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Passive Marker based Optical System for Gait Kinematics for lower extremity

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Abstract

Human gait quantification assists in physical therapy, sport science and medical diagnostics. Most gait capture systems use direct measurement techniques to acquire specific motion information, but at high cost for hardware and the subject's natural motion is hindered due to the presence of cables or other components. To overcome these limitations, this paper introduces an alternative by using passive marker based optical gait analysis system developed at RAMAN Lab at Malaviya National Institute of Technology, Jaipur. The co-ordinates of markers were obtained by using a simple arrangement consisting of a camera, 5 reflective passive markers and a personal computer. From the analyses, kinematic gait parameters i.e. joint angles and walking speed can be obtained. The main benefits are that it doesn't consume 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 also the effect of the markers on the subject's movement is reduced. The prototype of the system provides decent quantitative kinematics gait parameters i.e. joint angles. The quantitative data specified by this system can help Healthcare professionals for better understanding of Indian patient's gait pathology, treatment and rehabilitation

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Keywords: Optical based gait analysis system; Passive maker; 2D analysis; Gait kinematics for lower extremity

1. Introduction

Human gait provides a way of locomotion. As a species, human are "bipedal" meaning we move on two extremities. Walking is combined effort of brain, nerves and muscles. Human gait analysis has several applications, such as individual identification & verification, prosthetic joint replacement, sport science and animation industry [1, 2, 3, 4, 5, 6, 7, and 8]. In gait analysis for medical rehabilitation optical-based motion analyzer systems have been widely used to monitor a patient's response [6]. Physiotherapists, orthopedists and neurologists have examined human motion, for long to evaluate a patient's status, treatment and rehabilitation.

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Pattern of locomotion (walking, running, crawling, etc.) combined with their posture is known as gait. Research associated with human walking is known as gait analysis. Gait Analysis is a way to reveal the mechanisms of human way of walking by quantifying the factors that governs the functionality of the lower extremities. Conventionally, the human gait has been considered subjectively through visual observations but now with technological advancement, human gait analysis can be done objectively and empirically. Gait research has two main tracks. One is clinical gait analysis [9], which depends on collecting the gait data in controlled environments and another is biometric goal of human gait analysis, which depends on collecting the gait data in different areas and scenarios [1].

Kinematic measurements convey the motion of body parts, joints, and other body landmarks of interest in space without any reference to forces. Anatomical position markers are observed using motion capture systems.

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. Presently, for the 2D and 3D analysis many camera-based motion capture systems are available in the market. Kinematic gait analysis can be subdivided into two types [10, 11]. First one is direct measurement or contact based techniques. These include accelerometers and goniometers sensors. Another is optical or non-contact based measurement technique. Optical based techniques using active or passive makers, were developed to perform real time kinematics gait analysis [12]. Active marker is triggered to illuminate as they use light-emitting didoes (LEDs). This signal is used to locate position of marker as individual markers work at predefined frequencies. Passive markers are spheres covered with reflective scotchlite tape. They are specially designed to reflect incident light directly back along its line of incidence.

Direct marker systems are more popular to find the kinematics of a human. The cameras send out infrared light signals and detect the reflection from the markers attached on the body. The accuracy of these systems is commendable, given the fact that they can often locate markers uniquely within a distance as small as 1 mm [13]. However such systems have their own disadvantages such as the subject’s natural motion is hindered due to the presence of cables or other components that can affect subject’s gait pattern [6]. In India, it may not be within the budget of most hospitals. So there is urgent need of an alternative cost effective but reliable system.

Optical and Imaging Measurement Techniques can help overcome most of the problems that are encountered while employing direct measurement techniques. Researchers have proposed quantitative methods that are more affordable. These methods are based on optical gait measurements using a personal computer [14], [15] to obtain important parameters but some of the limitations of these techniques are that kinematic and dynamic data (joint angles, working forces at joints and foot) cannot be measured and also that the process is quite time consuming.

We propose a new simple 2D passive marker-based motion capture model by using five simple red colored markers with a single camera. Currently the development is continued further for a 3D dynamic analysis of human gait using two cameras. The main benefits for the presented system are that is doesn’t consume 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 is reduced.

2. Literature Survey

Conventionally, the human gait has been considered subjectively through visual observations but now with technological advancement, human gait analysis can be done objectively and empirically. Literature revels that physiotherapists and orthopedists can monitor and analysis gait movement variables i.e. stride length, step length, cadence, stance and swing phase etc. of such patients, to point out if improvement has taken place.

In 1878, Edweard Muybridge & Leland Stanford were the first one to study the gait mechanism. Till now, considerable research has been done in gait analysis area; still it has not yet been fully utilized. With the new evolving models and methods gait analysis research is an ongoing activity. Tatacipta et al. presented a review on the development of an optical based gait analysis system [16]. The system consists of a camera, LED markers and a personal computer. The marker positions data was then used for further kinematics and dynamic analyses. He also resolves the problem of occlusion. Author uses Direct Linear transformation (DLT) to reconstruct 3D analyses. Michela Goffredo et.al. proposed 2D Human motion markerless Gait Analysis system [17]. Kinematic information was extracted by using silhouette-based approach after studying video sequences. They obtained good results; the performance of the proposed method is particularly encouraging for its appliance in the real medical context.

Mohamed Rafi et.al [18] implemented Hough transform technique for gait analysis. 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 discussed a new technique for an automated marker less system to evaluate, and classify human gait motion by using a k-nearest neighbor classifier to classify the gait patterns [19]. 2D stick figures can be used to represent human gait motion. Surer proposed a two-dimensional marker-based technique that used digital video cameras to capture the gait, and the gait joint position is extracted from the image sequences [20]. Eman Fares Al Mashagba et al. [21] present an efficient two dimensional (2D) marker-based method that extracts the gait parameters Using Gaussian Mixture Model from an image. They use three simple colored markers and with that they find the kinematic parameters.

These proposed systems are very precise but such benefits come at a price. Along with this active marker- based human gait analysis suffers from many shortfalls discussed by many researchers [22, 23].

To reduce these active marker-based limitations, in this paper we propose a new simple 2D passive marker-based motion capture Model by using five single red colored passive markers. The presented system doesn't consume excessive time and complexity required for marker placement, no requirement of a controlled environment to acquire high quality data, very low cost of passive markers as compared to active markers, and the no effect of the markers on the subject's movement. The coordinates of the markers were obtained by capturing digital images and then processing them. Currently the development is continued further for a 3D dynamic analysis of human gait using two cameras. Along with this, we are trying to develop a database of Indian normal gait which will be the first of its kind. The quantitative data provided by this system can help physiotherapists; orthopedists and neurologists for better understanding of Indian patient's gait pathology and plan treatment in a better way.

Details of this system are described in the remainder of this paper. The paper is organized as follows: Section 3 covers the methodology of the 2D Optical Gait Analysis system; section 4 covers experimental results. Finally, conclusions and future scope are discussed in section 5.

3. Methodology of 2D Optical Gait Analysis System

Walking is a series of gait cycles. The gait cycle is the time interval between two consecutive occurrences of one of the repetitive events of walking. Gait cycle is a combined function of the lower extremity, pelvis, and spinal column. It is a single sequence of functions by one limb. It begins when reference font contacts the ground and end with subsequent floor contact of the same foot. A single gait cycle is known as a STRIDE. Generally walking is taken for granted by most of us, but is an extremely complex movement. Dysfunctional gait can arise from acute or chronic injury or either because of improper biomechanics. It prohibits normal weight-bearing competence on the bipedal and influences stresses placed on joint surfaces.

Gait analysis includes the measurement of temporal, Kinematics, Kinetics and Dynamic Electromyography based parameters and conclusions about the subject (health, age, size, weight, speed, etc.) can be drawn [24]. Temporal or Spatial parameters, includes parameters such as step length, cadence, stride rate, velocity, etc. phases (stance/swing) ,and events (foot-strike, toe-off). Kinematics parameter is the movement of the body in space without any reference to force. It is the angle of joints such as trunk angle, hip angle, knee angle, ankle angle and foot angle

3.1. System Description

To overcome the limitations of active marker-based techniques we propose to add five single color passive marker to the clothes of the targeted subject at anatomical points of concern i.e. shoulder, hip, knee, ankle and toe as shown in Fig 1. We consider lateral plan for our experiment. 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 position of the markers was obtained from digital video images of markers that were fastened to the subject's body.

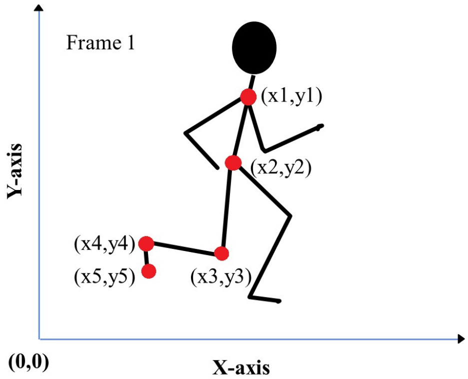

Fig. 1: Marker locations at anatomical points on subject body (in red color)

The typical data that we consider in this study are the x and y locations of the segment endpoints. These are digitized from video capture by a digital camera. Considering the Canadian Society of Biomechanics (CSB) Gait Standards Fig. 2 [25]. In this model we used segment angle to calculate trunk, thigh, leg, and foot angle as described in fig 2(a). Absolute or segment angle is the angle between a segment and the right horizontal of the distal end.

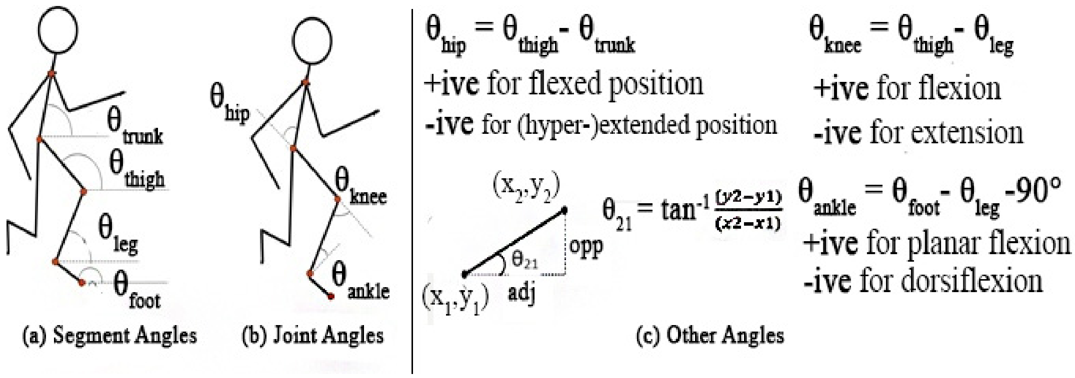

Fig. 2. CSB Gait standard angle calculation method; Source [25]; (a) Segment Angles; (b) Joint Angles; (c) Other Angles

It should be consistently measured in the same direction from a single reference – either horizontal or vertical. We consider it in horizontal way, thus trunk angle is 90 degree for the normal human gait. While joint or relative angle is used to calculate hip, knee and ankle angle as described in fig 2(b) & 2(c). Anatomical position or straight fully extended position is generally defined as 0 degrees in this case.

3.2. Experimental Setup

The Recording environmental for gait analysis at RAMAN Lab-MNIT is shown in Fig.3. The proposed system consists of digital video camera for recording and personal computer for data acquisition and processing. 2D joint movement tracking is done using an optical motion-capture system. This movement is in the form of the position of the markers in 2D space. Further processing of the data acquired from the conducted experiment is done using a Gait Analysis model that is developed using a simulation framework, which assists in kinematic and dynamic analyses of human gait.

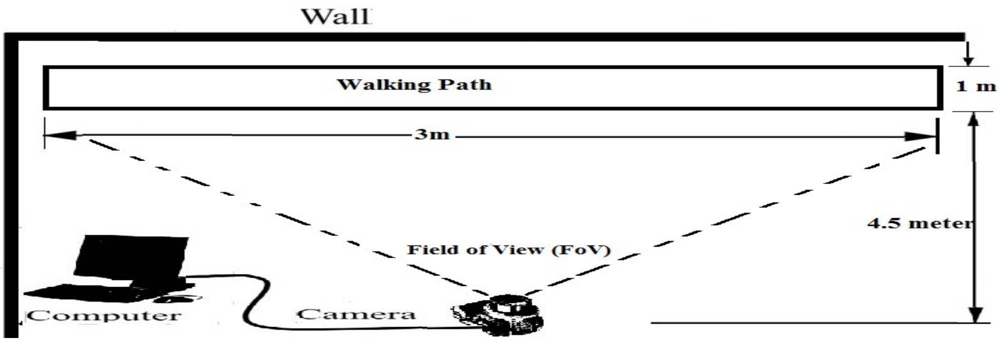

Fig. 3 . Description of the first 2D gait analysis system

The walking path, which has been used in this experiment, has a total length of 3m, which gives the subject enough room to take at least two steps after breaking inertia. In this study, the subject walks at a normal pace from right to left on walking path. A home digital video recorder is used to acquire the motion of the markers in sagittal plane at 29 frames per second (fps). A set of five reflective passive markers is attached on five positions of the subject's body, viz. malleolus, pelvis, hip, knee and lateral metatarsal to track the joints. All these markers are placed on the left side of the subject's body. Fig. 4 shows the markers position on the subject's body.

Fig. 4. Marker tracking, during motion.

The system is still in development phase. The joint co-ordinates data obtained from 5 reflective markers are then used for a 2D kinematics analysis of human gait. It is used to determine 2D gait parameters of 20 healthy subjects to initiate the development of Indian gait database. Gait data of 20 subjects comprise both male and female within the age group between 18 to 30 years are measured as part of an effort to develop normal walking database of Indian people. The first prototype of the system provides decent quantitative kinematics gait parameters i.e. joint angles.

3.3. Development of 2D-Gait Analysis System

This section introduces our technique to develop a 2D Gait analysis system, using a simple home-based digital camera, using the MATLAB software. Our methodology of gait analysis involves four phases: Preprocessing, Marker detection and Tracking and Kinematic Extraction phase. Fig. 5 describes proposed 2D gait analysis system.

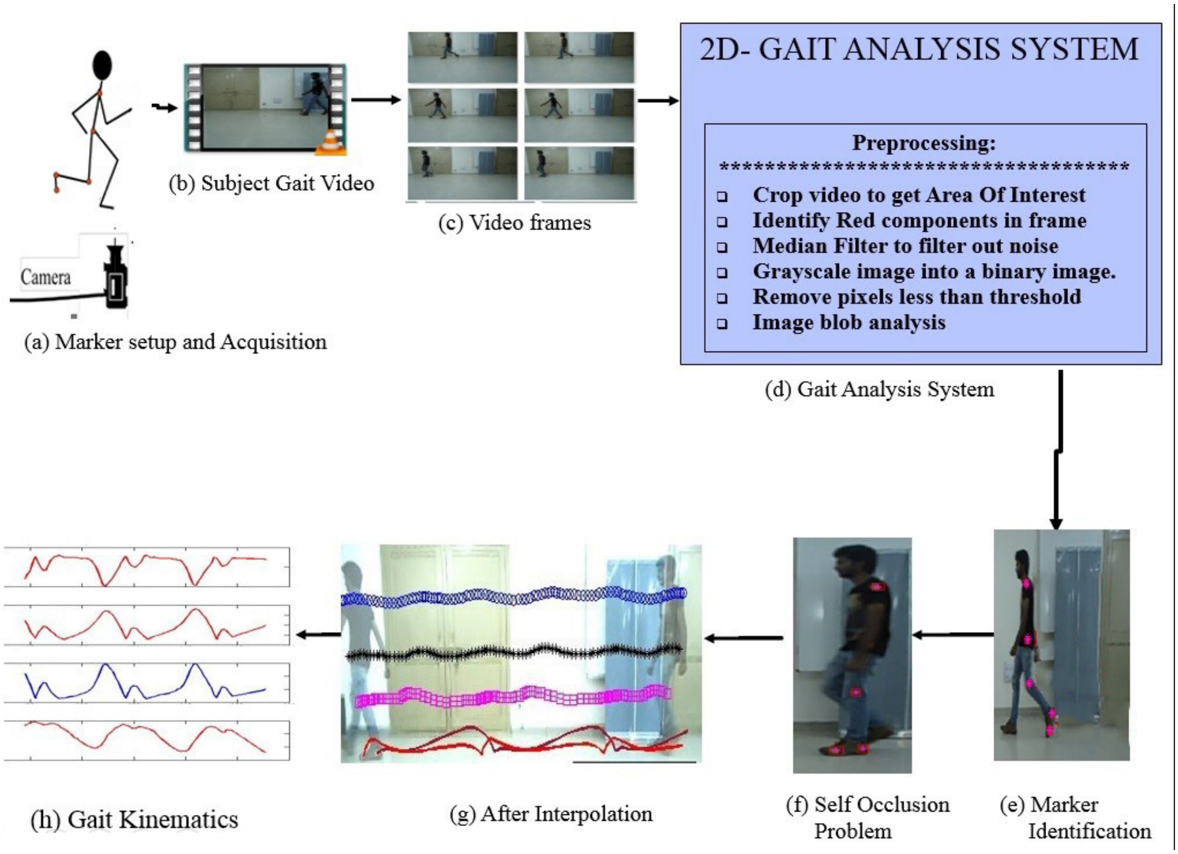

Fig. 5. Proposed Methodology for Optical 2D Gait Analysis System; (a) Marker setup and Acquisition; (b) Subject gain video; (c) Video frames; (d) Gait analysis system; (e) marker identification; (f) Self-Occlusion Problem; (g) After Interpolation; (h) Gait KinematicsPreprocessing

3.3.1. *Preprocessing*

In pre-processing phase, a set of 5 red color passive markers are attached to the clothes of target subject at anatomical points of concern i.e. shoulder, hip, knee, ankle and toe. Then walking gesture video is extracted into frames as shown in Fig 5 (a) and 5 (b). It contains 180-220 frames in each sample video. Area of interest is extract by cropping the frame with 640 x 480 dimension each. The extracted frame image data is in RGB format. Each pixel in this format is a mixture of three colors, namely red, green and blue. The perfect red color has only red component and no green or blue components. Thus the approach adopted is to search for red colored regions in frame. RGB image is converted into intensity format (grey scale), then into binary format, by introducing a threshold value. Every pixel having intensity below the threshold value was converted to black and everything above becomes white. After fixing the threshold process, the white markers representing shoulder, hip, knee and toe ankle from the images could then be reliably extracted as shown in Fig. 6. The x, y – coordinate, in pixels, of each marker were then calculated by locating the centroid of the markers in the image plane. Image blob analysis technique is performed to extract the feature of the image.

3.3.2. *Marker detection and tracking*

The proposed system implements, segmentation procedure to subtract the background from the moving body parts on the acquired image frames. At this point, the positions of the markers have been identified in the image. The image coordinates of each of the 5 markers in each frame of the video is obtained by Marker Detection and Tracking module as shown in Fig. 5(e). In the algorithm applied, the marker recognition process began from the top of the frame to the bottom, but the order of marker position in each frame is not always consistent; especially the toe and ankle markers. Thus on the basis of co-ordinates in 2D, toe and ankle is identified. In the current sagittal record setting, when left hand blocked marker attached on hip joint, self-occlusion problem is identified as shown in Fig. 5(f). The break in the path of joint co-ordinates shows the occlusion problem. Linear interpolation technique is used to calculate or fill the location of missing marker (hip) co-ordinates and thus overcome the occlusion problem. A linear interpolation is able to find the correct marker position after the overlapping occurs and changes the marker data arrangement [26]. Once the interpolation process is complete, the position of each marker is plotted in correct arrangement. Figure 5(g) shows the interpolated value of each joint.

Fig.6. Marker detection scheme and its corresponding position in System

3.3.3. Kinematic Extraction phase

After successfully detecting and tracking the position of the markers, feature extraction phase starts. In this, joint regions of gait (marker co-ordinates) contain significant information that helps in the identification of gait kinematics of an individuals is extracted. The multi-rigid body model adopted for the kinematic analysis consisted of the rigid body segments such as: trunk (shoulder and hip), thigh (knee and hip) and shank (ankle and knee) are connected by line segment. The model was illustrated by four degrees of freedom: the trunk angle (trunk), thigh angle (thigh) and the shank angle (shank) and foot angle.

4. Experimental Result

In this section, we demonstrate the result of gait analysis parameters. We are in mode of building our own Indian gait database using the digital camera. Each video consists of a gait image size of 640 x 480 pixels in AVI format. Each gait video in the experiments has 180 to 200 frames. We save 5 video sequences from 20 different subjects. MATLAB Toolbox was used to implement the gait analysis process. Gait kinematics of the one of the subject aged 19 male, extracted trunk, hip, knee, leg, foot, and ankle region in the gait sequence for the subject are shown in Fig. 7(a)-(f).

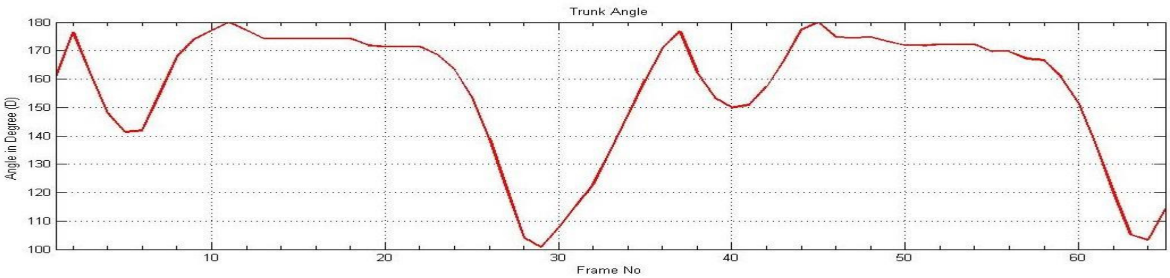

Fig. 7. (a). Trunk Angle using 5 set of passive markers

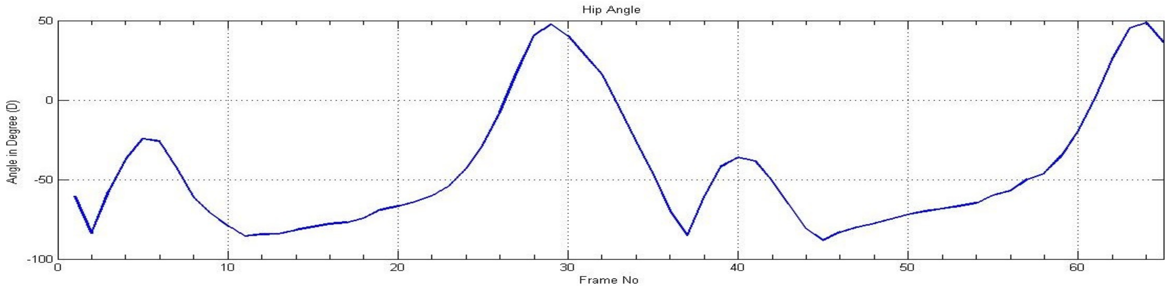

Fig. 7. (b). Hip Angle using 5 set of passive markers

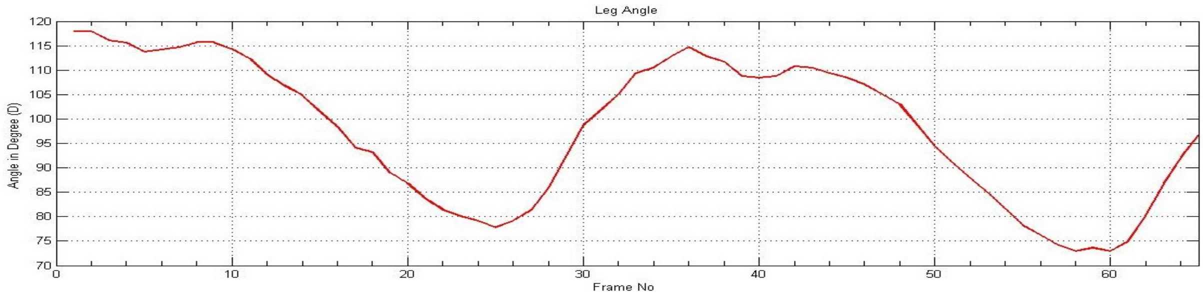

Fig. 7. (c). Leg Angle using 5 set of passive markers

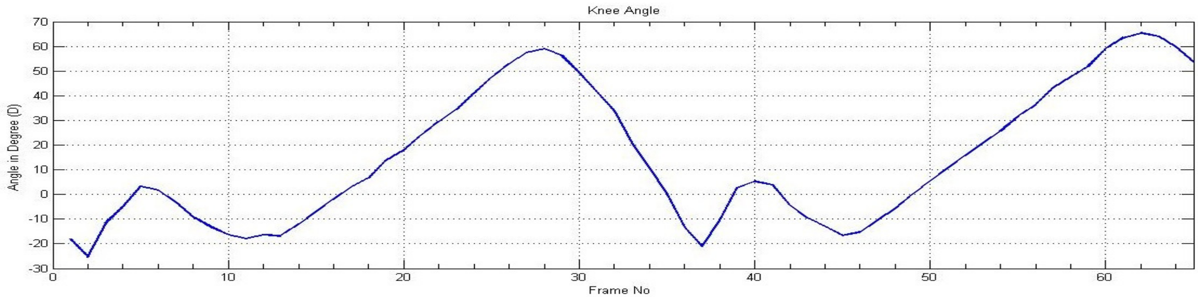

Fig. 7.(d). Knee Angle using 5 set of passive markers

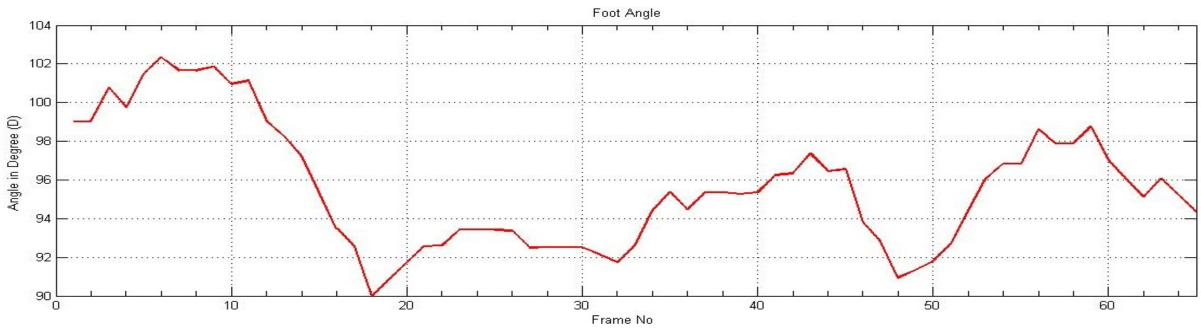

Fig. 7.(e). Foot Angle using 5 set of passive markers System

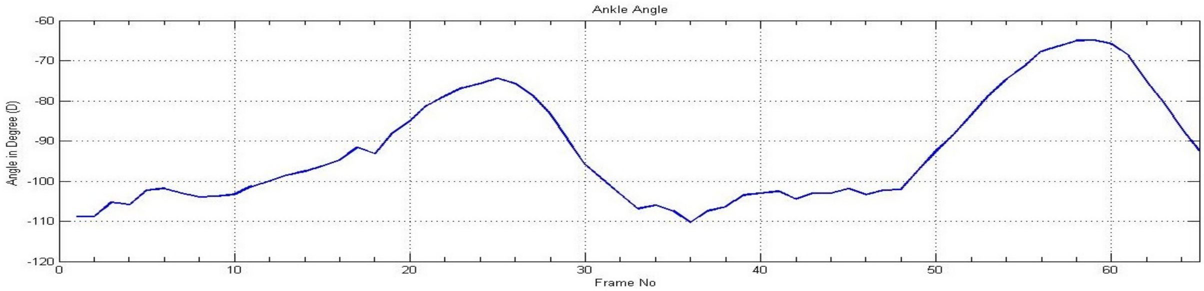

Fig. 7.(f). Ankle Angle using 5 set of passive markers System

Upon processing the recorded videos, the result of tracking process can be seen. A plot of 2D sagittal plane of the real time position of the markers that are attached onto the subject's body is shown in Fig. 8. It consists of 70 frames and has 2 walking steps. Therefore, the number of frames required for the subject to walk 1 step is 35. With 29cal fps camcorder, the walking period of the subject comes out to be 1.206 second. This gives us a general idea that Indian move faster and taller as compared to Indonesian [16].

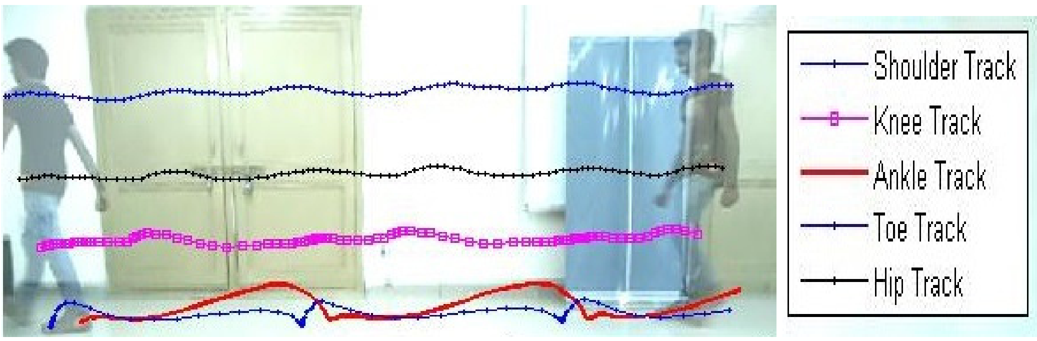

Fig. 8. Marker Tracking Result

5. Conclusion

We propose a new simple 2D passive marker-based motion capture Model by using five simple red colored markers with a single camera. It is an automated 2D tracking based, easy to use and very cost-efficient but reliable system. The presented system doesn't consume excessive time and complexity required for marker placement, no requirement of a controlled environment to acquire high quality data, very low cost of passive markers as compared to active markers, slightly costlier than a home video camera and the no effect of the markers on the subject's movement. The first prototype of the system provides good quantitative kinematics gait parameters i.e. step length; gait velocity and joint angles could be computed. This quantitative data can help physiotherapists; orthopedists and neurologists for better understanding of Indian patient's gait pathology and plan treatment in a better way.

The development is continued further for a 3D dynamic analysis of human gait using two cameras using Indian gait database. Developing a 3D gait analysis will help in analyzing more gait parameters. As a future work we can use these gait parameters and can identify individual.

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