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BIOMECHANICAL APPROACH FOR FORCE ANALYSIS OF HUMAN BODY

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Abstract: This article provides a brief introduction of the bioengineering and biomechanical modelling approaches use to determine the force and moment, structural stability, and risk of injury. Model gives the conceptual construction which allows the formulation and testing. The analysis of complete body is done using link segment model. Throughout the article various modelling methods are presented and their applications are discussed. The computer program is developed for calculation of result. The program is user friendly in operation and change in the input can be made easily.

Keywords: Force analysis, Bioengineering, Biomechanical Models, Link Segment Model, MATLAB**.**

I. INTRODUCTION TO BIOENGINEERING

The bioengineering of human body and animal body is an interesting field. Who among us has never marveled at the graceful motions of a dancer, or the rapid finger movements of a musician? From the time of Aristotle onward there have been countless books written on the topic of movement in animals and humans. Despite the great minds that have considered the topic, it is just recently that much advancement has been made experimentally. Historically, the study of human body has been costly and very time consuming. This is because in order to study them, body is almost always dicretized and then analyzed step-by-step. Human body and animal body are undergoing various changes at day to day basis. These changes are due to various activities such as walking, running, bending and twisting the body, pushing and pulling, applying force etc. The various mechanical factors results into adverse effect on the body. In order to face these changes some corrective action should be taken. Various mathematical models are best suited to study the changes. These models are helpful in determining the forces and structural stability within the body. [1]

II. MODELLING OF BIOMEDICAL SYSTEMS

Models are conceptual constructions which allow formulation and testing of hypothesis. A mathematical model attempts to duplicate the quantitative behavior of the system. Mathematical models are used in today's scientific and technological world due to the ease with which they can be used to analyze real systems. The most prominent value of a model is its ability to predict as yet unknown properties of the system. The major advantage of a mathematical or computer model is that the model parameters can be easily altered and the system performance can be simulated. Mathematical models allow the study of subsystems in isolation from the parent system. Model studies are often inexpensive and less time consuming than corresponding experimental studies. A model can also be used as a powerful educational tool since it permits idealization of processes. Models of physiological systems often aid in the specification of design criteria for the design of procedures aimed at alleviating pathological conditions. Mathematical models are useful in the design of medical devices. Mathematical model simulations are first conducted in the evaluation of the medical devices before conducting expensive animal testing and clinical trials. Models are often useful in the prescription of patient protocols for the use of medical devices.

There are two types of modeling approaches: the black box approach and the building block approach. In the black box approach, a mathematical model is formulated based on the input-output characteristic of the system without consideration of the internal functioning of the system. Neural network models and autoregressive models are some examples of the black box approach. In the building block approach, models are derived by applying the fundamental laws (governing physical laws) and constitutive relations to the subsystems. These laws together with physical constraints are used to integrate the models of subsystems into an overall mathematical model of the system. The building block approach is used when the processes of the system are understood. However, if the system processes are unknown or too complex, then the black box approach is used. With the building block approach, models can be derived at the microscopic or at the macroscopic levels. Microscopic models are spatially distributed and macroscopic models are spatially lumped and are rather global. The microscopic modeling often leads to partial differential

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equations, whereas the macroscopic or global modeling leads to a set of ordinary differential equations. For example, the microscopic approach can be used to derive the velocity profile for blood flow in an artery; the global or macroscopic approach is needed to study the overall behavior of the circulatory system including the flow through arteries, capillaries, and the heart. Models can also be classified into continuous time models and models lumped in time domain. While the continuous time modeling leads to a set of differential equations, the models lumped in time are based on the analysis of discrete events in time and may lead to difference equations or sometimes into difference-differential equations. Random walk models and queuing theory models are some examples of discrete time models. Nerve firing in the central nervous system can be modeled using such discrete time event theories. Models can be classified into deterministic and stochastic models. For example, in deterministic modeling, the rate of change of volume of an arterial compartment to be equal to rate of flow in minus the rate of flow out of the compartment. However, in the stochastic approach, we look at the probability of increase in the volume of the compartment in an interval to be dependent on the probability of transition of a volume of fluid from the previous compartment and the probability of transition of a volume of fluid from the compartment to the next compartment. While the deterministic approach gives the means or average values, the stochastic approach yields means, variances, and covariance. [2]. Another form of model is equilibrium based model. This class of models uses the principles of mechanical equilibrium. The definition of mechanical equilibrium refers to a system in a state of balance between opposing forces and moments. The basic principles governing equilibrium based models are predicated by Newtonian laws. According to Newton's first law of motion, for static equilibrium where position or velocity is constant, the sum of forces (**F**) and moments (**M**) acting on the system must equal zero. [3]

III. LINK SEGMENT MODEL

One of the equilibrium based biomechanical model Link Segment model approaches is suitable when the moments and reactive forces at numerous joints are needed. The human body can be compartmentalized into linked body segments, each treated as a separate entity represented as a free-body diagram. Starting with the first segment proceed further. Link Segment model Analysis can be started with a bottom-up approach where ground reaction forces acting on the feet are entered into the model first or a top-down approach where forces acting on the hands are used to drive the analysis. Link segment model is of two types

a) Static link segment model

b) Dynamic link segment model

Link segment model for the force analysis in the body when the load of certain amount is lifted in the bending condition. Fig. 1 shows the detail link segment model drawing of the human body in bend position.

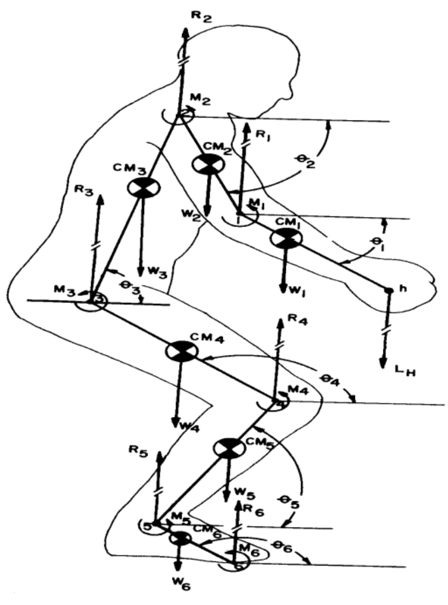

Fig. 1 link segment model of human body

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Static link segment model is used to determine the forces and moments about the joints. Link segment model is best suited for the right, regular geometry. Here separate analysis of each and every part of the body is done. During the analysis free body diagram of the body part as shown in the Fig 2 is made, in the later stage equation for the force and equation for the moment is written down. In the next stage standard and known values are substituted in the equation. Finally the value of force and moment at the particular joint and for a particular body is obtained.

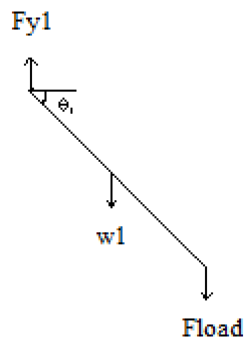

Fig. 2 Forearm of human body

A. Method for force and moment calculations using link segment model

A female of weight 50 kg and height of 156 cm is considered and values corresponding to the body are taken. Consider free body diagram of forearm as shown in Fig. 2 at an angle ‘θ1’ with load ‘Fload’ holding in hand, weight ‘w’, moment ‘M1’ at elbow joint, reaction force ‘Fy1’ at the elbow joint, length of the segment ‘L’, centre of mass of the segment ‘rload’.

$$Fy1-w-Fload=0 \quad (1)$$

$$-Fload*(\cos \theta1*L)-w1*(\cos \theta1* rload)-M1=0 \quad (2)$$

By substituting the known and standard value in the equations 1 and 2 values of force F1 and moment M1 are find out.

Fy1 = 59.3000

M1 = 676.8750

The force and moment is transferred to other part of the body for finding corresponding force and moment of other parts of the body.

IV. PROGRAM CODE FOR LINK SEGMENT MODEL OF HUMAN BODY

The program code is written in MATLAB (R2011a) version. MATLAB provides interactive platform for executing numerical computation. The program is developed to determine the force and moment at various joints of the body which is otherwise need to be attempted by hand calculation [4].

The program is developed for forearm were the variable load Fload, angel θ1, weight of segment w1, centre of mass of segment rw1, length of segment l1 are declared. The equation of the force F1 and equation of the moment M1 is formulated using equilibrium method which says total force and moment is equal to zero. These equations are solved by substituting the known and standard values and the obtained values are saved as Fy1 and M1.

For Fore arm

```
Fload=49; %%Total load
theta1InDegrees=300; %%angle
theta1InRadians=theta1InDegrees*(pi/180);
w1=10.3; %%weight of forearm
rw1=12.5; %%center of mass of Forearm
l1=25; %%length of forearm
Fy1=w1+Fload%%reaction at joint of forearm and upperarm
M1=-Fload*(cos(theta1InRadians)*l1)-w1*(cos theta1InRadians)*rw1) %%moment at fore arm and upper arm joint
```

For upper arm

```
l2=27;%%length of upperarm
w2=13.243;%%weight of upperarm
rw2=14.6;%%center of mass of upperarm
theta2InDegrees=330;%%angle
```

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```
theta2InRadians=theta2InDegrees*(pi/180);
Fy2=w2+Fy1%%reaction at sholder joint
M2=-M1-Fy1*(l2*cos(theta2InRadians))-w2*(rw2*cos(theta2InRadians))%%moment at sholder joint
```

Similar program is written in MATLAB for rest of the body parts with change in syntax and standard values and necessary force plot is obtained as shown in Fig.3
Results for rest of the body parts are shown in Table I

Table I.
Result for rest of the body parts.

Body parts	Force (N)
Forearm	59.3000
Upper arm	72.5430
Vertebral column	90.5430
Femur	131.2545
Tibia-fibula	158.2320
Feet	164.1180

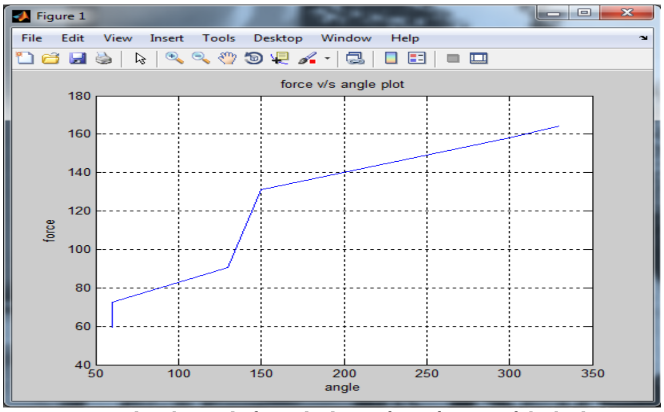

Fig. 3 Force plot obtained after calculating force for rest of the body parts

VI CONCLUSION

The issue of calculating the force on various parts of the body can be address properly by biomechanical models. The link segment model which is equilibrium based model is one of the simplest methods for force calculation. Developed program is helpful in calculating the force for different inputs. The computer programming technique is employed to minimize computational cost and time.

VII. DISCUSSION

A simplest method to calculate the force at various parts of the body is discussed in this paper. This method can be used for complete body as well as for the single section of the body where the force needs to be calculated.

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