Abnormal Gait Recognition

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Abstract

Due to increasing crime rate identification using biometrics has become an important field of research. When it is not possible to take snapshot, to read iris, to take finger prints etc then identification using gait may be proved an effective tool to identify a person. This paper presents a method which distinguishs between normal and abnormal gait. A person having abnormal gait may be categorize as suspicious and alarming actions may be taken. Experiments have been done on real world data and system has been trained for normal walk for real world subjects.

Keywords

Abnormal Gait, Binarization, Video Segmentation, Angular Acceleration, Gait Challenges, Silhouette.

1. Introduction

Due to increased security problems gait analysis has become area of interest for researchers from the last few decades. Gait analysis can be categorize as clinical gait analysis and biometric gait analysis. Clinical gait analysis uses collection of kinematic data in controlled environments using motion analysis systems and the data acquisition system is integrated with motion analysis. Motion analysis provide information regarding gait cycle, speed, walking events etc. Biometric gait analysis can be used for authentication purposes because reliable authorization and authentication has become an integral part of every man's life for a number of routine applications. Biometric is an automated method of recognizing a person based on a physiological or behavioral characteristic. Recognizing a person by his gait is strongly driven by the need for automated person identification systems for visual surveillance and monitoring. Biometrics, such as face, voice, speech, iris, fingerprints, gait etc. have come to occupy an increasingly important role in human identification due, primarily, to their universality and uniqueness. Gait is a vision-based human identification at a distance and has recently gained wider interest from the computer vision community due to day by day increasing crime rate and terrorism. Identification using gait has applications in security-sensitive environments such as banks, shopping malls, parking lots, and airports etc. It is considered a reliable solution for protecting the identity and the rights of individuals as it recognizes unique and immutable features. Biometrics can be used for two different authentication methods:

• Identification: This involves establishing a person's identity based only on biometric measurements. The comparator matches the obtained biometric with the ones stored in the database bank using a 1:N matching algorithm for identification.

• Verification: It involves confirming or denying a person's claimed identity. A basic identity (e.g. ID number) is accepted and a biometric template of the subject taken, is matched using a 1:1 matching algorithm to confirm the person's identity.

In this paper an algorithm has been proposed to distinguish between normal and abnormal gait of a person or to identify a suspicious person. Sometimes an identified person may be suspicious. His gait at the time of crime may be found abnormal. Work has been done on real world subjects and real time database has been prepared. Experiments have been done at Govt. Polytechnic for Women, Faridabad(Haryana). And the factors affecting the normal gait also has been considered. The process is defined in section 4.

2. Gait Challenges

The factors that influence a biometric gait system categorize into two classes:
• External factors: Such factors mostly impose challenges to the recognition approach. e.g.
-Viewing angles like frontal view, side view etc.
-Lighting conditions like day/night, shadow etc.
-Outdoor/indoor environments e.g. sunny, rainy days
-Clothes e.g. Sarees, Suits, Trousers or Skirts, gown etc.
-Walking surface conditions e.g. hard/soft, dry/wet, grass/concrete, level/stairs, etc.
-Shoes types e.g. mountain boots, sandals
-Object carrying e.g. bag, backpack, briefcase etc.

• Internal factors: Such factors cause changes of the natural gait due to internal changes in body.
-Sickness
-Foot injury
-Lower limb disorder

-Parkinson disease
-Physiological changes in body due to aging, drunkenness, pregnancy, gaining or losing weight and so on.

3. Related Work

From the very beginning gait recognition derive a gait signature from a spatio temporal pattern. In [1] human gait is recognized using clustering partitioning. In [2] eigen vectors are used as gait features. In [3] the model based gait recognition system models human walking as a pendulum. Hough transform with a Fourier representation is used to obtain the gait signatures. In [4] a structural model is used to recover static body and stride parameters. In [5] ellipses were fitted to seven regions representing the human body, then derived two types of features across time: mean and standard deviation, and magnitude and phase of these moment based region features. In [6,11,15] the method is based on angular motion of hip and thigh, where angular motion of hip and thigh is defined as Fourier series. In [12] an approach to describe the hip, thigh and knee angular motion of both walking and running gaits first by an empirical motion model, then by an analytical model motivated by coupled pendulum motion. In [14] modified independent component analysis is used for human identification and NLPR gait database is used for experimental purposes.

3.1 Gap in previous researches

Although previous researchers have claimed that gait recognition has applications at air ports, malls, parking lots etc. but every time system has been trained with very controlled database. In malls, airports etc. the clothing conditions, heals, carrying conditions can not be controlled. Emotions of different persons may be different. So system should be able to work with real world database in real world conditions. The researches are silent from security point of view that how system will categorize the gait of an identified person as abnormal or suspicious.

4. Material and Method

In this section data collection techniques and working algorithms are discussed in detail.

4.1 Data acquisition

The experiments have been done on 77 subjects having age 18 and above at Govt. Polytechnic for Women, Faridabad(Haryana). The purpose of experiments was explained to each subject before taking part into experiments. 26 number of males and 51 number of females participated in these experiments. During experiments subjects were wearing different types of clothes like pent, shirt, jacket, suit, salwar and saree etc. The shoe heels also have been considered during experiments. They were told to walk on the track shown in Figure 1.

4.2 The Process

Video has been recorded using SONY HVR-Z7U video camera. The distance between camera and track was around 26 feets and length of track was 21 feets. 77 persons have participated in experiments.

Figure 1. Background with track of walking

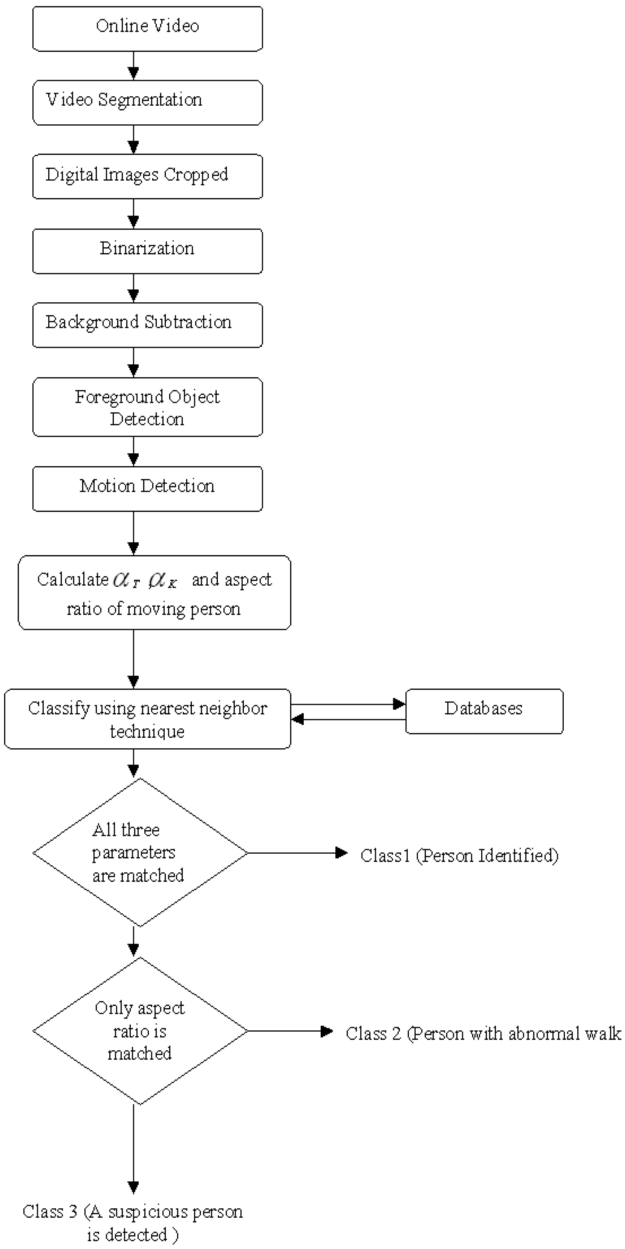

Figure 2. Algorithm for abnormal gait detection

Video has been recorded for each subject. After that video has been segmented as per gait cycle of each person and period of gait cycle has been recorded. From the segmented video, the digital snaps has been captured and cropped. After that binarization of these images has been done. The background also has been modeled and image of background has been subtracted from the current image to detect the foreground object. Motion has been detected by subtracting the image from its next consequent image. If there is significant difference of pixels between the two then motion is there. Put a bounding box upon the moving object by calculating its extreme points. Now, its aspect ratio is calculated. The edges of moving object has been detected using Sobel edge detector.

Now, thigh angle, knee angle and ankle points has been calculated for each image. After that mean angular displacement of thigh and knee for each person has been calculated and compared with that stored in database.(This time the actual physical measurements.) Nearest neighbor technique has been used to classify the image belongs to class1 (person identified), class 2 (person with abnormal walk) or class 3 (a suspicious person). For all this modeling MATLAB programming has been used. The above process has been shown in Figure 2.

Figure 3. One subject from Real World Database at S.No. 9 of Table 1 and 2

4.3 Pattern of Movement

It is observed that human walking is periodical/ oscillatory motion. One of the unique characteristics of human gait is bilateral symmetry [12] between the two legs as shown in figure 3. Figure 4. and 5. shows a graph of angular displacement of thigh and knee of Sr. No. 6 of Table 1. These two figures shows the actual physical measurements. It is very clear from the graph that the motions of the left and right leg are coupled by half a period phase shift.

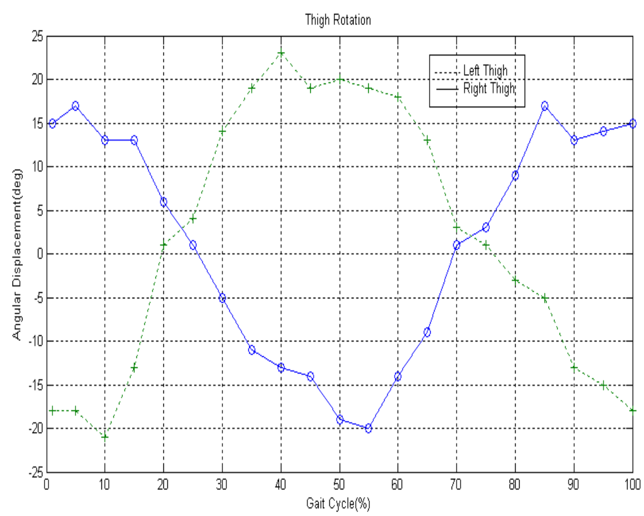

Figure 4. Graph of actual physical measurements of thigh rotation of Sr. No. 6 of Table 1.

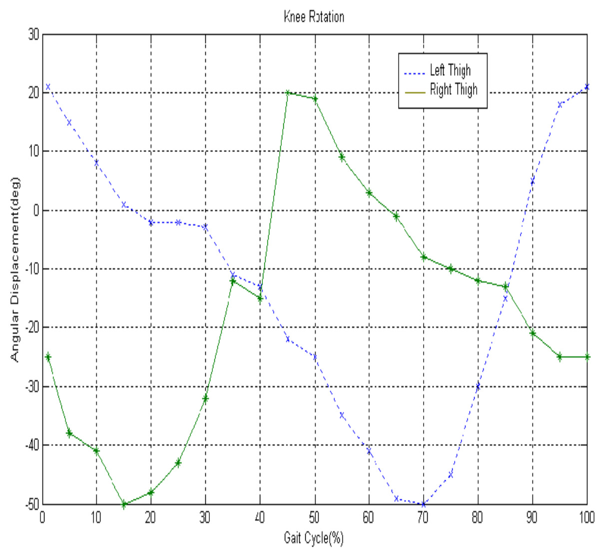

Figure 5. Graph of actual physical measurements of knee rotation of Sr. No. 6 of Table 1.

4.3.1 Thigh and Lower Leg Motion

The human lower leg can be represented as two penduli joined in series as shown in figure 6.

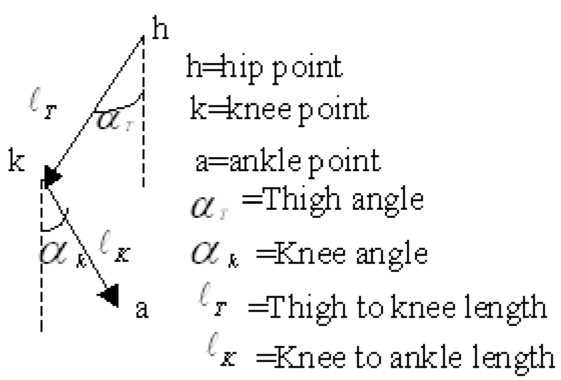

Figure 6. Line representation of human leg

As per the kinematics of two penduli in series where external force is zero, the motion equation can be represented as follows[13]

$$\alpha_T'' + \frac{\omega_T^2}{m_T}\alpha_T = 0 \tag{1}$$

where α_T is angular displacement from the vertical, α_T'' is the angular acceleration, m_T is the mass and ω_T is natural frequency. So the motion can be modeled as

$$\alpha_T = P\cos\left(\frac{\omega_T}{\sqrt{m_T}}t\right) + Q\sin\left(\frac{\omega_T}{\sqrt{m_T}}t\right) \tag{2}$$

where *P* and *Q* are constants, and *t* is the time index which varies from 0 to 1. The acceleration is given as

$$\alpha_T'' = -\frac{\omega_T^2}{m_T}\left[P\cos\left(\frac{\omega_T}{\sqrt{m_T}}t\right) + Q\sin\left(\frac{\omega_T}{\sqrt{m_T}}t\right)\right] \tag{3}$$

which contributes to the driving force to the lower pendulum. As per Newton's Law *F=m*a* where *m* is mass and *a* is acceleration. So this force is given by

$$F(t) = -\omega_T^2\left[P\cos\left(\frac{\omega_T}{\sqrt{m_T}}t\right) + Q\sin\left(\frac{\omega_T}{\sqrt{m_T}}t\right)\right] \tag{4}$$

so the motion equation for lower pendulum is

$$\alpha_K'' + \frac{\omega_k^2}{m_k}\alpha_K = -\frac{F(t)}{m_k} \tag{5}$$

Substituting Eq. 4 into 5 will give

$$\alpha_K'' + \frac{\omega_k^2}{m_k}\alpha_K = \frac{\omega_T^2}{m_k}\left[P\cos\left(\frac{\omega_T}{\sqrt{m_T}}t\right) + Q\sin\left(\frac{\omega_T}{\sqrt{m_T}}t\right)\right] \tag{6}$$

The solution for α_k will comprise the general solution, α_{kg}, and the particular solution, α_{kp}, i.e. $\alpha_k = \alpha_{kg} + \alpha_{kp}$. The general solution is obtained by setting $F(t) = 0$ in Eq. 5 solving this gives

$$\alpha_{kg} = P\cos\left(\frac{\omega_K}{\sqrt{m_T}}t\right) + Q\sin\left(\frac{\omega_K}{\sqrt{m_K}}t\right) \tag{7}$$

where *R* and *S* are constants. Let $a = \omega_T / \sqrt{m_T}$, $b = \omega_k / \sqrt{m_k}$, and the result is

$$\alpha_{kp} = -\frac{\omega_T^2}{m_k(a^2 - b^2)}(P\cos at + Q\sin at)$$

(8)

By substituting Eq.8 and Eq.9

$$\alpha_k = R\cos bt + S\sin bt - \frac{\omega_T^2}{m_k(a^2-b^2)}(P\cos at + Q\sin at)$$
(9)

Phase (ϕ_T), amplitude(E), offset (M_T, M_k) and scaling (Z) are added to the original motion models that serve as the foundation of describing the motion of the thigh Eq.3 and lower leg Eq.10 and yield,

$$\alpha_T = P\cos\left(\frac{\omega_T}{\sqrt{m_T}}t + \phi_T\right) + Q\sin\left(\frac{\omega_T}{\sqrt{m_T}}t + \phi_T\right) + M_T \quad (10)$$

$$\alpha_k = E[R\cos(Zbt) + S\sin(Zbt) - \frac{\omega_T^2}{m_k(a^2-b^2)}(P\cos(Zat+\phi_T) + Q\sin(Zat+\phi_T) + M_T)] + M_K \quad (11)$$

5. Structural Model of Thigh and Lower Leg

As shown in Figure 6 that points *h*, *k* and *a* corresponds to hip, knee and ankle. The position of knee at any time t depends upon the thigh angle and length from thigh to knee. In trigonometric form this can be represented as follows:

$$k_x(t) = h_x(0) - \ell_T \sin\alpha_T(t) \quad (12)$$

and

$$k_y(t) = h_y(0) + \ell_T \cos\alpha_T(t) \quad (13)$$

where ($h_x(0)$, $h_y(0)$) is initial position of hip.

Similarly, the position of ankle depends upon the position of knee and length from knee to ankle which can be represented as

$$a_x(t) = k_x(t) - \ell_k \sin\alpha_k(t) \quad (14)$$

and

$$a_y(t) = k_y(t) - \ell_k \sin\alpha_k(t) \quad (15)$$

So, the above equations form the basis of model and used to determine the lines of motion during feature extraction.

6. Feature Extraction

High quality video of waking persons are made. These are segmented into frames and individual images. These images are resized to reduce the computational costs and converted to grayscale images. Then simple Sobel edge operator is applied to get the silhouette and hence the database has been prepared as shown in figure 7. The value of threshold is adjusted [13] using the Eq. 16.

$$X = \begin{bmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{bmatrix} Y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \quad (16)$$

$$Th = \sqrt{X^2 + Y^2}$$

where *Th* is threshold value.

Figure 7. The process of transforming a colored image to leading edge silhouette.

The angles during the walk are calculated and aspect ratio of moving person is measured which are acting the major features of this model.

7. Experiments and Results

Experiments have been done on 77 subjects. For each person Torso length, Waist to knee and knee to foot lengths are calculated. Stride lengths are measured and angles are calculated as shown in Table 1 and Table 2. For experiments M_T =1 has been taken. It has been observed that ϕ_T is different for each person and it varies from 45-53 degrees normally. For experimental purposes it has been taken 45 degrees. Angular frequencies are measured through camera and results are shown in Table 2. During the experiments the shoe heels during walk also have been considered.

Test sequences has been divided into three categories viz S1, S2 and S3. S1 is sequence of images of a person with normal walk from the database with which system has been trained. S2 is sequence of images of a running person. S3 is a sequence of a person who is not a part of training database. In case of S1 recognition rate varies from 65% to 78%. In case of S2 recognition rate varies from 54% to 58%. In case of S3 recognition rate varies from 16% to 38%.

TABLE 1. First fifteen persons from real world data with actual physical measurements for normal gait.

S. No.	Name	Designation	Sex (M/F)	Age	Clothing	Height (in inches)	Torso Length(in inches)	ℓ_T Waist to Knee(inches)	ℓ_K Knee to Foot(inches)	Stride Length(inches)	Shoe Heels(inches)
1	Nand Kishor	Peon	M	32	Jacket, Pent	67	20	19	21.5	18	0.5
2	M.S. Lohan	DSO	M	54	Jacket, Pent with Muflar around	68	19	21	22	20	1
3	Pratap Singh	Assistant	M	45	Swetar and Pent	63	17	17	19	12	1
4	Krishan Kumar	Clerk	M	46	Swetar and Pent	63	18	18	18	19	1
5	Karan Kumar	Peon	M	29	Swetar and Pent	66	19	18	19	18	0.5
6	Himmat Singh	Instructor	M	31	Swetar and Pent	69	20	20	22	22	0.5
7	Anil Kumar	Assistant	M	42	Swetar and Pent	65	19	19	21	15	0.5
8	Sandeep Kumar	Lecturer	M	30	Jacket, Pent	69	19	19	22	18	0.5
9	Vivek Dalal	Lecturer	M	30	Swetar and Pent	71	18	22	22	22	0.5
10	Narender Pal	Lecturer	M	31	Jacket, Pent	76	22	22	22	17	0.25
11	Kripa Ram	Instructor	M	44	Swetar and Pent	68	18	20	21.5	19	0.5
12	Raj Kapoor	Instructor	M	45	Swetar and Pent	67	19	19	21	15	1
13	Hem Lata	Lecturer	F	37	Suit-Salwar, Swetar and Shawl around	63	18	22	19	19	0.25
14	Vinita Yadav	Sr. Lecturer	F	40	Suit-Salwar-Duptta and Swetar	67.5	18	23	22	18	0.5
15	Meenu Raman	Sr. Lecturer	F	40	Coat and Saree	65	18	19	21	18	1

TABLE 2. Comparison of Model outputs and actual measurements.

S.No.	Name	Actual Measurements			Calculated by Model		
		θ_T mean	θ_k mean	Aspect Ratio	θ_T mean	θ_k mean	Aspect Ratio
1	Nand Kishor	23.563	16.332	0.27	25.67	18.31	0.26
2	M.S. Lohan	26.678	23.345	0.29	27.63	24.66	0.31
3	Pratap Singh	21.783	14.224	0.19	22.44	15.22	0.18
4	Krishan Kumar	28.543	27.565	0.3	28.89	27.21	0.31
5	Karan Kumar	27.345	24.677	0.27	26.54	23.68	0.22
6	Himmat Singh	29.656	28.986	0.31	28.64	27.31	0.3
7	Anil Kumar	26.234	23.432	0.23	27.22	23.78	0.22
8	Sandeep Kumar	26.876	24.568	0.26	27.32	25.86	0.27
9	Vivek Dalal	30.791	29.976	0.31	29.34	28.99	0.3
10	Narender Pal	27.685	24.4567	0.22	27.21	23.63	0.21
11	Kripa Ram	28.987	21.654	0.28	29.35	22.18	0.27
12	Raj Kapoor	29.563	23.453	0.22	30.76	24.48	0.21
13	Hem Lata	26.456	23.897	0.3	25.72	23.01	0.29
14	Vinita Yadav	28.867	18.764	0.27	29.2	19.59	0.26
15	Meenu Raman	NA	NA	0.28	NA	NA	0.29

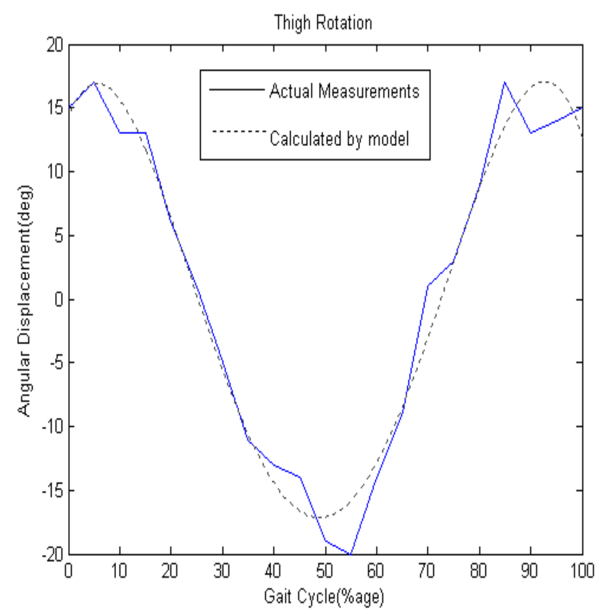

Figure 8. Thigh rotation measurements actual and calculated by model of subject 34 of experiment list.

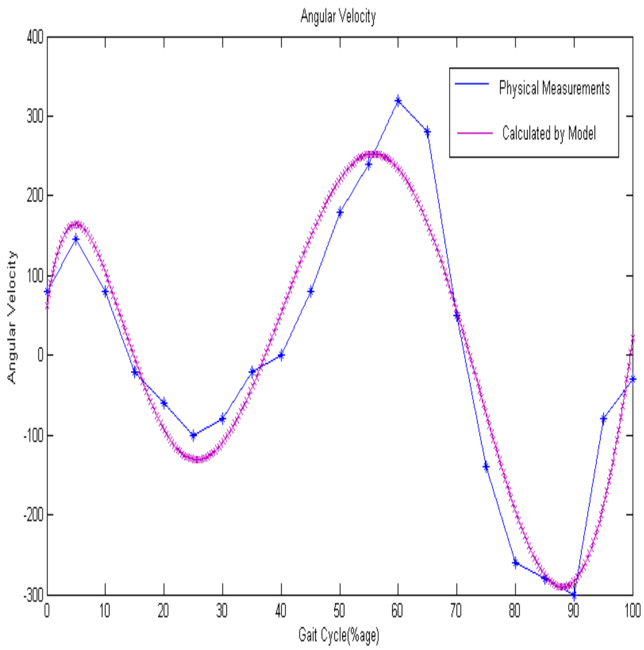

Figure 9. Comparison of angular velocity calculated by model and physically measured.

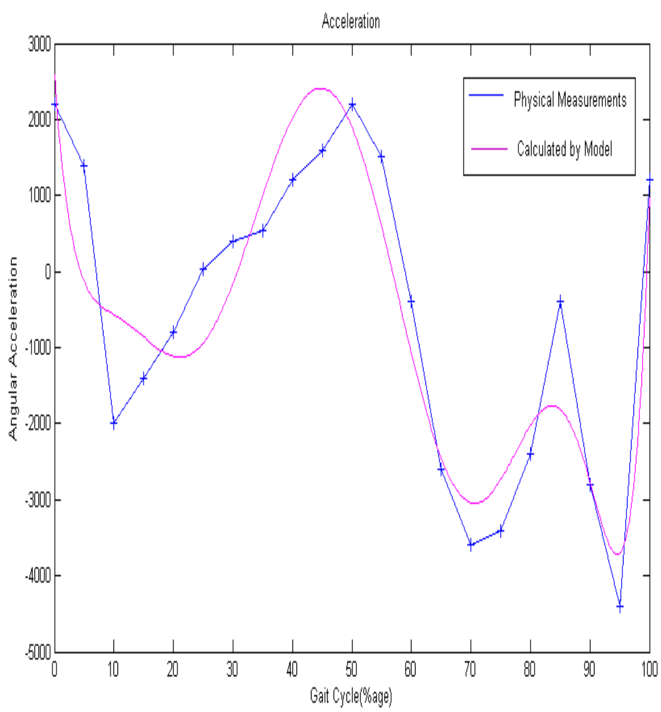

Figure 10. Comparison of angular a acceleration calculated by model and physically measured.

Figure 11. S.No. 15 of Table 1 and 2, wearing saree.

8. Conclusion and Future Work

The validity of a biometric system cannot be measured accurately, and can only be enumerated on the occurrence of errors like the chance of accepting an intruder i.e. the False Accept Rate (FAR) and conversely the probability of rejecting a genuine individual i.e. False Reject Rate (FRR) which could turn out to be detrimental to any system and hence to this model also. Firstly, If some person is having injury in his leg then his angles of movements will be different and the authentication of that person will be rejected and will fall in the category of suspicious. Second, for calculation purposes the phase shift has been taken constant due to that angles calculated by model are not as accurate as should be for surveillance applications. Although, shoe heals have been considered during walk and hence have been included during the measurement of aspect ratio but it has been observed that change in shoe heals directly affecting the aspect ratio due to that a genuine person may be rejected.

Although, this model is invariant for walking and running but is silent about clothing conditions. As during these experiments one subject was wearing saree shown in Figure 11 and through camera we are unable to calculate angles during her walk.

In our practical life when we see try to recognize a person without seeing his face then our mind applies a mixed approach of holistic and modular. Our mind keep track of his body shape, hands movements, angles during walk, stride etc. Our mind over come the problem of clothing or carrying because while these are affecting one or two parameters of recognition but others are clear in our mind. So to recognize a person accurately through camera by his gait it becomes necessary to apply a holistic and modular approaches in combined form.

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