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Simple and Efficient Marker-Based Approach in Human Gait Analysis Using Gaussian Mixture Model

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ABSTRACT

Background: Gait analysis is a valuable tool that can be used in human motion tracking in many applications. Most motion tracking are performed using Marker-based System technologies**. Objective:** we present a simple but efficient two dimensional (2D) marker-based method that extracts the gait parameters automatically from an image sequence to be used in different human identification applications. The proposed method consists from four main steps: 1) three simple colored markers are added to the clothes of the targeted subject; where ankle has a green color ,knee has a blue color and hip has a red color 2)a gait video sequence captured by a static camera; and we are concerned with only side view videos and normal gait3) Segmentation method based on Gaussian Mixture Model is used to partition each frame to ankle, knee, hip and outlier region, and 4) the joint position and other variables such as segment lengths, and dynamic parameters of human gait were then calculated to extract gait features. For each frame within the video sequence we form a vector that contain position, Angular position, Angular displacement, Angular velocity and Angular acceleration; this vector is created for each low limb joint and segment part; then all frame vectors are stacked on each other to form a feature vector for gait motion parameters. **Results:** Our results shows that The developed method can effectively establish the gait motion parameters to be used in human gait identification applications**. Conclusion:** The main advantages for the presented system is that it does not suffers from the common shortfalls of skin based marker techniques such as skin artifact, the excessive time and complexity required for marker placement, the need for a controlled environment to acquire high-quality data, the high cost for the markers, and the effect of the markers on the subject's movement**.**

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INTRODUCTION

Gait analysis is a valuable tool that can be used in the evaluation of neuromuscular disorders, musculoskeletal biomechanics, athletic injuries, to provide realistic animation for the entertainment industry, individual recognition and identity verification, and prosthetic joint replacements.

Currently, most of human motion tracking is performed using Marker-based System technologies (MBS), especially for medical applications (Bonnechère *et al.*, 2012). The ability to identify an unknown subject without their knowledge or cooperation is often required in many situations such as surveillance applications (Seely, 2010).When the recognition must should cover a large area and performed from a distance, techniques such as face or ear based recognition becomes impractical because of the insufficient resolution provided by the surveillance camera.

Gait analysis is a challenging research topic; in recent times the gait identification has received attention and has become an active area of computer vision (Mohamed Rafi *et al.,* 2011).The way in which one walks has been shown to vary between individuals; this was first recorded by (Murray *et al.,* 1964). Each person appears to have his or her own characteristic gait pattern (Lars *et al.,* 2006; Seely, 2010). The demand for automatic human identification systems is increasing in many important applications, and it has recently gained more interest from the pattern recognition and computer vision researchers. It is essential in many areas of modern day life; authorizing, financial transactions, and in preventing certain targeted individuals from travelling into a certain palace or country (Seely, 2010). Human motion analysis has many challenging issues related to the segmentation and analysis of motion (Jang And Mark, 2003); this is because the highly self-occlusion and flexible structure of the human body.

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Gait research in the present can take two main directions: first; the Clinical gait analysis which depends on collecting the gait data in controlled environments such as (Rohit Katiyar and Vinay, 2010; Surer, 2011), second: Biometric goals of human gait analysis which depends on collecting the gait data in different areas and scenarios as in (Sudha and Bhavani, 2011).

Most gait capture systems use external markers to acquire specific motion information, but require specialized hard ware and subject contact. This research area has been addressed as “marker-based”. Marker-based human movement analysis suffers from many shortfalls discussed by many researchers (Moe, 2011; Bonnechère *et al*., 2012). Amongst those shortfalls are; the instrumental errors, the soft tissues artifacts problem, the excessive time and complexity required for marker placement, the need for a controlled environment to acquire high-quality data, the high cost for the markers, the effect of the markers on the subject’s movement, and anatomical landmark misplacement. In this paper and to reduce these marker-based limitations we propose a new simple 2D marker-based technique based on Gaussian Mixture Model and three simple colored markers that can overcome the abovementioned difficulties of marker-based systems. We add three colors to the clothes of the targeted subject; where ankle has a green color, knee has a blue color and hip has a red color.

Considerable research has been done in gait analysis research. In (Tatacipta *et al.,* 2012) the authors presented a review on the development of an optical based gait analysis system at Institute Teknologi Bandung. The development process started with a 2D inverse dynamic analysis of human gait using five linkages; based on an experimental motion data. The system consist of a camera, LED markers and a PC, the position of the markers were obtained by capturing and processing digital images of markers attached to human body during motion. The marker positions data was then used for further kinematics and dynamic analyses. From the analyses, the spatiotemporal gait parameters such as stride-length, cadence, cycle-time, speed and joint angles can be obtained as well as forces and moments. In the second development stage, the 2-D analysis was improved by using seven linkages to include the foot. The improved system has been able to analyze ankle angle, position of the center of pressure and ground reaction force distribution. In the third current development stage; a 3D dynamic analysis of human gait using two cameras and a PC is implemented. As an outcome of this development, a database of Indonesian normal gait was established. in (Michela *et al.,* 2009) the authors presented a 2D gait analysis system which is completely marker-less, they extracted kinematic information by analyzing video sequences obtained from an RGB video camera. They obtained good results; the performance of the proposed method is particularly encouraging for its appliance in the real medical context. in (Mohamed Rafi *et al.,* 2011) the authors described a new model-based feature extraction analysis based on Hough transform technique that help in determining the main parameters to generate gait signatures that automatically recognize the human gait by extracting and describing it using certain parameters. The authors extracted a sequence of picture frames for each video; then they used them to feed the Canny edge detection algorithm to detect edges of the image, they used Gaussian filter to decrease the noise, then they design their line based model based on Hough transform to get the gait distinguishing variables. They tested their model on a database composed from twenty subjects. Their results were promising, and they suggested that the algorithm could be used to build a robust system for gait monitoring. (Jang And Mark, 2011) presented a new method for an automated marker less system to describe, analyze, and classify human gait motion. They used a sequential set of 2D stick figures to represent the gait motion for humans, and then a set of parameters were extracted from the motion and sent to a k-nearest neighbor classifier to classify the gait patterns. In (Leong, 2007) the authors proposed a novel method of body feature extraction from a marker-less scanned body. They Employ image processing and computational geometry techniques to automatically identify the body features from the torso cloud points.

Motion capture with a single camera is a significant task since data acquisition is very simple, besides being an interesting computer vision challenge that focuses on inference as much as movement (Surer, 2011). In (Surer, 2011) a two dimensional marker-based technique have been proposed. They used digital video cameras to capture the gait, and the gait joint position is extracted from the image sequences. The gait motion from frame to frame was described by tracking the moving points.

Gait Analysis Method:

Motion capture with a single camera is a significant task since data acquisition is very simple, besides being an interesting computer vision challenge that focuses on inference as much as movement (Surer, 2011). In this paper we intended to introduce a simple system that relay on a single camera.

To overcome the limitations of marker-based techniques we propose to add three colors to the clothes of the targeted subject; where ankle has a green color, knee has a blue color and hip has a red color. Our proposed 2D marker-based approach uses simple, comfortable to wear, error free instrument, fast to wear, free from anatomical landmark misplacement, and low cost markers. The proposed system uses the Gaussian Mixture Model as a segmentation procedure to subtract the background from the moving body parts on the acquired image frames. The proposed system also uses a number of techniques which will be described in the coming text to extract kinematic information by analyzing video sequences obtained from an RGB video camera. The proposed method have the following main steps: video capture, Segmentation, feature extraction. It is shown in figure 1.

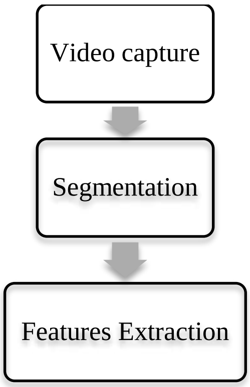

Fig. 1: Gait analysis Process.

The joint regions of gait contain significant information that helps in the identification of individuals, and therefore joint motion is extracted. Human gait motion is non-rigid structured, because the gait consists of many connected parts which can create complex kinematics, we can capture global gait motion and local joint motion to help us in the gait analysis, global motion such as the pose of the leg. Where the local motion can be determined by a set of joint angles. But it should be clear that the human gait motion is difficult to model. Usually, the gait can be modeled in several aspects such as shape, kinematical structure, and dynamics.

To capture clear gait motion in full “degree of freedom” (DOF), both global gait motion and local joint motion should be determined from video sequences. It is a challenging problem to analyze and capture gait motion. Different methods have been taken to solve this problem.

Several color representations are currently in use in color image processing. The color itself can be represented in many different ways such as the RGB color space; the RGB color space has been widely used for processing and storing digital image data. The simplicity of these color spaces has been the main reason for their popularity in color detection.

Hue Saturation Lightness (HSL) model describes the color with dominant color (Hue), colorfulness in proportion to the brightness (Saturation), and the amount of luminance (Lightness).

A multivariate normal distribution of a D-dimensional random variable x is defined in equation 1 taken from (Chuong, 2013) as:

$$N(X;\mu,\sum)=\frac{1}{\left(2\pi^{\frac{D}{2}}\right)|\sum|^{\frac{1}{2}}}\exp[-\tfrac{1}{2}(x-\mu)^{T}\epsilon\sum^{-1}(x-\mu)] \quad (1)$$

Where μ is the mean vector and the covariance matrix of the normally distributed random variable X. The model parameters are estimated from the training data using the following equations.

$$\mu=\tfrac{1}{2}\sum_{i=1}^{n}c_i. \quad (2)$$

$$\sum=\frac{1}{n-1}\sum_{i=1}^{n}(c_i-\mu)(c_i-\mu)^{T}. \quad (3)$$

Either the p $((c/colored))$ probability or the Mahalanobis distance from the c color vector to mean vector μ, given the covariance matrix can be used to measure the similarity of the pixel with the colored.

Gait joint details are necessary for identification human gait, it is therefore sufficient to extract the motion regions of gait. Towards this end, we use color and geometric cues to extract those regions and motion for gait analysis. We use Gaussian mixture model presented by the researchers in (Caetano And Barone, 2001; Manoria *et al.*, 2005; Hassanpour *et al.*, 2008; Griffin, 2001; Bashir *et al.*, 2005; Elmezain *et al.*, 2009) to model color distribution in Hue Saturation Intensity (HIS) color space to reduce the effect of illumination. By transforming the RGB image to HSI we can use hue to uniquely identify color segments, reduce the critical color dimension from two to one, and gain additional color label knowledge. When applying the multivariate Gaussian mixture the characteristics of the HSI color space can be used. Although color temperature and brightness effects the perception of colors, the theoretical range of hues for each color and the sequence of hue color labels can be used to identify color classes. It is the only dimension that must be unique and the color labels are constrained to the order: red, orange, yellow, green and blue. White and black are constrained to low saturation segments. The following steps are taking to accomplish the analysis of human gait:

Video Capture:

Gait of a person can be recognized easily when extracted from side view; that is why we are concerned with only capturing the side view videos. We also concerned with analyzing the normal gait; this is because the majority of the people have normal walk. Gait has two important components, first: the structural component which captures the physical build of a person. Second: the dynamic component which captures the transitions for the body during a walk cycle.

The input to our system is a gait video sequence captured by a static camera with the following assumptions:

1. The background will remain stationary with a color that is different from the joint region color. This necessitates that the camera be fixed and that lighting does not change suddenly. It is also possible to achieve accurate segmentation without this assumption, but such generality would require more computationally expensive algorithms.
2. The subject (the moving person) wears black clothes.
3. Three color pieces are added to the subject body; where ankle has a green color, knee has a blue color and hip has a red color.

Towards this end, we use color and geometric cues to extract those regions and motion for gait analysis, the details of the segmentation algorithm is in the following step:

Segmentation Method:

The objective of the segmentation procedure is to subtract the background from the moving body parts on the acquired image frames. To accomplish this aim, the Mixture of Gaussians method (GMM) was applied. The GMM is a widely used statistical method, it is used by (Surer, 2011); and it was an effective method when dealing with moving objects and illumination changes. In this structure, the underlying principle is to describe each single pixel in the image statistically, through a set of Gaussian probability distributions.

We manually loaded five sample images. The mask of the green ankle region, blue knee, and red hip was taken by using MATLAB function called roipoly .This method was chosen so that user can have freedom to select any desirable part of an image. Since mask consists of one's within enclosed area selected by the user and zeros elsewhere. Accumulate the data for a set of masks from their corresponding images and return the ankle, the knee and hip masks, then calculated the mean and covariance for each colored region. By transforming the RGB image to HSI and calculating the covariance and the mean of each Gaussian in the mixture, the correct statistical distribution of the corresponding joint region is determined. Pixel values that do not fit the region distributions from the background pixels. This approach manages “lighting changes, slow-moving objects and introducing or removing objects” successfully.

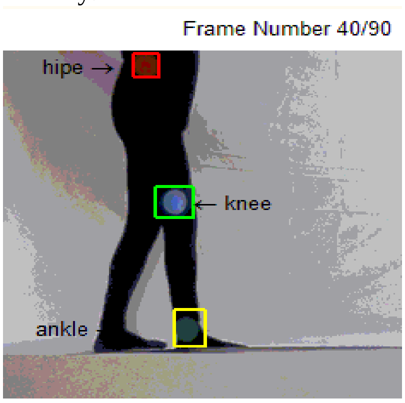

Fig. 2: The Result of Segmentation method.

In segmentation step, each image is partitioned into regions using a color cue, where ankle has a green color, knee has a blue color and hip has a red color. The regions are extracted from each frame, a hip, knee and ankle locations are specified with reference to zero locations. It should be emphasized that this motion segmentation algorithm is depending on color and geometric information. The three colored regions are detected and marked as separate components. Ideally, we expect an image with four components: the outlier, the hip, the knee and ankle. The segmented outputs of the images can be seen in Figure 2. The GMM probability density function can be defined according to (Hassanpour *et al.*, 2008) in equation 4 as a weighted sum of Gaussian as:

$$P(x;\theta) = \sum_{i=1}^{N} \alpha_I \, G(x;\mu_i,\alpha_i). \quad (4)$$

Where α_i is the weight of i^{th} component. The weight can be interpreted as a priori probability that a value of the random variable belongs to the i^{th} group. G is a Gaussian probability density function with parameters µ and σ. In addition, x is a sample input and N is the number of components. The parameter list of the Gaussian mixture model probability density function is given by:

$$\theta\{\alpha_i, \mu_i, \sigma_i\} For i = 1..N. \quad (5)$$

The output for the segmentation method is the extraction of the gait joint regions from the image sequences, then tracking the moving points between key-frames in the following step:

Features extraction:

The multi-rigid body model adopted for the kinematic analysis consisted of the rigid body segments: shank (ankle and knee) and thigh (knee and hip) connected by line segment. The model was characterized by three degrees of freedom: the trunk angle (θtrunk), thigh angle (θthigh) and the shank angle (θshank) as described using Figure 3.

Segmentation method partitioned each frame to ankle, knee, hip, and outlier region. For a given video sequence, we made a list for the position of the centroid for each of ankle, knee, and hip in each frame. This will simplify the motion trajectories tracking for the ankle, knee and hip over time. The mathematical formulation for dynamics analysis could be constructed. Using the experimental joint position and other variables such as segments lengths, and dynamics parameters of human gait we made a list of linear kinematic and angular kinematic for each joint and low limb segment across the two frames using change in position over time.

Human movement can be created by rotating the body parts and segments about the joint centers. kinematic analysis of angular motion is usually named as the Angular kinematics. Angular motion is the motion of all parts of an object that move through the same angle with different linear displacement. Example of angular motion is the motion of your thigh around your hip joint as you walk to home (Arvind and Sabri, 2012; Bashir *et al*., 2005).

According to (Tatacipta *et al.*, 2012; Neelesh *et al.*, 2010; Jang And Mark, 2003; Sudha and Bhavani, 2011; Nicholas and John, 2003; Malley *et al.*, 1993; Arvind and Sabri, 2012; Banchadit *et al.*, 2012 ;Jang And Mark, 2011) the relationships for linear kinematics are comparable to those in angular kinematics, Angular kinematic variables are described by (lab manual, downloaded 2013), table 1 presents those variables.

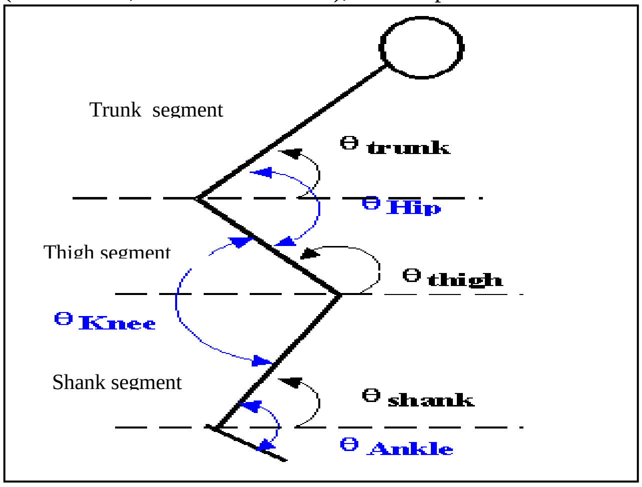

Fig. 3: Relative and Absolute angle. Source (lab manual, downloaded 2013).

Table 1: Angular kinematic variables.

kinematic variables	Symbol	Defined as	Equation
Angular displacement: measured in radians or degrees, where (2π radians $= 360^{o)}$	**Δθ**	the difference between the initial and final angular positions of the rotating object	$\Delta\theta = \theta_{final} - \theta_{initial}$
Angular acceleration	***α***	change in angular velocity over a period of time	$d\omega //dt$
Angular velocity	***ω***	change in angular position over a period of time	$d\theta/dt$
Angular position: measured in radians or degrees, where (2π radians $= 360^{o)}$	**θ**	the angle of a segment or joint	

Figure 3 taken from (lab manual, downloaded 2013); can show us the absolute angles such as: (θ_{shank} ,θ_{thigh} , $and\ \theta_{\text{trunk}}$) and the relative angles such as (θ_{hip} , θ_{knee}). Figure 3 guided by equation 5 and 6 taken from (lab manual, downloaded 2013) also can show us how to measure the relative angles.

$$\theta_{hip} = \theta_{trunk} + (180 - \theta_{\text{thigh}}). \quad (5)$$

$$\theta_{knee} = \theta_{\text{shank}} + (180 - \theta_{\text{thigh}}). \quad (6)$$

To determine the absolute joint angles and to calculate them using the MATLAB, we need a reference system in which we will assume the following assumptions: first: that trunk angle is 90 degree for the normal human gait (Świtoński *et al.*, 2011). Second: we will use the distal joint as our origin (0, 0). Based on the previous assumptions we will calculate the absolute segment angles using the following trigonometric relationship in figure 7, and equations 7,8 and 9 , which all are extracted from (lab manual, downloaded 2013):

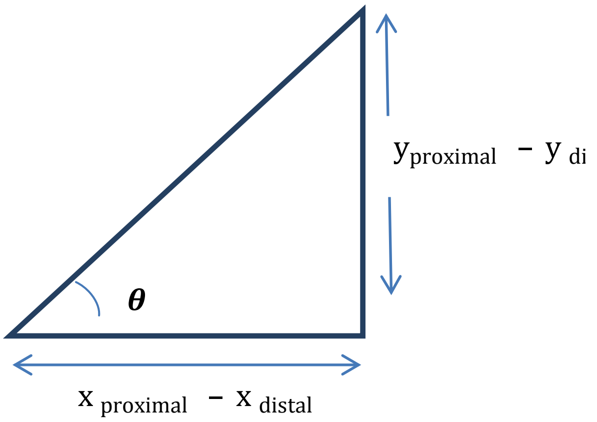

Fig. 7: Trigonometric relationship. Source (Barliya, 2006).

$$\tan\theta = (y_{\text{proximal}} - y_{\text{distal}})/(x_{\text{proximal}} - x_{\text{distal}}). \quad (7)$$

Taking the inverse tangent of both sides gives you:

$$\theta = \tan^{-1}((y_{\text{proximal}} - y_{\text{distal}})/(x_{\text{proximal}} - x_{\text{distal}})). \quad (8)$$

In MATLAB the absolute angle is calculated using the following formula:

$$\theta = tan2(x_{\text{proximal}} - x_{\text{distal}}, y_{\text{proximal}} - y_{\text{distal}}) \quad (9)$$

Finally and to get the angle in degrees we used the following equation:

$$\theta = \theta * (180/pi). \quad (10)$$

The final stage for us was to create a vector for each frame (for each low limb joint and segment part) that contains the following parameters [Angular position (θ), Angular displacement ($\Delta\theta$), Angular velocity (ω), Angular acceleration (α)]. All of the frame vectors are stacked to each other to form a feature vector for gait motion parameters.

Experimental Results:

In this section, we give a brief description of the databases that we have used in our experiments and demonstrate the result of gait analysis parameters.

We collect our own sample of video for the gait. The sample was filmed using OLYMPUS camera. Each video consists of a gait image size of 243×360 pixels, 24bit color in tiff format.

Each gait video in the experiments has 70 to 200 frames. We collected 5 video sequences from 5 different subjects; MATLAB Toolbox was used to implement the gait analysis process.

Samples of the extracted hip, knee and ankle region in the gait sequence for the first subject are shown in Figure 5.

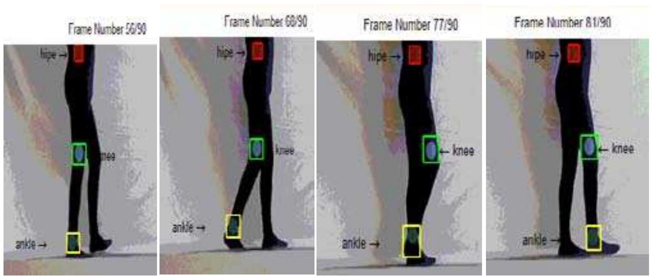

Fig. 5: Sample of the Extracted Hip, knee and ankle Region in the gait Sequence of Sample 1, Time Increase Left to Right and Top to Bottom.

For each frame we form a vector [position, velocity displacement($\Delta\theta$),acceleration displacement, Angular in radians, Angular in degree(θ),Angular velocity , Angular acceleration] for each low limb joint and segment part as shown in Figure 6(a1) position for subject 1. 6(a2) angle in degree for subject 1 , 6(a3) hip angle. 6(a4) knee angle. 6(a5) shank angle. 6(a6) thigh angles.

As we can see; and using the figures (a3, a4, a5, a6); each subject has a unique line that is different from the other subject lines; this means that we can recognize each subject using its features from the others easily, and this is our main goal.

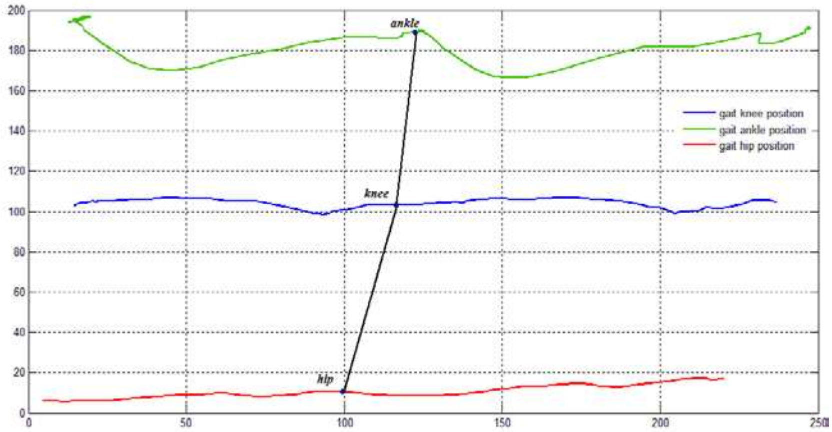

Fig. 6: (a1) position for subject 1.

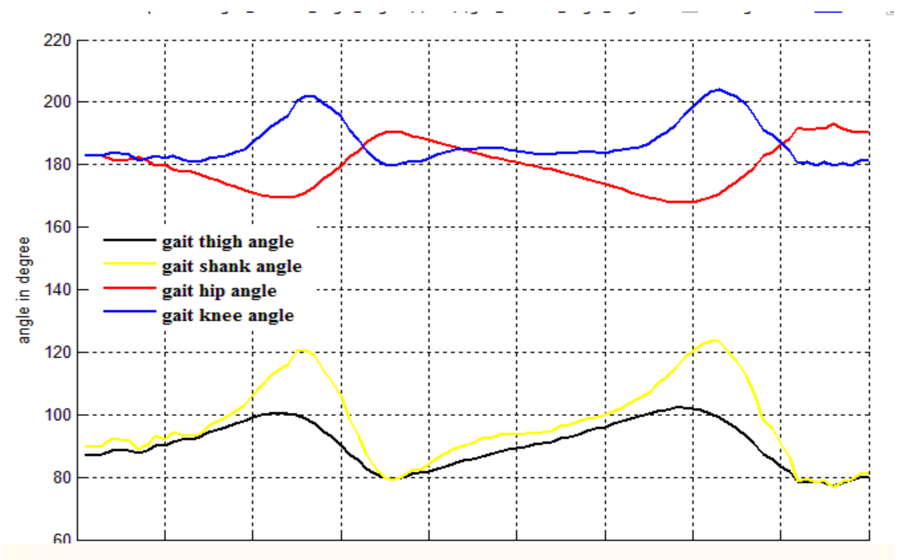

Fig. 6: (a2) angle in degree for subject 1.

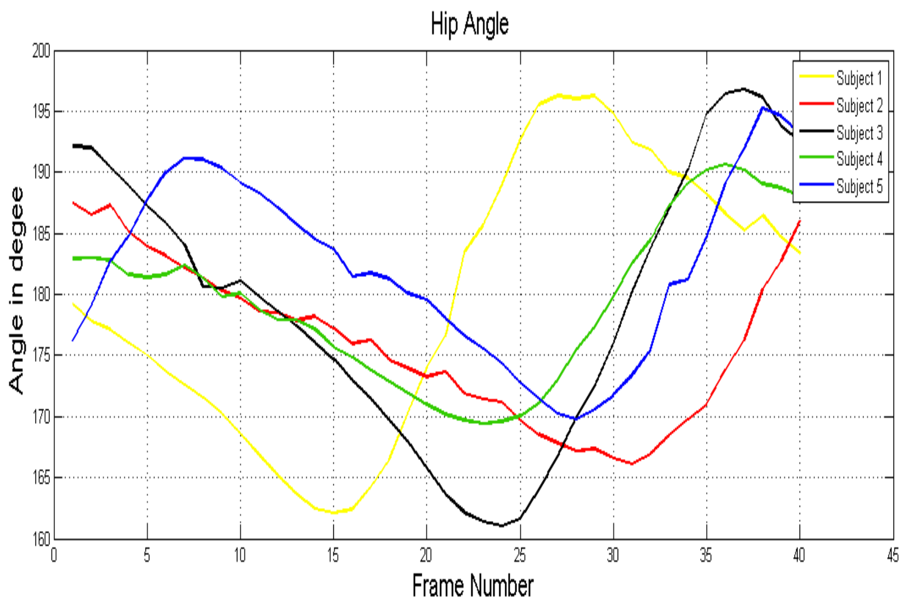

Fig. 6: (a3) hip angle for all subjects.

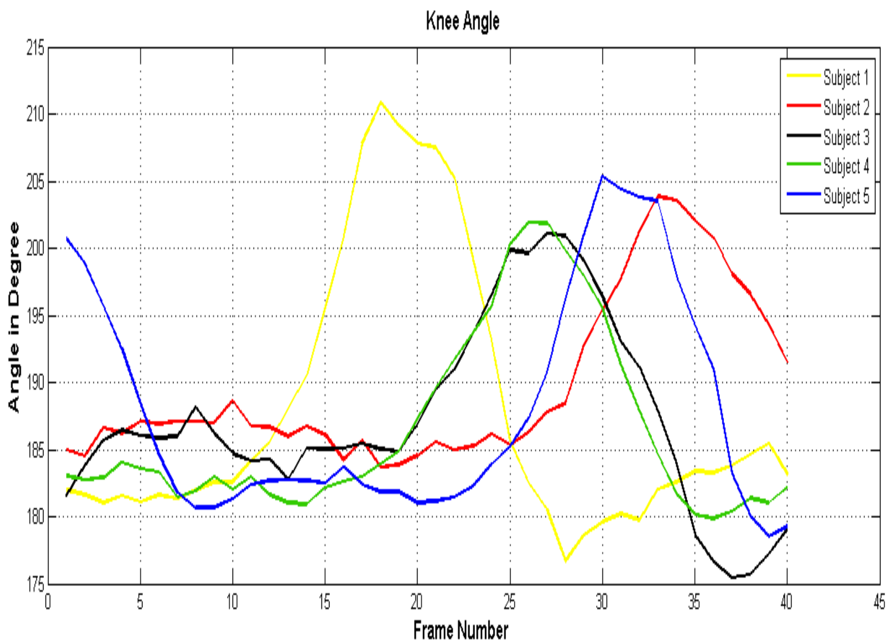

Fig. 6: (a4) knee angle for all subjects.

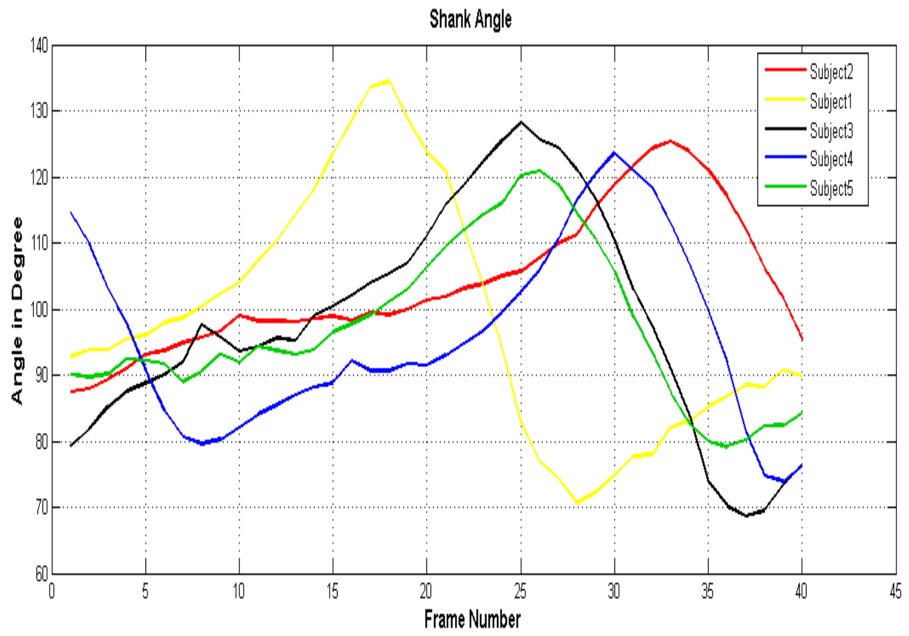

Fig. 6: (a5) shank angle for all subjects.

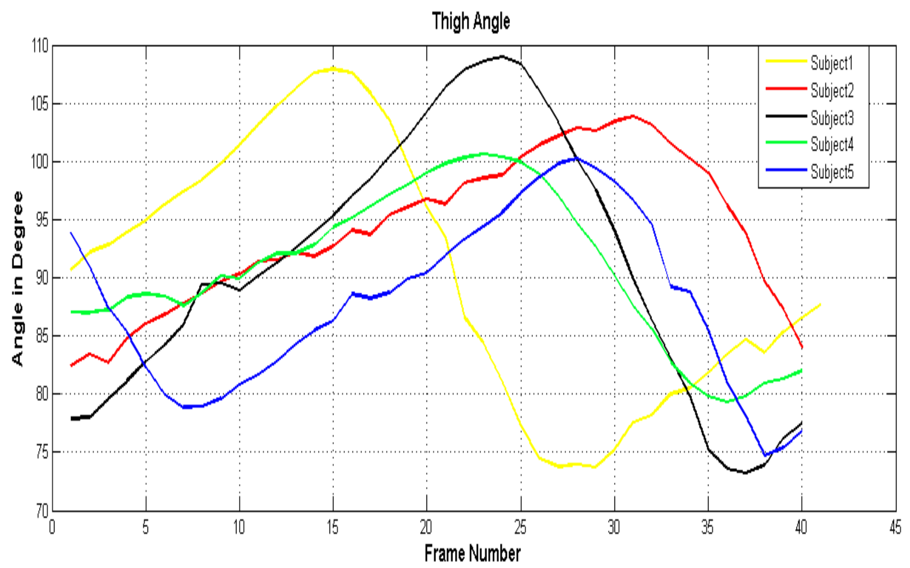

Fig. 6: (a6) thigh angles for all subjects.

Conclusion:

A new simple method for marker-based gait analysis has been presented. it extracts kinematic features by analyzing video sequences using GMM model and geometric analysis to extracted joint position for a sequence of video frame. The joint angles extracted from a sequence of segmentation frame using trigonometric relationship. Also, linear and angular kinematic features were extracted to form the gait motion parameters. Resulted curve was akin to position and angle curve for positions and angles determined using other methods (Neelesh *et al.*, 2010; Tatacipta *et al.*, 2012 ;Smith, 2007).

The main objective of this work to extracts the gait parameters automatically from the image sequence to be used in different human identification applications. Gait identification can improve surveillance systems, intelligence, and analyze customers for store managers, it can also capture gait at a far distance without requiring physical information from the targeted subject.

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