Analyzing and Measuring Human Joints Movements using a Computer Vision System

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ABSTRACT
Range and patterns of movement estimation is a crucial concern for clinicians in the diagnostic and functional assessment of patients with musculoskeletal disorder. To obtain a record of the degree of permanent impairment of an individual, Range-Of-Motion (ROM) measures are used. Currently, clinicians use all or any of numerous assessment instruments, a universal goniometer, an inclinometer or a tape measure to make these estimations. However, such tools appear to have major drawbacks in measuring ROM. Markerless vision-based human motion analysis can provide an inexpensive, non-obtrusive solution for range of joint motion measurement. This paper outlines the problem of measuring human joints movements using a computer vision system that supports the physiotherapist as a diagnosis tool to aid rehabilitation of joint movement disorders and its treatment plan.

Keywords
Motion analysis, range of motion, joint motion, joint movement disorders, computer vision.

1. INTRODUCTION
Motion analysis in general is a very active area in computer vision, specificallythose who consider the human motion. The emphasis is on three major procedures involved in a human motion analysis: feature extraction, which identifythe objects characteristics in the image frames; feature correspondence, which involves matching features between sequential frames; and finally the high level processing, which reflect recognition of human activities or poses[1]-[4].

However, in order to analyze the human movements, human body can be modeled by describing its kinematic properties, as the shape and appearance. Most of the models describe the human body as a kinematic tree, consisting of segments that are linked by joints. Every joint has a number of Degrees Of Freedom (DOF), indicating in how many directions the joint can move. All DOF in the body model together form the pose representation. However, these models can be described in either 2D or 3D [5]-[11].

A wide variety of human motion analysis systems have been developed. Gavrila [12] divides research into 2D and 3D approaches. Aggarwal and Cai [4] use a taxonomy with three categories: body structure analysis, tracking and recognition. Moeslund and Granum [13], [14] use a taxonomy based on subsequent phases in the pose estimation process: initialization, tracking, pose estimation and recognition. Wang et al. [15] use taxonomy similar to [4]: human detection, human tracking and human behavior understanding. Wang and Singh [16] identify two phases in the process of computational analysis of human movement: tracking and motion analysis.

In general, the techniques ofhuman motion analysis may be classified according to theimposed intended degree of abstraction between the human actor and the virtual equivalent. The applications abstracted of motion analysis are primarily concerned with motion character, and only secondarily concerned with fidelity or accuracy.

In addition, these applicationsnecessitate the development of a distinctive procedure to take the characteristics of the human and its range of motioninto account, and often depend on a mixture of multiple actors, multiple input devices and procedural effects.

On the other hand, efforts to accurately analyze human motion depend on limiting the degree of abstraction to a feasible minimum. These applications typically attempt to approximate human motion on a rigid-body model with a limited number of rotational degrees of freedom. This work requires paying close attention to actual limb lengths, offsets from sensors on the surface of the body to the skeleton, error introduced by surface deformation relative to the skeleton and careful calibration of translational and rotational offsets to a known reference posture.

Additionally,the production of an articulated rigid body is critical if additionaldynamicsdependent motions are to be added, either from dynamical simulation or space-time constraints; moreover, accurate motion analysis is significant to the study of biomechanics [17]-[26].

However, the introduction of new technology may even lead the way in standardizing protocols for movement and measurement of joints for more new techniques. The second section in this paper will briefly explain the system design, while the third section will present the system methodology. Then, comes the fourth section which will provide higher detail in kinematics. Finally, in the last section we will present a preliminary evaluation on the proposed system against the traditional manual ways of measurements done by the universal goniometer.

2. SYSTEM DESIGN
The purpose of the current study is to develop a feasible and reliable computer vision system to support a physical therapist rehabilitation program for joint activities during human movements. The proposed system is computer based, where a digital camera is used to provide a video sequence, of the Sagittal, Frontal, or Transverse plane, however if more than

one plane is required in the same time we may use three digital cameras one for each plane. These planes are shown in Figure 1. The system is capable of analyzing the video sequence to measure the human joints movements.

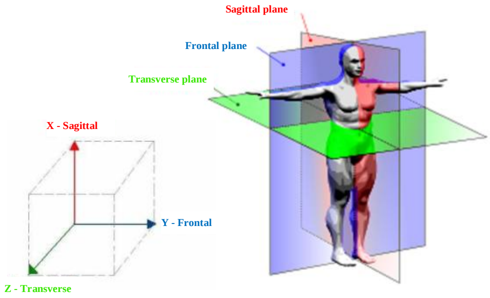


Figure 1: Anatomical planes

Movements can be defined as an object's relative change of place or position in space within a time frame and with respect to some other object in space. Thus, movement may be measured by analyzing its position before and after an interval of time. While linear motion is readily demonstrated in the body as a whole as it moves in a straight line, most joint movements are combinations of translatory and angular movements that are more often parallel to the cardinal planes rather than diagonal. In addition to muscle force, joint movement is governed by factors of movement freedom, axes of movement, and range of motion. The human skeletal system is often simplified into the major joints in the body which is shown in Figure 2a. This is considered as a skeleton model which can be projected after scaling and alignment into any human position as shown in Figure 2b. This figure also shows the degrees of freedom of each of the major joints.

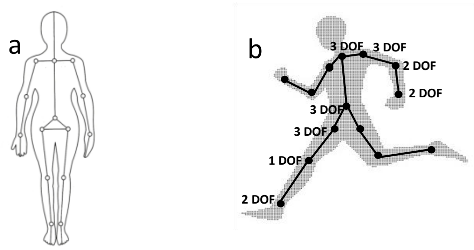


Figure2: a) Skeleton model, b) Skeleton projection along with the degree of freedom for major joints

Degrees of freedom (DOF) are related to the movement possibilities of rigid bodies. Kinematic definition for DOF of any system or its components would be "the number of independent variables or coordinates required to ascertain the position of the system or its components". The study of joints movements is concerned with kinematics as it lets us describe the characteristics of a joint movements and position. The whole system is illustrated in Figure 3.

3. METHODOLOGY

3.1 Video preprocessing

Before using the digital camera video sequence for later process, it should be preprocessed by smoothing in order to maximally reduce noise or instability, and then some of the frames are discarded according to a threshold function that determines the amount of movement occurred in these frames, and if it was too low these frames would be automatically discarded.

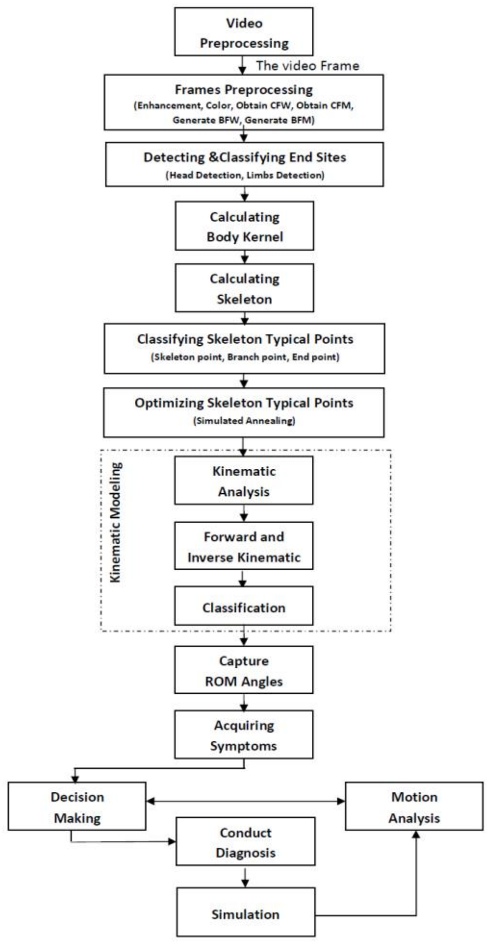


Figure 3: Main Structure of the System

3.2 Frames preprocessing

For each of the remaining frames we do the following:

- Subtract the background to obtain Colored Frames for the Whole body (CFW)
- Subtract non-moving parts of the body to obtain Colored Frames for only the Moving part in the body (CFM)
- Apply Binarization to CFW to obtain Binary Frames of the Whole body (BFW)
- Apply Binarization to CFM to obtain Binary Frames of the Moving part of the body (BFM).

3.3 Detecting and classifying the end sites (head, limbs)

Curve Detection: By detecting curvatures contour of the BFW. For more robustness, if we still could not find all the end sites we are looking for as they are shaded by the body, we also detect the curvature contour of the CFM to be able to detect the end site of the moving limb even after being shaded by the body. However, if we succeeded in detecting the shaded moving end site and we still could not find all the end sites, this means that there is an end site that is shaded and in the same time is not moving, so we also detect the curvature contour of the CFW in order to find it, but although this case will take more processing, it is a very rare case which rarely happen as the subject is normally instructed to make its initial position in which the limbs are fully extended along the body.

Figure 4 shows that all the end sites were successfully detected even the right arm which was shaded by the body.

Head Detection: By matching the detected curvatures with a head/shoulder template contour.

Limbs Detection: By selecting high positive convex curvatures other than the boundaries of the detected head.

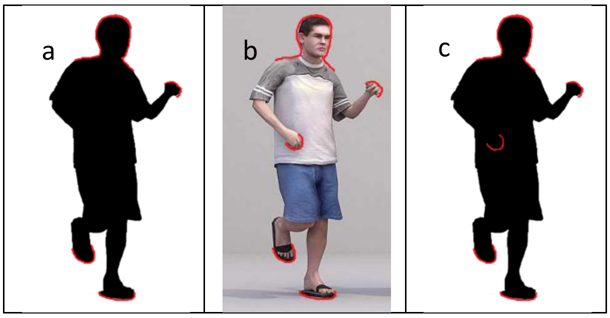


Figure4: a) After detecting curvatures contour of the BFW, we could not find all the end sites since the right arm is shaded by the body, b) After detecting curvatures contour of the CFW, c) All the end sites were successfully detected including the shaded right arm.

3.4 Calculating the body kernel

By applying Euclidean distance transformation to both BFW and BFM then combining the two to formulate the body kernel. Figure 5 shows the result of applying distance transformation.

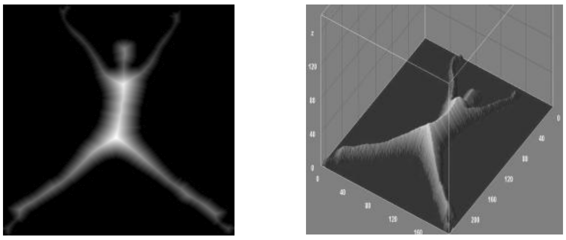


Figure 5: The result of applying distance transformation

3.5 Calculating the skeleton

Which is the set of connected pixels in the middle, and it is considered as the medial axis of the original body representing its topology. It can be obtained by applying erosion and thinning algorithm to the body kernel.

3.6 Classifying skeleton typical points

As shown in Figure 6

- Skeleton point: Two neighbours
- Branch point: Three neighbours
- End point: One neighbor

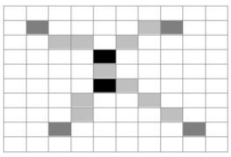


Figure 6: Classifying skeleton typical points, Gray: Skeleton point, Dark gray: End point, Black: Branch point.

3.7 Optimizing skeleton points

We need to search for the skeleton shape S that minimizes a function F, which measures how much the skeleton fits with the video sequence.

$$F = \alpha K + \beta E + \gamma H \quad (1)$$

This function is based on three terms: the kernel term K, the end sites term E, and the harmonic term H. The idea is to project the skeleton template on the calculated skeleton after scaling and alignment, then optimize this projection by the optimization function.In order to adjust the scaling of theskeleton we used the method illustrated in [27].The alignment is simpler since wealready detectedthe end sites positions and can be calculated on the skeletonby projection [28].

However, to get the kernel term we need to select some points on the skeleton including all the template joints then calculate their average kernel values at their locations

$$K = -\sum_{n} \frac{k(t)(p(n) \times T(t,S))}{N} \quad (2)$$

Where $k(t)$ is the kernel at time t, $p(n)$ is the nth selected point on the skeleton, $T(t,S)$ is the transform that converts the local coordinate vector of $p(n)$to its location, and N is the total number of selected points.
However, to get the end sites term, we need to make sure that the projected locations of the end sites are near the detected end sites:

$$E = \sum_{m} \frac{\|\delta(m) - \rho(m)\|^2}{M} \quad (3)$$

Where, $\delta(m)$is the m^{th} detected end site, $\rho(m)$ is its corresponding projected end site, and M is the total identified end sites at the current frame.
And, to get the harmonic term, the skeleton shape should not have sudden changes over time so we compare it with other shapes from previous frames:

$$H = \|S(t) - 2S(t-1) + p(t-2)\|^2 \quad (4)$$

After computing the three terms K, E,and H we compute the function F in equation 1 by adding them together after multiplying each term by its bias. As stated earlier our goal is to minimize F, which can cause a problem of having so many local minima. However, to overcome the problem of having so many local minima, we apply simulated annealing, to converge to the global minimum. Simulated annealing is a probabilistic method proposed for finding the global minimum of a cost function that may possess several local minima. It works by emulating the physical process whereby a solid is slowly cooled so that when eventually its structure is “frozen”, this happens at a minimum energy configuration. It may require only being able to evaluate the density function. This method was independently described by Scott Kirkpatrick, C. Daniel Gelatt and Mario P. Vecchi in 1983,[29] and by VladoČerný in 1985[30].It is an adaptation of the Metropolis-Hastings algorithm, a Monte Carlo method to generate sample states of a thermodynamic system, invented by M.N. Rosenbluth in a paper by N. Metropolis et al. in 1953 [31].

4. KINEMATICS

4.1 Kinematic Modeling

Kinematics studies the motion of bodies without consideration of the forces ormoments that cause the motion. A digital human can be modeled as a mechanical system that includes link lengths and mass moments of inertia. The motion of his limbs could be approximated as an articulated motion of rigid body parts [32]-[35].

Figure 7a depicts the modeling of a human using a series of rigid links connected by joints; the circles represent kinematic joints.

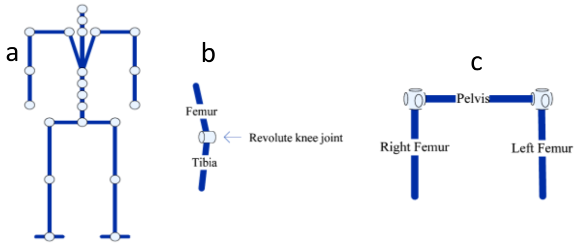


Figure 7: a) Digital human modeling using a series of rigid links connected by joints, b) Knee joint modeling using revolute joint, c) Hip joint mechanical model

The body segments are assumed to be connected by rotational (revolute) joints. For instance, consider the right knee joint of a human, shown in Figure 7a. The knee joint is composed of ligaments and tendons between two segments, which are the femur and the tibia. Since the knee is bent in one direction, it is assumed to be a one degree of freedom revolute joint as shown in Figure 7b.

The kinematics of human locomotion describes visually observable qualities or quantities, although in many cases these can be accurately measured only by the use of instrumentation (time, distance or angles). It remains relatively stable between individuals and is obtained under the following headings: a) Temporal (Time), b) Spatial (Distance), c) Angular displacement.

A more complicated joint can be modeled in the same manner. Figure 7c depicts human hip joint anatomy and its mechanical model.

The model used in this paper, takes into account a certain revolute joints to represent each physical joint in the human. Prismatic joints, or sliding joints, could have been included, but by only including revolute joints in the human model it simplifies the skeleton, while still providing a very good approximation of gross motion for the human [36].

For instance, a ball and socket joint, like the shoulder, is modeled by three revolute joints located on top of each other and corresponds to three degrees of freedom. Examples of the joints used for the shoulder, elbow, and wrist are shown in Figure 8a.

Since the shoulder and hip joints can rotate in any direction, they are assumed to be universal joints, which have three degrees of freedom. The knee joint is assumed to be one degree of freedom rotational (revolute) joints. The elbow, wrist, and ankle joints are to be two degree of freedom rotational joints.

The joint structure of the digital human model is seen in Figure 8b; the figure shows the 53 coordinate systems and 49 DOF for the human body. The human model includes 5 chains of joints, one chain for each limb: right arm, left arm, right leg, left leg, and the head.

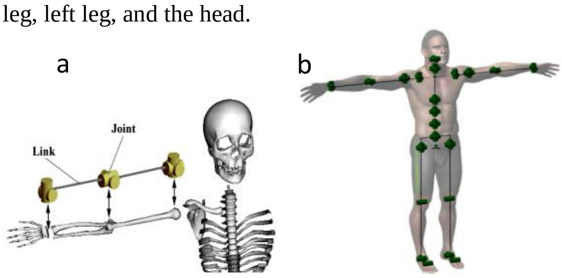


Figure 8: a) A human skeleton showing the physical joints and the corresponding mathematical joints and links, b) The model for the virtual human

In general, human locomotion means the body moves around. In other words, the global degree of freedom exists with respect to an inertial reference frame in the mathematical sense. The global degrees of freedom are composed of three translational (prismatic) joints and three rotational (revolute) joints. Figure 9 depicts how the global degrees of freedom are set up.

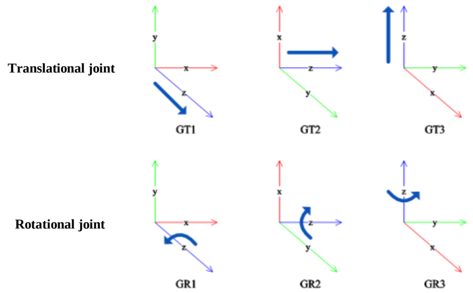


Figure 9: Global degree of freedom description

4.2 Kinematic Analysis

The simplest way to describe the translational and rotational relationship systematically between adjacent links in articulated chains is the matrix transformation method. The transformation matrix is represented in a 4×4 homogeneous matrix. This method represents each link coordinate system in terms of the previous link coordinate system. Any local coordinate system (including the end-effector of the manipulator or serial chain) can be expressed in a global reference frame. So, basically, the method represents a vector in one coordinate frame in terms of another coordinate frame. This method has its base in the field of robotics, but it can be used for modeling human kinematics as well.

As shown in Figure 10, any point of interest in the i^{th} framecan be transferred to the global reference frame${}^{0}r$:

$$ {}^{0}r = {}^{0}T_i \; {}^{i}r \tag{5} $$

where${}^{i}r$ is a 4×1 vector in terms of the i^{th} reference frame and ${}^{0}T_i$ is a 4×4 homogeneous transformation matrix from the i^{th} reference frame to the global reference frame. The format of the vector ${}^{i}r$ is:

$$ {}^{i}r^{T} = [r_x \quad r_y \quad r_z \quad 1] \tag{6} $$

wherer_x, r_y, and r_z represent any point of interest in the i^{th} frame in terms of the Cartesian coordinates.

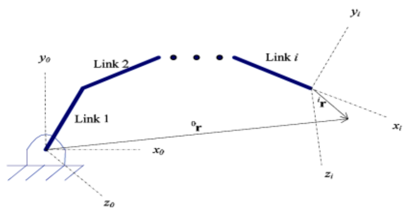


Figure 10 Articulated chain

Here the transformation of a vector to the global reference frame is simply the multiplication of transformation matrices, which is given as:

$$ {}^{0}T_i = {}^{0}T_1 \; {}^{1}T_2 \cdots {}^{i-1}T_i = \prod_{n=1}^{i} {}^{n-1}T_n \tag{7} $$

According to this method, the four parameters in Figure 11a are defined as follows:

1) θ^{i} is the joint angle between the x_{i-1} axis and the x_i axis about the z_{i-1} axis according to the right-hand rule.

2) d_i is the distance between the origin of the i-1[th] coordinate frame and the intersection of the z_{i-1} axis with the x_i axis along the z_{i-1}axis.
3) a_i is the distance between the intersection of the z_{i-1} axis with the x_i axis and the origin of the i^{th} frame along the x_i axis. Or, the shortest distance between the z_{i-1} and z_i axes.
4) α_i is the angle between the z_{i-1} axis and the z_i axis about the x_i axis according to the right-hand rule.

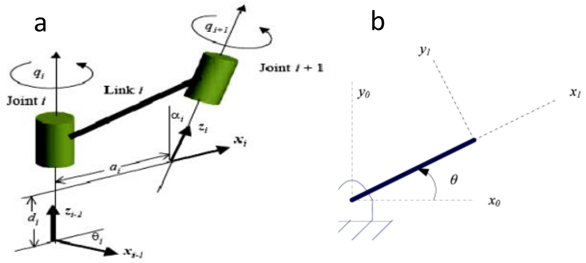


Figure 11: a) Transformation parameters, b) : Local reference frame

Then, the transformation matrix ${}^{i-1}T_i$ is composed in the following sequence of transformations:
WhereR_z and R_x represent rotation about the z and x axes, respectively, and $Trans_z$ and $Trans_x$ represent translations along the z and x axes, respectively. In other words, Equation (8) represents the following:
1) first, the i-1th frame is rotated by angle θ about the z axis;
2) second, the rotated frame is translated by distance d along the z axis;
3) third, the translated frame is translated again by distance a along the x axis; and
4) Fourth, the translated frame is rotated by angle α about the x axis.

This allows us to establish the home configuration, which is the starting configuration of the mechanical linkage; a suitable home configuration must be established in order to use the transformation method. In summary, to use this method, the coordinates system must satisfy the following two conditions:
1) The axis x_i is perpendicular to the axis z_{i-1}.
2) The axis x_i must intersect the axis z_{i-1}.

The transformation matrix from the i^{th} frame to the i-1th frame is then given as:

$$\begin{bmatrix} \cos\theta_i & -\cos\alpha_i\sin\theta_i & \sin\alpha_i\sin\theta_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\alpha_i\cos\theta_i & -\sin\alpha_i\cos\theta_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (9)$$

In the case of a rotational joint, the joint parameters d_i, a_i, and α_i are constant (which means they are fixed). Only θ_i is treated as a rotational degree of freedom, q_i. In a mechanical model, q_i is the vector of generalized coordinates, and each transformation matrix has one degree of freedom.
The local coordinate system is located at the end of the link in this representation. So, if we consider that there is a one-degree-of-freedom manipulator as shown in Figure 11b and the global reference frame is x_0, y_0, z_0 (z axis is perpendicular to the paper), then the local reference frame x_1, y_1, z_1, is located at the end of the linkage, according to this method.
The derivatives of transformation matrices are necessary for evaluating the equation of motion and for calculating gradients in gradient-based optimization. The derivatives are needed with respect to the joint displacements. The joint displacement that locates coordinate system i from the previous coordinate system is q_i; however the displacement is added to θ_i for a revolute joint and d_i for a prismatic joint. The derivative of a single transformation matrix (i.e. between x_i and x_{i-1}) is calculated by differentiating each entry of the matrix.

The derivative of transformation matrix from the i^{th} frame to the i-1th frame is calculated for a revolute joint by Equation (10).

$$\begin{bmatrix} -\sin\theta_i & -\cos\alpha_i\cos\theta_i & \sin\alpha_i\cos\theta_i & -a_i\sin\theta_i \\ \cos\theta_i & -\cos\alpha_i\sin\theta_i & \sin\alpha_i\sin\theta_i & a_i\cos\theta_i \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (10)$$

The second and third derivatives are found similarly. The derivatives of a general transformation matrix can be calculated using the chain rule. If the transformation matrix spans more than one joint, then only the transformation matrix that is a function of q_i is differentiated [36], [37].

4.3 Forward and Inverse Kinematic

Human kinematics can be divided into forward kinematics and inversekinematics.In general, forward kinematics entails finding the position and orientation of a point on the body, given the angles of the joints of the body.

Alternatively, inverse kinematics entails finding the angles of the joints of the body, given the position and orientation of a point on the body or determining that there is no solution.

Forward kinematics problem is straightforward and there is nocomplexity deriving the equations. Hence, there is always a forward kinematicssolution of a manipulator. Inverse kinematics is much more complicated than forward kinematics, especially for a system like the human body, which is redundant, and involves a large number of DOFs.. The solution of the inverse kinematics problemis computationally expansive and generally takes a very long time in the realtime control of manipulators.

The forward kinematics specifies the Cartesian position and orientation of the local frame attached to the human limb relative to the base frame which is attached to the still joint (e.g. shoulder or hip joint). They are provided by multiplying a series of matrices parameterized by joint angles, so finding a solution isn't difficult at all.

On the other hand, the inverse kinematics problem is ill-posed as infinite solutions exist due to the self-motion manifold, e.g. a self-motion surface, etc. [38]-[41]. With reasonable constraints or prior knowledge, a plausible solution can be found. However, our goal is to estimate the limb position, this is possible if some acquired angle-related data were given.

S. Kucuk and Z. Bingul [42], explained both forward and inverse kinematics for arobot, which is similar to human. They also provided solution techniques for this problem including analytical and numerical methods.

However, in order to reduce error rate as much as possible, after analyzing the video sequence and acquiring both positions and angles for each joint, we use both methods to validate the computed data.

5. EXPERIMENTAL RESULTS

The proposed system is computer based, where the digital camera provides a video sequence, and the software allows 300 Hz sampling rate. The computer is a PC with a Pentium (R) 4/2.4GHz CPU.

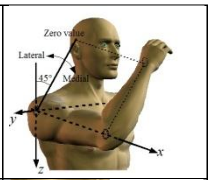
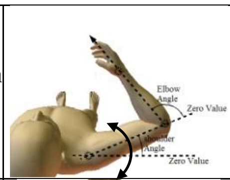
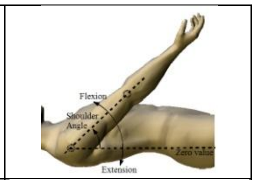
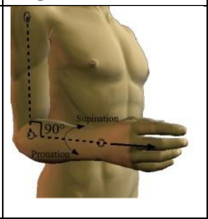
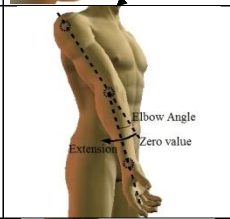
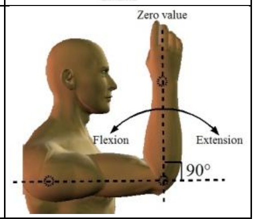
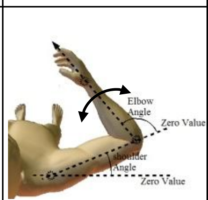
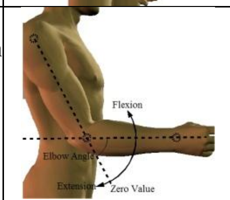
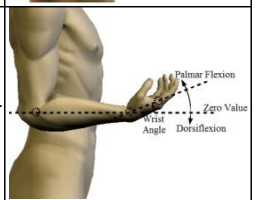
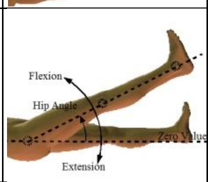
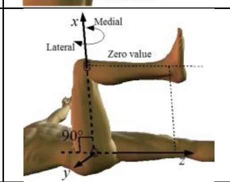
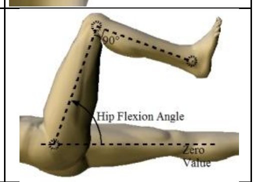
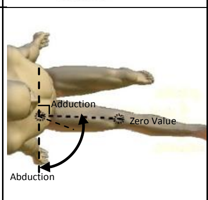
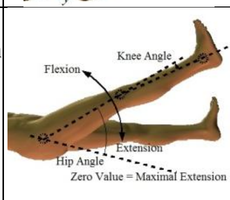
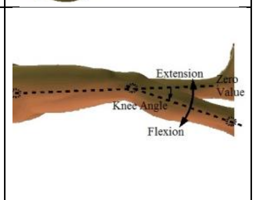
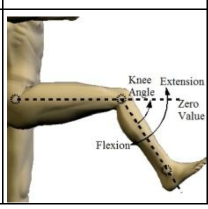
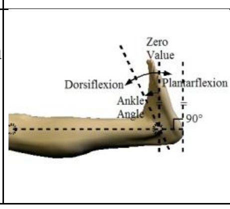
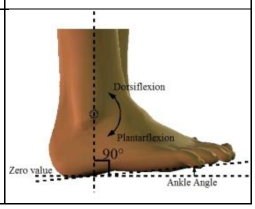
The kinematic data of the human limbs of a three subjects during daily activities were collected using motion capture system at a sampling frequency of 120 Hz. The subjects were instructed to perform three repetitions of the same activity.

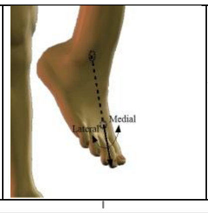
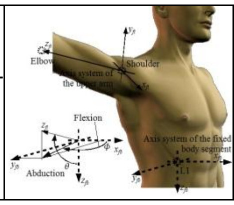
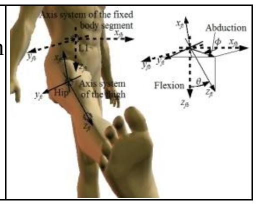
The activities were divided into two subgroups: (1) general motions, and (2) actions. Selecting the specific human activities was based on previous surveys of the disabled community indicating the desired tasks and functionality of powered orthotic devices and rehabilitation programs [43]-[46]. The general motion included a movement through a full range of motion of each of the human joints in different postures. The human actions during daily activities were performed in different body postures depending on the nature of the activity.

Given these conditions, no external forces or torques were applied on the human. Every action and general motion started from an initial position in which the limbs were fully extended along the body. The activities in Table1 were included in the experimental protocol.The movement dynamics were captured for each subject using analytical and numerical approaches. A model of the subject is then developed and its data is stored. In addition, the dynamics of the subject body is simulated numerically using a numerical model.

Figure 12, illustrates the movement angles after three repetitions of three activities of the hip joint along the three planes of movement (sagittal, frontal, and transverse) which are computed and displayed as a trace graph with degrees of movement plotted against time and look somewhat smooth and stable. These three activities are flexion/extension, abduction/adduction, and lateral/medial rotation of the hip joint; they are illustrated in figure 13. In the hip joint activities the flexion/extension appear on the Sagittal plane with a range of motion 0°-126° (0-2.2 RAD), abduction/adduction appear on the Frontal plane with a range of motion 0°-46° (0-0.8 RAD), and lateral/medial rotation appear on the Transverse plane with a range of motion 0°-44.5° (0-0.76 RAD).

Table 1: Activities included in the experimental protocol (first 19 are general motions, last 2 are actions).

Shoulder Lateral /Medial Rotation		Shoulder Horizontal Flexion-Extension		Shoulder Flexion-Extension	
Elbow Lateral/ Medial Rotation (Pronation-Supination)		Elbow Extension		Elbow Flexion-Extension	
Elbow Horizontal Flexion-Extension		Elbow Flexion-Extension while changing initial shoulder posture during measurement		Wrist Flexion-Extension (Palmar Flexion-Dorsiflexion)	
Hip Flexion-Extention		Hip Lateral/ Medial Rotation		Hip Flexion-Extension when the knee angle is 90°	
Hip Abduction-Adduction		Hip Flexion-Extension while changing initial knee posture during measurement		Knee Flexion-Extention	
Knee Flexion-Extentionwhile changing initial hip posture during measurement		Ankle Flexion-Extension (Dorsiflexion-Plantar Flexion) from supine position		Ankle Flexion-Extention (Dorsiflexion-Plantar Flexion) during sitting	

Ankle Lateral/ Medial Rotation		Shoulder Complex Motion including Flexion-Extension and Adduction-Abduction		Hip Complex Motion including Flexion-Extension and Adduction-Abduction	

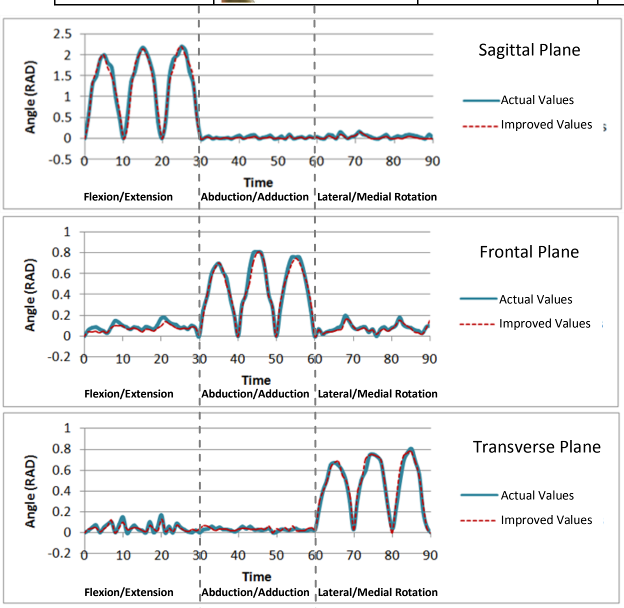


Figure 12: Measurements from the three different planes of movement (sagittal, frontal, and transverse) of the hip joint, the subject was instructed to perform three repetitions of flexion/extension, abduction/adduction, and lateral/medial rotation. As the hip joint has three degrees of freedom, it moves in all the three planes: 1) Sagittal: flexion/extension, 2) Frontal: abduction/adduction, and 3) Transverse: lateral/medial rotation.

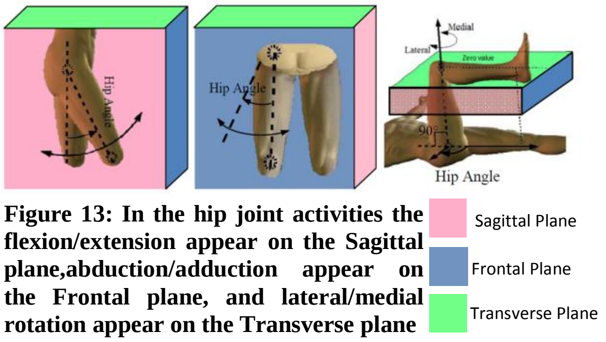


Figure 13: In the hip joint activities the flexion/extension appear on the Sagittal plane,abduction/adduction appear on the Frontal plane, and lateral/medial rotation appear on the Transverse plane

For the purpose of validation, static ranges of movements were measured by goniometer. That is, the subject performs the required movement then holds the final position whilst the measurement of that movement is taken by the goniometer. However, dynamic movements, including combinations of movements and the velocity of movement, which can be captured by the system, cannot be captured by the goniometer and so a complete picture of the movement is not obtained. This may be particularly clear in the movement of a complex joint, like the shoulder and hip joints, where movement is three-dimensional. These goniometer measurements were compared to the system results and the average difference was less than 2% in all cases.

6. CONCLUSIONS & FUTURE WORK

In this paper, we developed a computer vision system that is capable of analyzing and measuring human joints movements which can provide an attractive alternative to manual instruments such as goniometer, inclinometer or a tape. In addition, this system can provide an opportunity to perform accurate measurements without using expensive sensors, or special environments. Furthermore, it is easy to use, without any difficult requirements, and gives the opportunity for physiotherapist to diagnose and aid rehabilitation of joint movement disorders.

Although this kind of research yields valuable information, it only takes in to consideration revolute joints to represent each physical joint in the human. However, further research on prismatic joints is needed.

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