left(\cos\alpha\cos\beta - \cos\theta\sin\alpha\sin\beta\right) + \sin\alpha\sin\theta}{\tan\psi\sin\theta\sin\beta + \cos\theta} \tag{4}$$

This equation is invariant to subject position and camera focal distance, therefor also invariant to camera view angle.

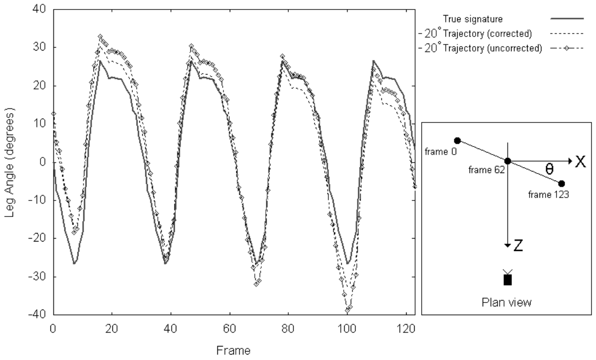


Figure 2: Multiple periods of synthetic gait signature for trajectories at 0 and -20 degrees with a 30 degree camera elevation angle and a 6 degree thigh inclination angle.

Figure 2 shows multiple periods of synthetic gait signature for subjects walking at 0 and -20 degree trajectories with a 30 degree camera elevation angle. It also shows that the fundamental period of gait is unaffected by the pose and projection transforms, and that equation 4 is a good correction close to the optical axis of the camera where the error of neglecting the positional components is minimal, i.e: a tracking camera system. However, corrected angles deviate greatly from the true reference signature at greater distances from the optical centre.

4. Off Axis Correction

Obviously the position of the subject can't be ignored, this is due to the translational contribution to the perspective distortion. The model must therefor be adjusted to incorporate the positional components. For simplicity we formulate a correction for trajectory θ and elevation β without the inclined thigh angle α, but note that a general correction is possible using the same method.

The pose transformed three space points H', K', defined by rotating the H, K points by the trajectory θ and elevation β angles then translating along the direction of motion, are mapped by projection of the camera to the image coordinates h and k. The measured angle equation can then be rewritten in terms of these image coordinates by substituting $\left[\frac{h_x}{f}, \frac{h_y}{f}\right]^T$ for the transformed points $\left[\frac{H'_x}{C_z - H'_z}, \frac{H'_y}{C_z - H'_z}\right]^T$.

$$\tan\phi = \frac{\frac{\sin\beta}{f}\left(h_y\tan\psi + h_x\right) + \tan\psi\cos\beta}{\tan\psi\sin\theta\sin\beta + \cos\theta - \frac{\sin\theta\cos\beta}{f}\left(h_y\tan\psi + h_x\right)} \tag{5}$$

The correction, equation 5, contains the camera focal length f, therefor unlike the simple angle correction of equation 4 is dependant on the camera viewing angle as well as position. The correction has no simple linear approximation that allows a measure to be directly extracted as in equation 2 without knowledge of the trajectory and elevation angles.

4.1. Laboratory Experiments

A test pattern with groups of points was placed on a rigid surface. The angle correction in equation 5 was applied to the measured cluster angles and the correspondences plotted for similar angle groups at different distances along the trajectory.

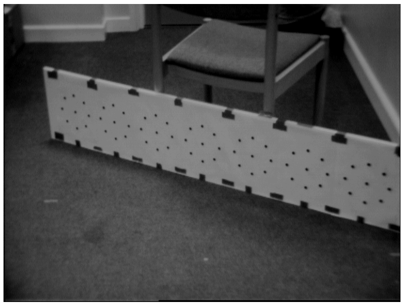
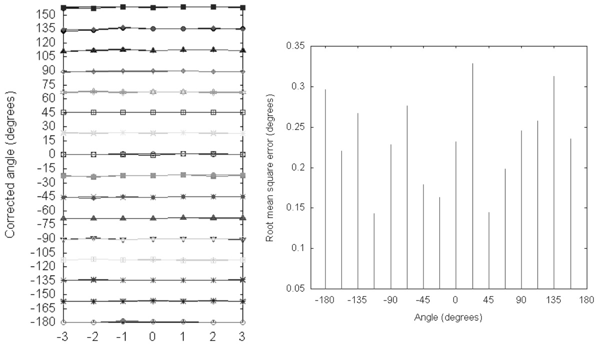


Figure 3: Test group patterns shown at -30 degree trajectory and 30 degree elevation angles, captured using a Hitachi KP-111 surveillance camera placed 6 metres from the target.

Since the orientation of the test pattern is known and the focal length f is constant the camera need not be calibrated. The true angle corresponding to the angle combination across the groups can be found by minimising the variance of the corrected angles over the range of f.



(a) Corrected angle groups for similar angles displaced along the trajectory

(b) Root mean squared error between true and corrected angles

Figure 4: Angle correction and error plots on a real data image for similar points across groups at -30 degree trajectory and 30 degree elevation angles.

Figure 4 shows that similar angles with differing displacements modified by the trajectory and the camera viewing transforms can successfully be corrected by using this method.

Equation 5 can be generalised to include the hip inclination angle α. On formulating the general correction and substituting the frontoparallel parameters $\theta = 0, \beta = 0$ into the equation leads to the correction required for hip inclination angle α in frontoparallel motion.

$$\tan\phi = \frac{\sin\alpha}{f}\left(h_y \tan\psi + h_x\right) + \tan\psi\cos\alpha \tag{6}$$

Angle warping is greatest further from the optical axis so image sequences where the subject is filmed traversing across and close to the camera could suffer from this distortion.

Figure 5 shows an error corresponding to a maximum difference of 3.7 and 1.9 degrees seen furthest from the optical axis in the 5 and 10 metre camera distance plots respectively. This may ultimately limit the recognition rates obtained in laboratory experiments[1, 5] if not taken into account.

5. Conclusions

We have shown that the small angle assumption for neglecting positional $[x, y]$ information in the generalised simple angle correction holds for positions close to the optical axis but quickly becomes distorted even under moderate camera distances. The simple angle correction may have an application in tracking camera systems where the subject is always targeted at the optical centre.

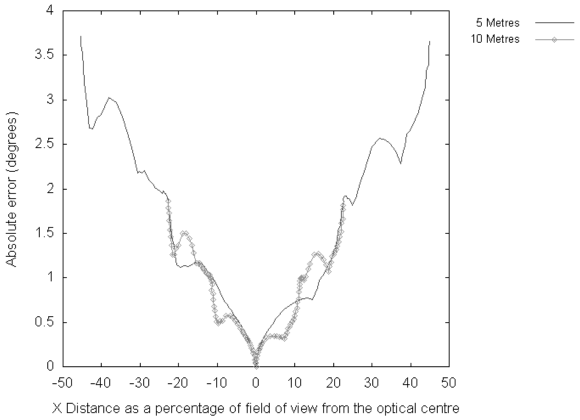


Figure 5: Absolute errors measured between the true gait signature and the measured angles for cameras placed at 5 and 10 metres from the subject in frontoparallel synthetic motion data. The hip inclination angle has been set to 6 degrees to generate the plots.

It has been shown that the new angle correction technique works under known orientation to the camera. We have shown that similar angles across point groups in test pattern images when transformed and projected can be corrected. This is directly applicable to human gait where similar angles in subject space are defined at positions of equal phase and at integer multiples of the period.

The results presented here could have implications on current techniques that use points and angles as a basis of biometric identification for subjects walking at angles to the camera. The model and the corresponding correction indicates that thigh inclination angles contribute to the distortion across frontoparallel motions, causing dissimilar signatures for near and far motions of the same subject. Experiments with real world multi period gait data is required to back up the theory in this work, especially concerning the error in projective distortion in frontoparallel motion.

References

[1] D.Cunado, M.S.Nixon, and J.N.Carter. Automatic gait recognition via model-based evidence gathering. In *AutoID '99: IEEE Workshop on Identification Advanced Technologies*, pages 27–30, 1999.

[2] J.N.Carter and M.S.Nixon. On measuring trajectory-invariant gait signatures. In *IAPRS*, volume XXXIII, Amsterdam, 2000.

[3] M.P.Murray. Gait as a total pattern of movement. *American Journal of Physical Medicine*, 46(1):290–332, 1967.

[4] M.S.Nixon, J.N.Carter, D.Cunado, P.S.Huang, and S.V.Stevenage. In A. Jain, R. Bolle, and S. Pankanti, editors, *Biometrics: Personal Identification in a Networked Society*, pages 231–250. Kluwer Academic Publishing, 1999.

[5] C. Yam, M.S.Nixon, and J.N.Carter. Extended model based automatic gait recognition of walking and running. In *AVBPA 2001*, 3, pages 278–283, June 2001.