A 2D Unified Gait Model for both single and double stances

Abhyudit Singh Manhas*, **Mowbray Rajagopalan#**, **Dr. Sourav Rakshit†**

* 4th year Bachelors Student
Department of Mechanical Engineering
Indian Institute of Technology, Madras
Chennai, Tamil Nadu, India
abhyudit309@gmail.com

Research Scholar
Department of Mechanical Engineering
Indian Institute of Technology, Madras
Chennai, Tamil Nadu, India
rvmowbray11@gmail.com

† Assistant Professor
Department of Mechanical Engineering
Indian Institute of Technology, Madras
srakshit@iitm.ac.in

Introduction

An inverse dynamics analysis for human walking involves the computation of the internal joint reactions and moments. This analysis usually requires (i) kinematic/gait data (ii) ground reaction forces (GRF), and (iii) data about masses of the body segments and locations of their centre of mass. Kinematic data is easily collected using human motion capture systems, and information about body segment parameters is available from anthropometric data. In some cases, GRF data might be collected from force plate measurements, but in many situations, this data might just not simply be available, or it might be infeasible to measure it. Thus, the ground reaction forces need to be determined from the kinematic data itself.

In this paper, we present a novel formulation in which the ground reaction force is estimated from a lagrangian analysis and the zero-moment point (ZMP) concept [3]. Walking is assumed to be a 2-dimensional activity, and all joints are assumed to be simple hinge joints. The formulation ensures that the number of unknowns in both the double stance and single stance phases remains the same. From this the GRF is determined, and they can now be considered external forces for say, a 13 dof humanoid, in which 1 dof is for trunk flexion, the hip is a ball and socket joint, the knee is hinge joint and the ankle is a 2 dof joint that allows dorsiflexion/plantarflexion and inversion/eversion. For this situation, the joint reactions and moments can be computed, which can be used further for rehabilitation purposes. For example, the motors of an exoskeleton can apply these values of moments to correct the gait of a patient.

Method

In double stance, the number of unknowns will be more as compared to single stance because both the feet are in contact with the ground. To tackle this, in the formulation, both the feet are assumed to be like rollers, with effectively one point of contact in the double stance phase, whereas in the single stance phase, the foot is approximated as a triangle, with two points of contact with the ground. This ensures the number of unknowns remains the same throughout the analysis. This is illustrated in Figure 1, which shows a 9 dof model of human walking in 2D. The x-axis is in the direction of walking (anteroposterior axis), and the y-axis is in the longitudinal direction.

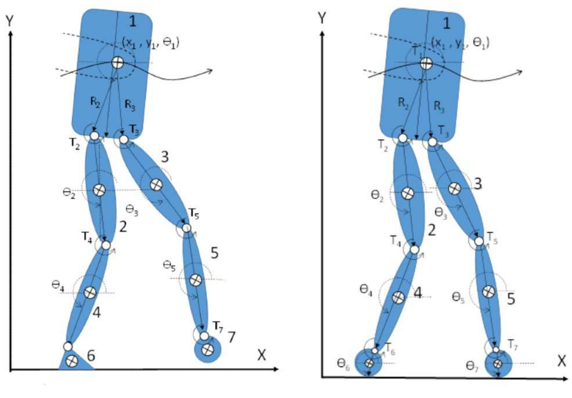

Figure 1: Nine dof humanoid model for (i) single stance (ii) double stance.

We have the equations of motion:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = 0 \tag{1}$$

where $q = [x_1, y_1, \theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6, \theta_7]$ denotes the 9 dof, and L is lagrangian of the system, given by

$$L = \sum_j \text{KE}_i - \sum_j \text{PE}_i + \text{W}_{ext} + \sum_k \lambda_k g_k \tag{2}$$

where g_k denotes the contact constraints. For each contact point, we have 2 contact constraints. In addition to this the ZMP equation [3] is also used, in which moments of all external and inertial forces are zero about the zero-moment point, which in this case is the projection of centre of mass of the system on the floor. Thus we have 10 equations, and in our formulation as well, we have 10 unknowns (irrespective of whether it is single or double stance), and so the unknowns can be determined. The lagrange multiplier corresponding to the contact constraint at the ground gives the ground reaction force in the x and y direction. Finally, a 3-dimensional, 13-degree of freedom humanoid model is developed, and the GRF calculated from the previous analysis is used, in conjunction with a recursive Newton-Euler formulation [2], to estimate the joint moments and forces. Note that when we transition from 2D to 3D, the GRF is still assumed to act only in the longitudinal and anteroposterior direction, and is neglected in the mediolateral direction, which is a fairly accurate approximation.

Results and Discussion

The GRF obtained from the lagrangian analysis of the 9 dof humanoid is now compared with the experimental values from [1], and is shown below.

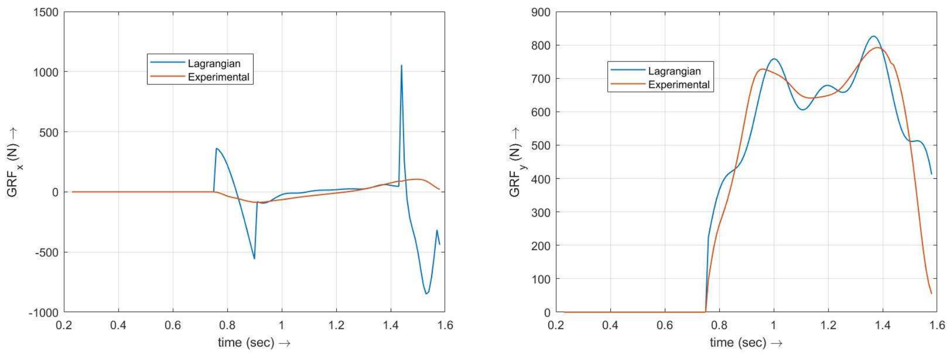

Figure 2: Plot of the x and y components of the GRF versus time for one gait cycle. The blue line denotes GRF computed from our formulation, and the orange line denotes experimental GRF from [1].

We can observe that there is good agreement between the experimental values, and the values calculated from the 2D lagrangian analysis. There are phases where the values don't match, and in that case, we propose to use experimental data from online datasets. We assume the GRF in these regions to be a function of joint variables, velocities, and accelerations. The parameters of this function are then estimated using regression techniques. Then as mentioned in the previous section, these GRF values are now considered to be external forces for a 13 dof humanoid, and the joint moments are finally determined.
Thus in conclusion, this formulation allows us to accurately compute the ground reaction forces from just the gait data, and without relying on separate measurements from force plates, which otherwise might be impractical or expensive.

References

[1] Schreiber, C.; Moissenet, F.: A multimodal dataset of human gait at different walking speeds established on injury-free adult participants. Nature, Article No. 111, 2019.

[2] Spong, M.; Hutchinson, S.; Vidyasagar, M.: Robot Modeling and Control (2^{nd} edition). Wiley, 2020.

[3] Vukobratovic, M.; Borovac, B.; Surla, D.; Stokie, D.: Biped Locomotion - Dynamics, Stability, Control and Application. Springer-Verlag, 1990.