The 6th Joint International Conference on Multibody System Dynamics and
The 10th Asian Conference on Multibody Dynamics
October 16-20, 2022, New Delhi, India

Modeling and Validation of Human Gait Dynamics using Modified Euler-Lagrange Approach

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Abstract
This paper presents a methodology for determining the lower-limb joint torques of a human model while performing tasks such as walking and running. A mathematical model based on the Euler-Lagrange formulation has been developed to formulate the motion. The existing E-L formulation has been modified to accommodate moving reference frames. The new modified model is then validated on a published data set and the estimated joint torques are compared with the reference joint torques. The results indicated that the proposed model is able to estimate the joint torques accurately.
Keywords: Lower-limb, Joint torques, Human gait, Euler-Lagrange dynamics

Introduction

Understanding the human gait is necessary for rehabilitation purposes or in the design of prostheses and exoskeleton devices. In the inverse dynamics problem of human gait, the joint reaction forces and moments are calculated from the known kinematic data and anthropometric measurements. The quantifiable data can be used for performance analysis or assessment of a person. The common approaches used to obtain the equation of motions are Euler-Lagrange (E-L) and Newton-Euler (N-E) formulations. Though the computation time to solve the dynamic equations is less in the N-E method as compared to the E-L method, the E-L method is more flexible and intuitive. As per the literature, in most E-L based formulations for human gait, the foot frame is considered to be stationary and as a base frame during the formulation. In this paper, the hip frame is assumed to be the base frame and also its motion parameters are considered for deriving the joint torques of the lower limb accurately.

Methodology

The lower limb is modelled as an open kinematic chain with four rigid links [1] as shown in Fig. 1. These rigid links are assumed to be connected by three universal rotational joints. The rigid links represent the pelvis, thigh, shank and foot whereas the three joints represent the hip, knee and ankle joints. The relative motion among the segments is understood by means of affixing frames to the joints. Denavit and Hartenberg (D-H) representation is used to represent each link's coordinate system at the joint with respect to the previous links' coordinate system. The parameters that would be required to obtain the dynamic equations are the segment lengths, masses, centre of masses of each segment and respective moments of inertia. As the E-L method has been used to derive the equations, the primary step in this regard is to obtain the Lagrangian function L. It is defined as the difference between the total kinetic energy (KE) and the total potential energy (PE) in the system. Once the Lagrangian function L is known, the joint moments can be calculated using the eq [1].

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = \tau_i \qquad [1]$$

where τ_i represents the generalised torque or force at joint i, L is the Lagrangian function, q_i is the generalised coordinate. The final set of equations that is obtained from the transformation matrices, potential energy, kinetic energy and Lagrangian L is given by eq. [2] where Tr represents trace of matrix, J represents the inertia matrix, A represents the transformation matrices, τ_{GRF} represents torque at joints due to Ground Reaction Force (GRF).

$$\boldsymbol{\tau}_i = \sum_{j=i}^{n} Tr\left(\ddot{A_p}\, {}^{0}A_j\, J_j U_{ji}^T A_p^T\right) + 2\sum_{j=i}^{n}\sum_{r=1}^{j} Tr\left(\dot{A_p} U_{jr}\, J_j U_{ji}^T A_p^T\right)\dot{q_r} + \sum_{j=i}^{n}\sum_{r=1}^{j}\sum_{s=1}^{j} Tr\left(U_{jrs}\, J_j U_{ji}^T\right)\dot{q_r}\,\dot{q_s} + \sum_{j=i}^{n}\sum_{r=1}^{j} Tr\left(U_{jr}\, J_j U_{ji}^T\right)\ddot{q_r} + \sum_{j=1}^{n} m_j g\left(A_p U_{ji}\, R_j\right) + \tau_{GRF} \qquad [2]$$

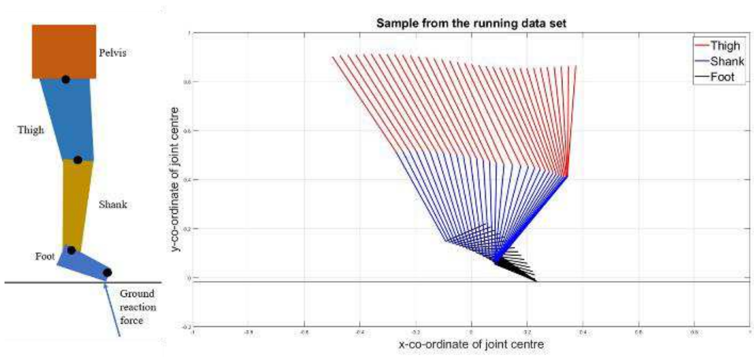

Figure 1: a. Lower-limb model b. Stick model simulation of running marker data set

A published dataset is used to validate the Inverse dynamics model of human gait presented in this paper. The data set is of a human running as in Fig.1b, sourced from the work done by Bogert et. al [3]. The data set contains 6001 samples, having a sampling interval of 0.1ms. From the data set, the joint angles, velocity and acceleration parameters are calculated which in turn are used for calculating joint torques using eq. [2].

Results and discussion

The calculated lower limb joint torques matched with the torque values as presented in the reference dataset. The torque obtained are compared with the reference torques as shown in Fig.2. The output torques do not have any noise as the data set includes a simulated marker set.

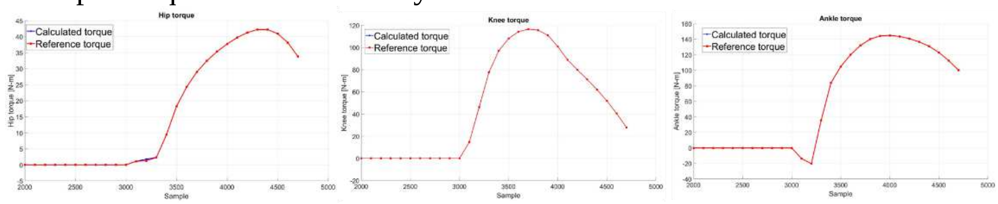

Figure 2: Comparison of calculated torques with reference torques of hip, knee and ankle joints

References

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