Dynamics and Analysis of human motion for the selective actions

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ABSTRACT

This is the lab report on Dynamics and Analysis of human motion for the selective actions. The main aim of the work is to study the human motion for the given set of actions using Newton Eulers formulation. The multi body dynamics is formulated based on Modified Hanavan Model. Finally the results are evaluated with the ground truth of the human actor recorded using ARTracking system and Force plates. The code for the experiment is available in https://github.com/franklinselva/study-human-motion-newton-eulers.git.

INTRODUCTION

In this report, our objective is to analyse the statistical data to represent the human race behaviour. At least 10 subjects are needed to generate the result of the human population instead of using a single sample which is impossible. Eventhough the work doesn't represent the complete population, the work is to carried out for determining the experimental setup. By using this statistical results body segment parameters are measured and estimated for the single human actor.

The main objective of this report is to calculate the dynamics of the human motion from the Newton-Euler equations. The validation and the hypotheses of the human model are compared with the calculation of ground reaction force (GRF) to the real measured data (force plate). These calculations are made in the reference frame R_0 for any body S_k with respect to the kinetic and the potential energies. In Preprocessing data, the mean and standard deviation are calculated with the help of statistical data to generalise the human model. In Model Dynamics, Newton-Euler's Formulation is derived. In Modelling Inverse Pendulum Model, dynamics of Simple Inverse Pendulum Model (IPM) and Double Inverse Pendulum Model (DIP) is calculated to validate the computed model before evaluating with human motion data. Experimentation and Validation is encountered and compared with the recorded data.

PREPROCESSING DATA

By using the statistical data, Human motion is generated with the help of 10 actors. But for explaining through the approach, a single actor is choosen and four measurements are taken by different groups. Then the mean and standard deviation of the readings are taken for proceeding with the BSP Parameterization.

Mean value of each body segment can be calculated by

$$\tilde{X} = \frac{1}{N} \sum_{i=0}^{N} X_i \tag{1}$$

Sample Standard Deviation by

$$\theta = \sqrt{\frac{1}{N-1} \sum_{i-1}^{N} (X_i - \tilde{X})^2} \tag{2}$$

BSP Estimation

The generalized data can be used to parameterize the into rigid solid models retaining the mass M, Centre of Mass CoM and the inertial matrices I. The geometric classification are grouped into three categories:*Semi-Ellipsoid (SE), Elliptical Solid (ES) and Stadium Solid(SS)*. The bodies are generated based on Modified Hanavan Model represented in Fig[1] and all bodies are assumed to be rigid and has uniform density.

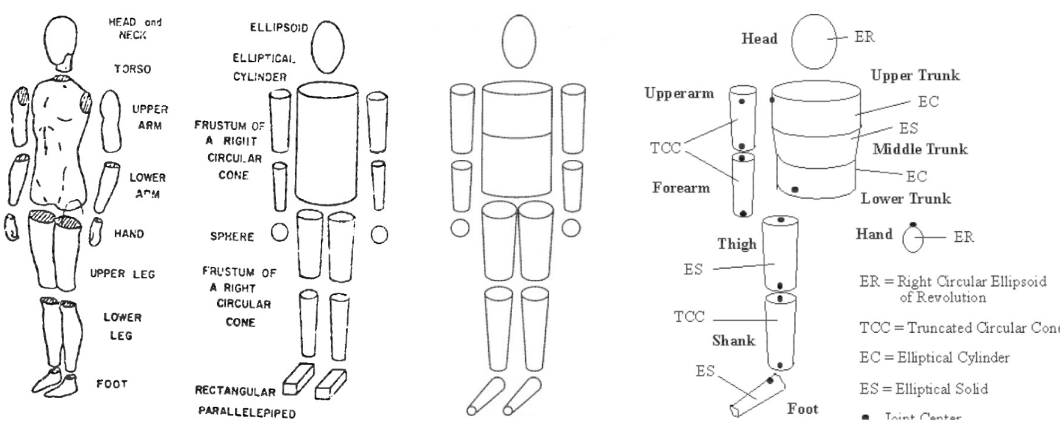

Figure 1: Modified Hanavan Anthropometric Approximation

The measurements of the actor by five groups are plotted as *errorbar* in figure [**??**].

Reading DRF files

The position and orientation of joints were recorded in DRF file using ARTtrack system. The motion capture system captures the frame at *60 Hz* records the content in DRF file. The sample data content of DRF file is shown below in fig[3].

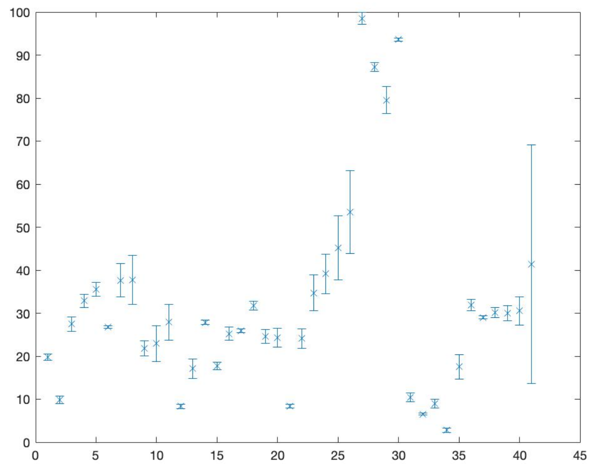

Figure 2: BSP Estimation - error plot for hanavan parameters

```
fr 34514
ts 64425.076492
6dcal 17
6d 15 [0 1.000][…
6dj 3 1 [0 20][0 1.000][562.7647 -128.7422 781.4459 -0.0000 0.0000 87.8071][0.038265
0.999268 0.000000 -0.999268 0.038265 0.000000 0.000000 0.000000 1.000000][1
1.000][564.9398 -128.8686 966.4164 1.1212 2.2889 88.7907][0.021088 0.999602 0.018721 -
0.998980 0.020320 0.040335 0.039939 -0.019552 0.999011][2 1.000][522.1646 -141.5154
1347.3978 0.3947 0.2996 89.6321][0.006420 0.999956 0.006855 -0.999966 0.006384
0.005273 0.005229 -0.006889 0.999963][3 1.000][654.3460 -144.7520 1504.9670 -1.5249
1.7823 90.0123][-0.000215 0.999646 -0.026605 -0.999516 0.000613 0.031097 0.031102 ….
```

Figure 3: Sample output of DRF file

where the prefixes fr represent frame counter; ts represent the time stamp; $6dj \quad 3 \quad 1$ represent 6 DOF joint data output, 3 human model calibrated and 1 human model data output; and [0   20] represent the first human model joints data, 20 joints data is defined. Having these representation, the file is parsed in MATLAB during runtime.

Signal Processing

The force data recorded from force plates are stored in *.csv* files for each of the recorded actions. The stored parameters are: *sequence, timestamp, forces and moments*. The readings are recorded at *1 kHz* from the forces plate while it can be noted that motion capture systems are recorded in *60 Hz*. Hence the forces are downsampled to *60 Hz* using *downsample() from Signal Processing Toolbox*.

The signal recorded shifts rapidly and hence need to reduce the noise using *Zero Phase Filtering applying butterworth lowpass filter* of degree 12. This smoothened the signal plots from recorded and calculated force and moments which can be shown as in figure [4]. The noises are reduced in such a way to retrieve the force information from the force plates.

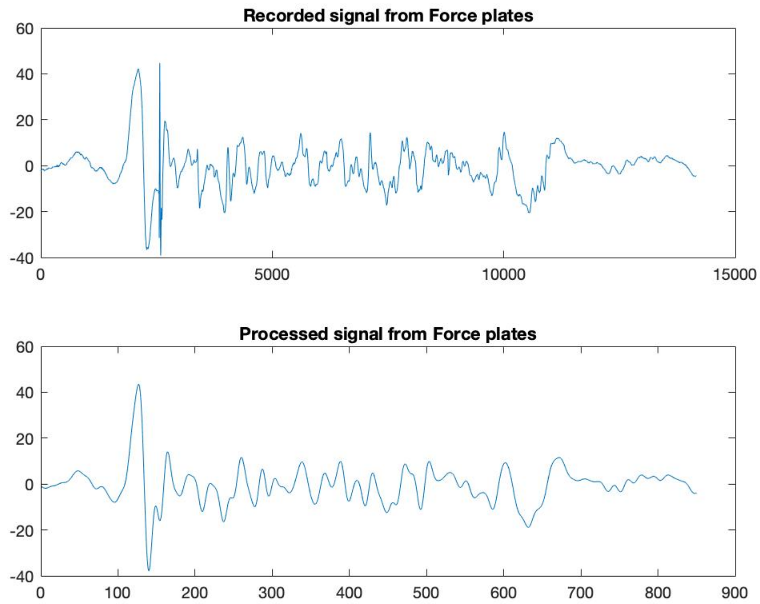

Figure 4: Representation of processed signal compared to recorded signals in force plates

Visualization of the data

The recorded and pre-processed data are visualized to estimate the action performed by the human actor. The visualization is carried out using MATLAB and is displayed in figure [5]. The animation is kept simple referencing to the equivalent body segments for Hanavan parameterization neglecting *mass, physics and inertial parameters*. Only the *pose and orientation* of the joint frames with respect to each of the parent frames are visualized.

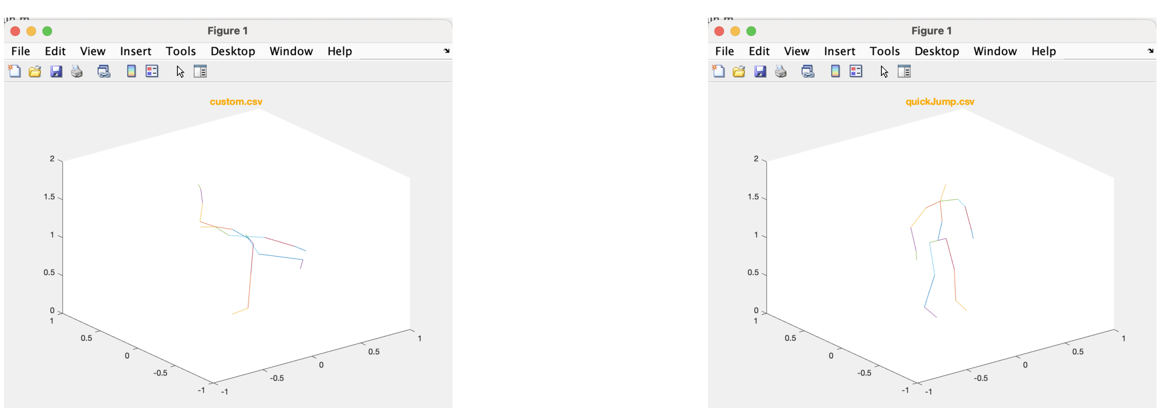

Figure 5: Visualization of *kick* (left) and *jump* (right) action performed by human actor recorded from ARTrack Motion Capture System

MODEL DYNAMICS

Newton Euler's Formalism

The human body has been generalized to modified Hanavan model. Now to calculate the force and moment, we use Newton Euler's approach. For each frame captured, the joint angles, their first-order derivative and their respective second-order derivative are calculated for this recursive dynamic approach. The Hypothesis considered for NE equations are as follows

- Body segments are rigid.
- Mass density is homogeneous.
- No friction, loss of energy from heat is considered. In other words, the body is energy-conservative.

For the computation of the velocity and acceleration, the joints *5, 6, 13 and 14* are neglected. From computing α_i and β_i, the force and moment of the feet are recomputed using the backward approach. The respective force computation is plotted in [6].

$$\begin{aligned} \sum f_i &= m_i \dot{v}_i + \dot{\omega}_i + ms_i + \omega_i \times (\omega_i \times ms_i) \\ \sum m_i &= I_{o_i} \dot{\omega}_i + ms_i \times \dot{v}_i + \omega_i \times (I_{o_i} \omega_i) \end{aligned} \tag{3}$$

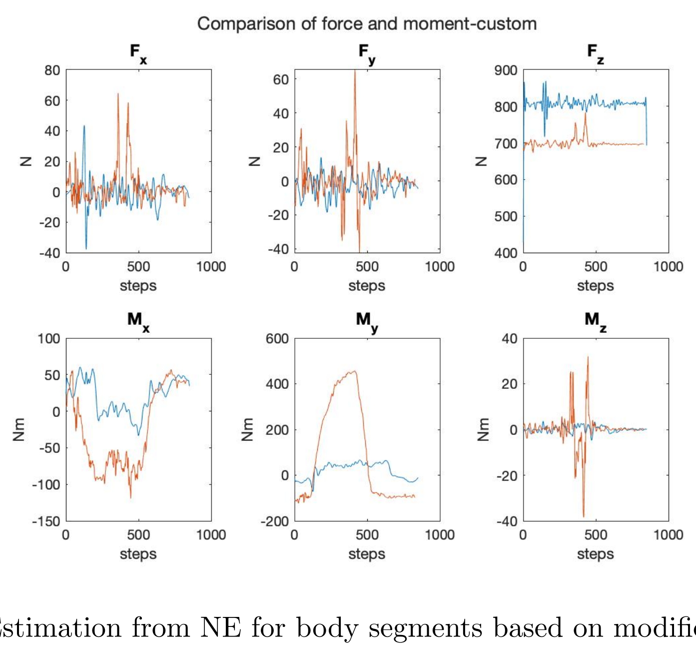

Figure 6: Force Estimation from NE for body segments based on modified Hanavan model

with,

$$ms_i = \begin{bmatrix} mX_i & 0 & 0 \end{bmatrix}^T$$

$$I_{oi} = \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix}$$

where ms_i and I_i represent the Centre of Mass and the Inertial matrix of the given body i respectively .

Energy Equations

The energy consumed by each body can be represented into kinetic energy [4] and potential energy [5].

Kinetic energy,

$$K_i = \frac{1}{2}(m_i^i v_i^{T^i} v_i +^i \omega_i^{T^i} I_{o_i}{}^i\omega_i + 2^i ms_i^T({}^i v_i \times^i \omega_i)) \tag{4}$$

Potential energy,

$$U_j = -\begin{bmatrix} {}^0g^T & 0 \end{bmatrix}{}^0 T - j(q) \begin{bmatrix} {}^j ms_j \\ m_j \end{bmatrix} \tag{5}$$

Then the total energy of the body i can be given by E_i and the total energy consumed by the entire model with all the links can be calculated as follows. The kinetic and potential energy of each body segment are plotted in figure [7] and [8].

$$E = \sum E_i \qquad\qquad E_i = K_i + U_i \tag{6}$$

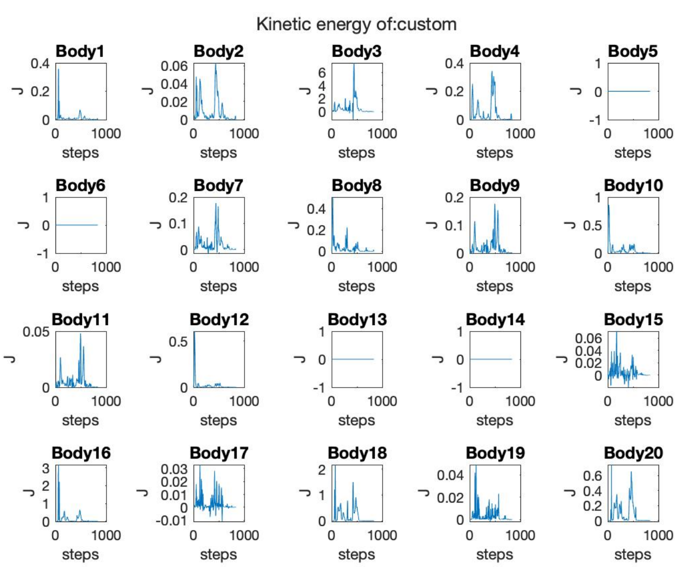

Figure 7: Kinetic Energy of each body i

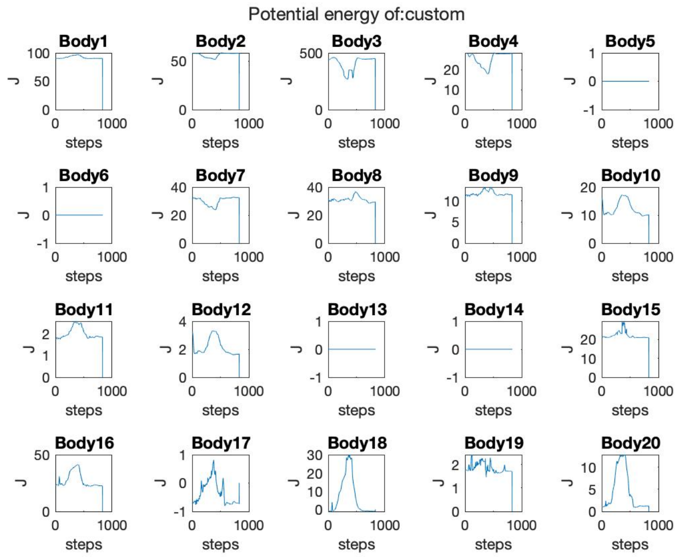

Figure 8: Potential Energy of each body i

MODELLING INVERSE PENDULUM MODEL

In this section, the dynamics of inverse pendulum model are discussed. The inverse pendulum model is used to evaluate the Newton formalism to estimate the ground force.

Simple Inverse Pendulum Model (IPM)

Consider a simple inverted pendulum model as in figure [9] with mass m and link length l_1, the kinematics and dynamics for the model can be represented as,

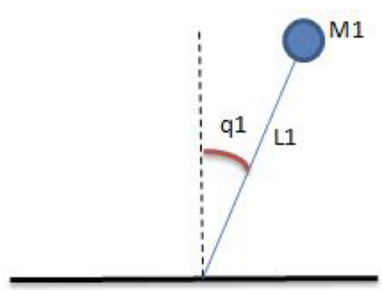

Figure 9: Simple Inverse Pendulum Model

Position:

$$
\begin{aligned}
x_1 &= -l_1 \sin q_1 \\
y_1 &= l_1 \cos q_1
\end{aligned}
\tag{7}
$$

Velocity:

$$\begin{aligned} \dot{x_1} &= -l_1 \cos(q_1)\dot{q_1} \\ \dot{y_1} &= -l_1 \sin(q_1)\dot{q_1} \end{aligned} \tag{8}$$

Acceleration:

$$\begin{aligned} \ddot{x_1} &= l_1 \sin{(q_1)}\dot{q_1}^2 - l_1 \cos{(q_1)}\ddot{q_1} \\ \ddot{y_1} &= -l_1 \cos{(q_1)}\dot{q_1}^2 - l_1 \sin{(q_1)}\ddot{q_1} \end{aligned} \tag{9}$$

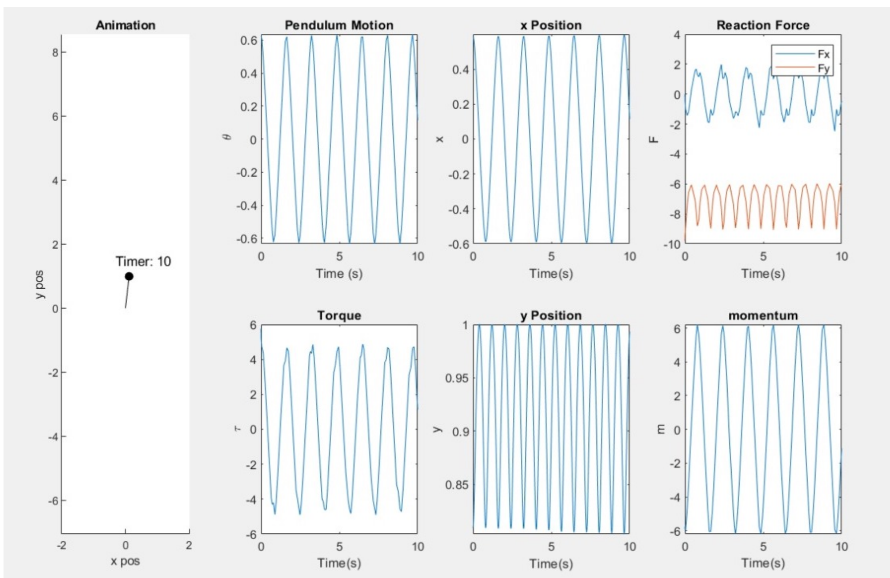

Figure 10: Force and Moment estimation for Simple Inverted Pendulum

Forces and Torques:

$$\begin{aligned} m_1\ddot{x_1} &= F_{x1} \\ m_1\ddot{y_1} &= F_{y1} - m_1 g \end{aligned} \tag{10}$$

$$\tau_1 = m_1 l_1^2 \ddot{q_1} + m_1 g l_1 \sin q_1 \tag{11}$$

where F_{x1} and F_{y1} represent the reaction forces on the link from the fixed point.

Double Inverse Pendulum Model (DIP)

Consider a double inverted pendulum model as in figure [11] with mass m and link lengths l_1 and l_2, the kinematics and dynamics for the model can be represented as,

Position:

$$\begin{aligned} x_1 &= -l_1 \sin q_1 \\ y_1 &= l_1 \cos q_1 \end{aligned} \tag{12}$$

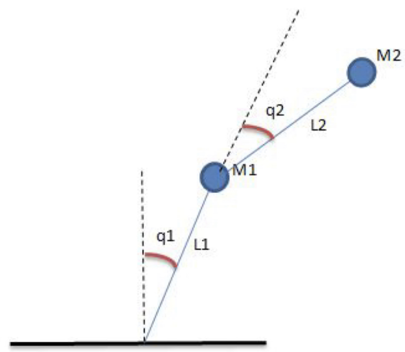

Figure 11: Double Inverse Pendulum Model

$$\begin{aligned} x_2 &= -l_1 \sin q_1 - l_2 \sin (q_1 + q_2) \\ y_2 &= l_1 \cos q_1 + l_2 \cos (q_1 + q_2) \end{aligned} \tag{13}$$

Velocity:

$$\begin{aligned} \dot{x_1} &= -l_1 \cos(q_1)\dot{q_1} \\ \dot{y_1} &= -l_1 \sin(q_1)\dot{q_1} \end{aligned} \tag{14}$$

$$\begin{aligned} \dot{x_2} &= -l_1 \cos(q_1)\dot{q_1} - -l_1 \cos(q_1 + q_2)(\dot{q_1 + q_2}) \\ \dot{y_2} &= -l_1 \sin(q_1)\dot{q_1} - -l_1 \sin(q_1 + q_2)(\dot{q_1 + q_2}) \end{aligned} \tag{15}$$

Acceleration:

$$\begin{aligned} \ddot{x_1} &= l_1 \sin (q_1)\dot{q_1}^2 - l_1 \cos (q_1)\ddot{q_1} \\ \ddot{y_1} &= -l_1 \cos (q_1)\dot{q_1}^2 - l_1 \sin (q_1)\ddot{q_1} \end{aligned} \tag{16}$$

$$\begin{aligned} \ddot{x_2} &= -l_1 \cos (q_1)\ddot{q_1} + l_1 \sin (q_1)\dot{q_1}^2 - l_2 \cos (q_1 + q_2)(\ddot{q_1} + \ddot{q_2}) + l_2 \sin(q_1 + q_2)(\dot{q_1} + \dot{q_2})^2 \\ \ddot{y_2} &= -l_1 \sin (q_1)\ddot{q_1} + l_1 \sin (q_1)\dot{q_1}^2 - l_2 \sin (q_1 + q_2)(\ddot{q_1} + \ddot{q_2}) + l_2 \cos(q_1 + q_2)(\dot{q_1} + \dot{q_2})^2 \end{aligned} \tag{17}$$

Forces and Torques:

$$\begin{aligned} m_1\ddot{x_1} &= F_{x1} + F_{x_2} \\ m_1\ddot{y_1} &= F_{y1} + F_{y_2} - m_1 g \end{aligned} \tag{18}$$

$$\begin{aligned} m_2\ddot{x_2} &= F_{x2} \\ m_2\ddot{y_2} &= F_{y2} - m_2 g \end{aligned} \tag{19}$$

where F_{x1},F_{x2},F_{x3} and F_{y1},F_{y2},F_{y3} represent the reaction forces on the link from the fixed point.

$$
\begin{aligned}
\tau_1 &= m_1 l_1^2 \ddot{q}_1 + m_1 g l_1 \sin q_1 \\
\tau_2 &= m_2 l_2^2 (\ddot{q}_1 + \ddot{q}_2) + m_2 g l_2 \sin(q_1 + q_2)
\end{aligned}
\tag{20}
$$

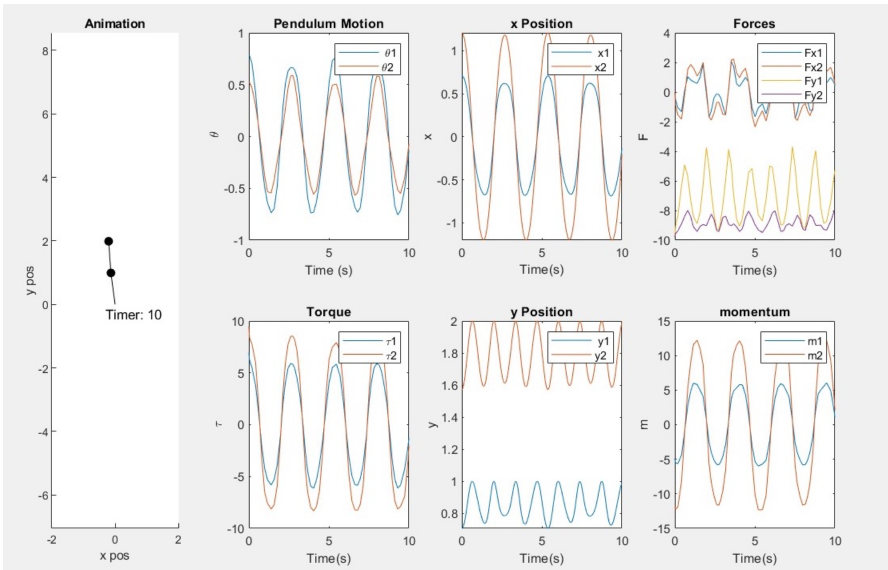

Figure 12: Force and Moment estimation for Double Inverted Pendulum

EXPERIMENTATION AND VALIDATION

In this section, the ground truth and the estimated data of force and moments of the actor are analysed and validated. The actor was been instructed to perform a set of actions in different modes; *slow, medium and fast* mode. Once each body forces and moments are calculated, the ground reaction forces and resultant moments for Human motion is computed as follow:

- Single support motion (kicking) :Now in this case, the free leg can be treated as the arms. So the sequence of recursion of NE equations as follow: 2 Arms, Head -¿ Upper trunk, the free leg $->$ Lower trunk $->$ the standing leg.
- Double support motions (Jumping, waving, sitting) Recalling the hypothesis of the equivalent reaction forces on 2 feet, the NE equation for Lower trunk actually become one input(from upper trunk), one output (to the two legs). Therefore, the sequence of recursion of NE equations as follow: 2 Arms, Head $->$ Upper trunk $->$ Lower trunk $->$ 2 legs.

The plots representing the kinetic and potential energy, force and moment on each body segment and error plots are plotted in this section.Each of the analysed action are presented in five plots

- Total energy (kinetic and potential energy)
- Force and Moment plot (Ground Truth and Estimated)
- Kinetic energy of each body segments
- Potential energy of each body segments
- Error plot between ground truth and estimated force and moments.

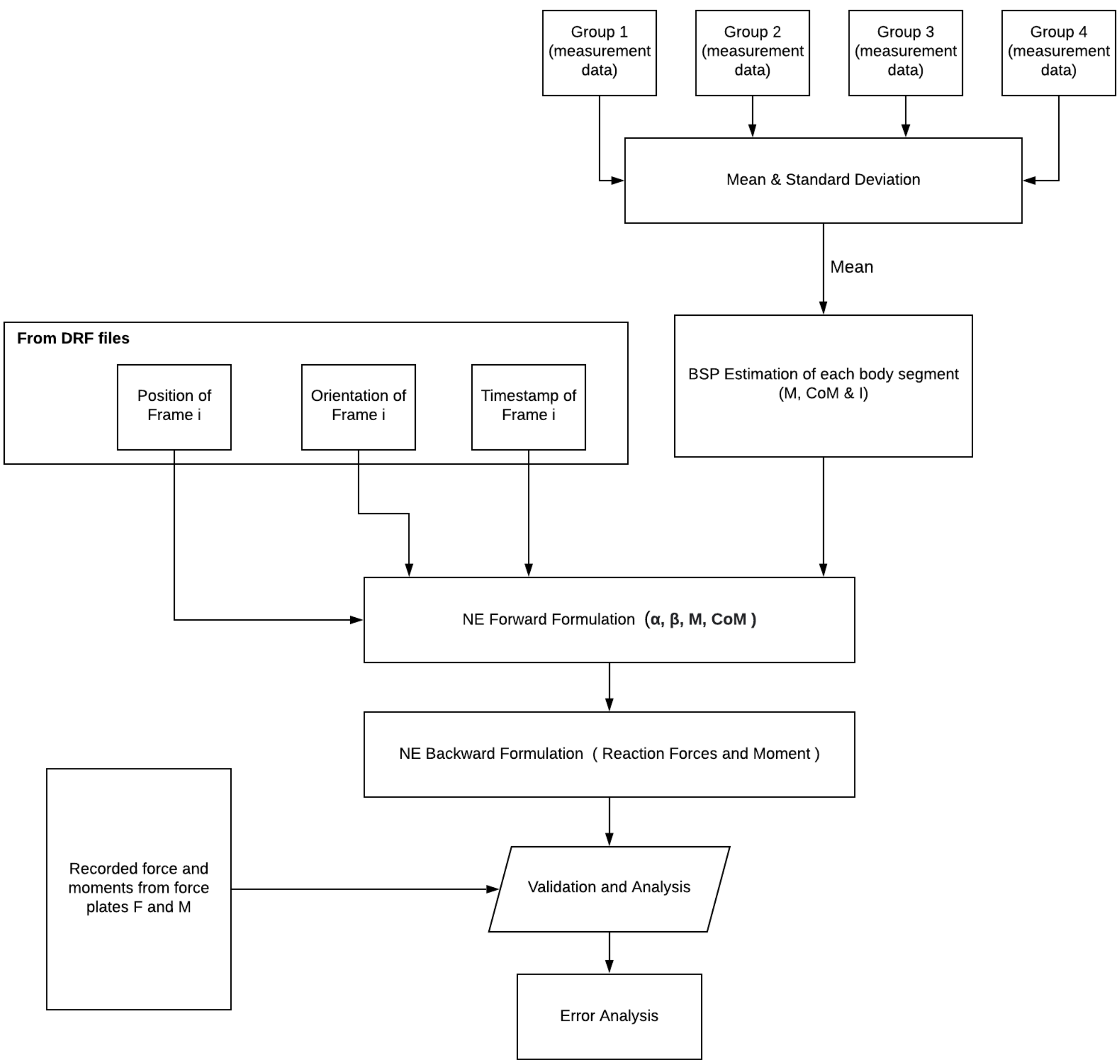

Figure 13: Workflow Approach for programming in MATLAB

1. Fast Arm actions are validated and plotted below:

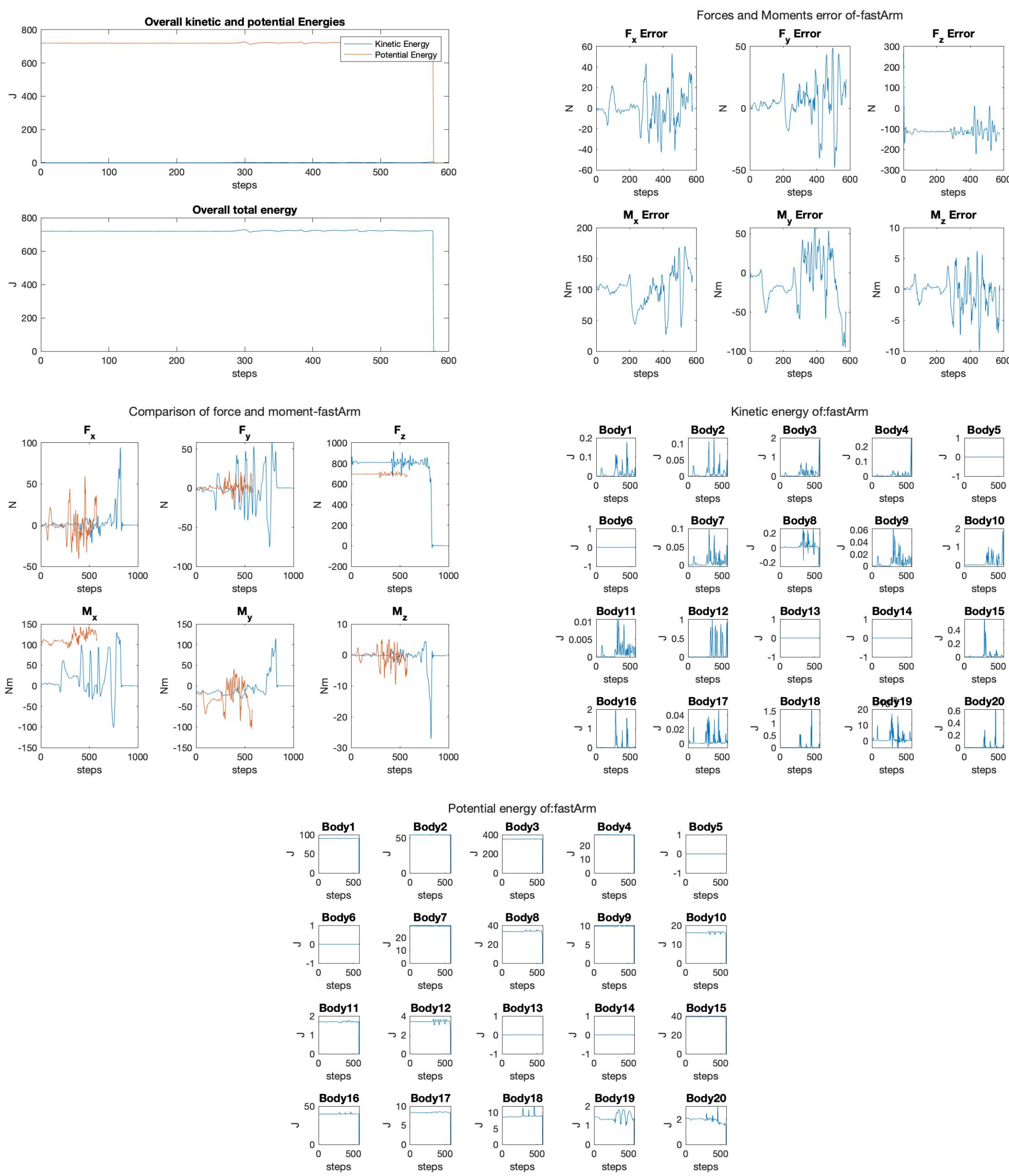

Figure 14: Fast Arm actions of each body i

2. Jump actions are validated and plotted below:

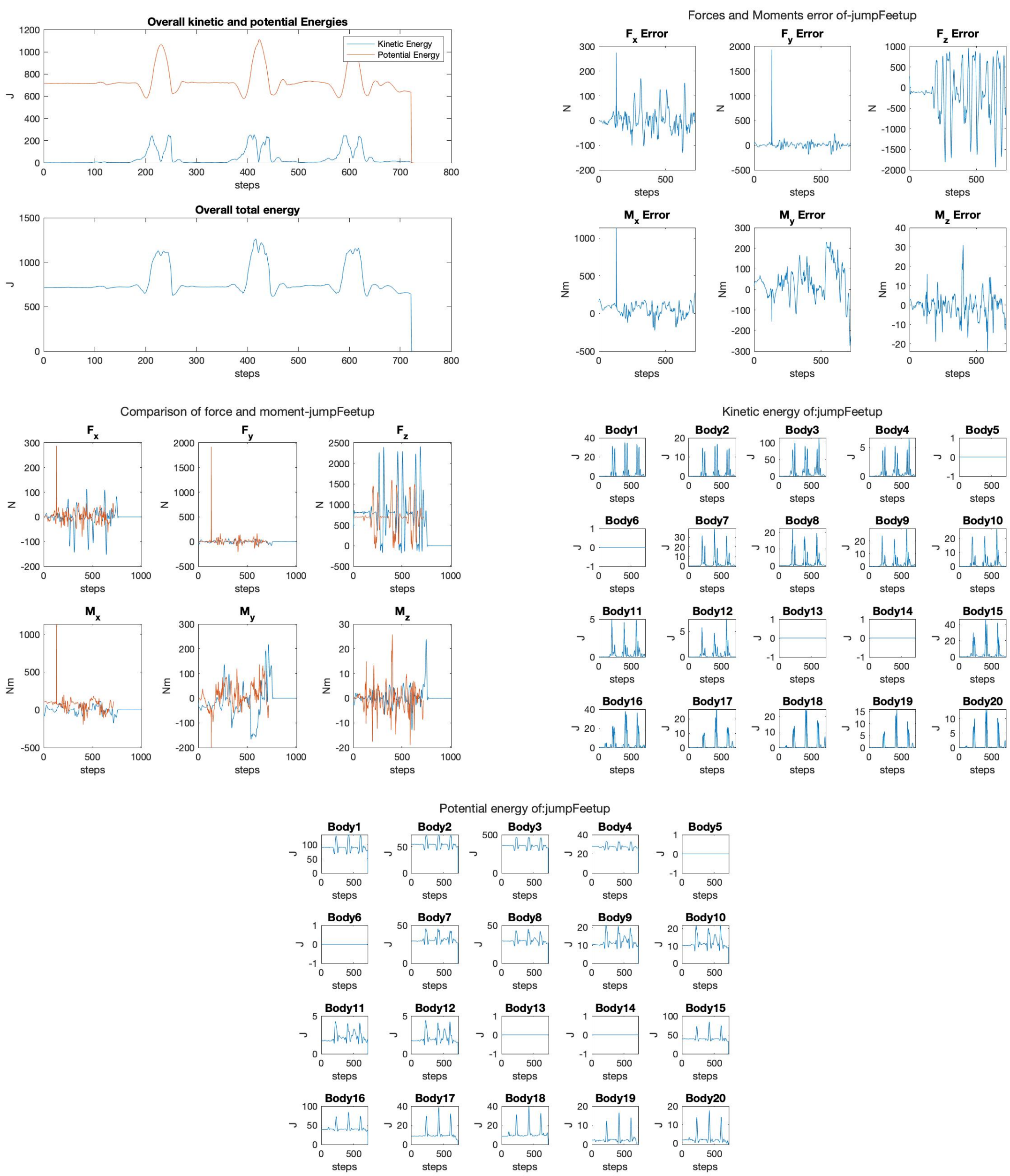

Figure 15: Jump Feetup actions of each body i

3. Max Jump actions are validated and plotted below:

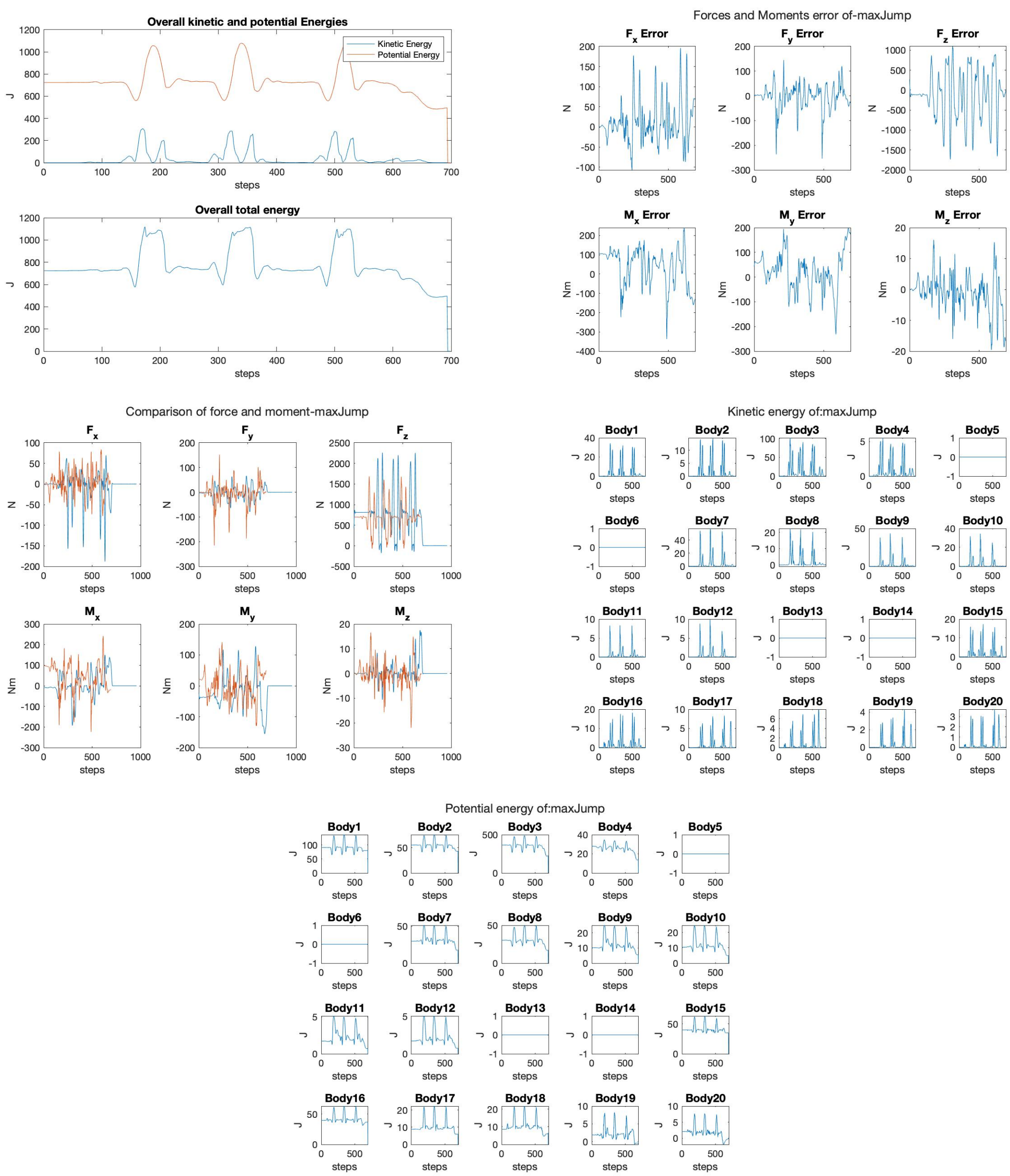

Figure 16: Max Jump actions of each body i

4. Medium Arm actions are validated and plotted below:

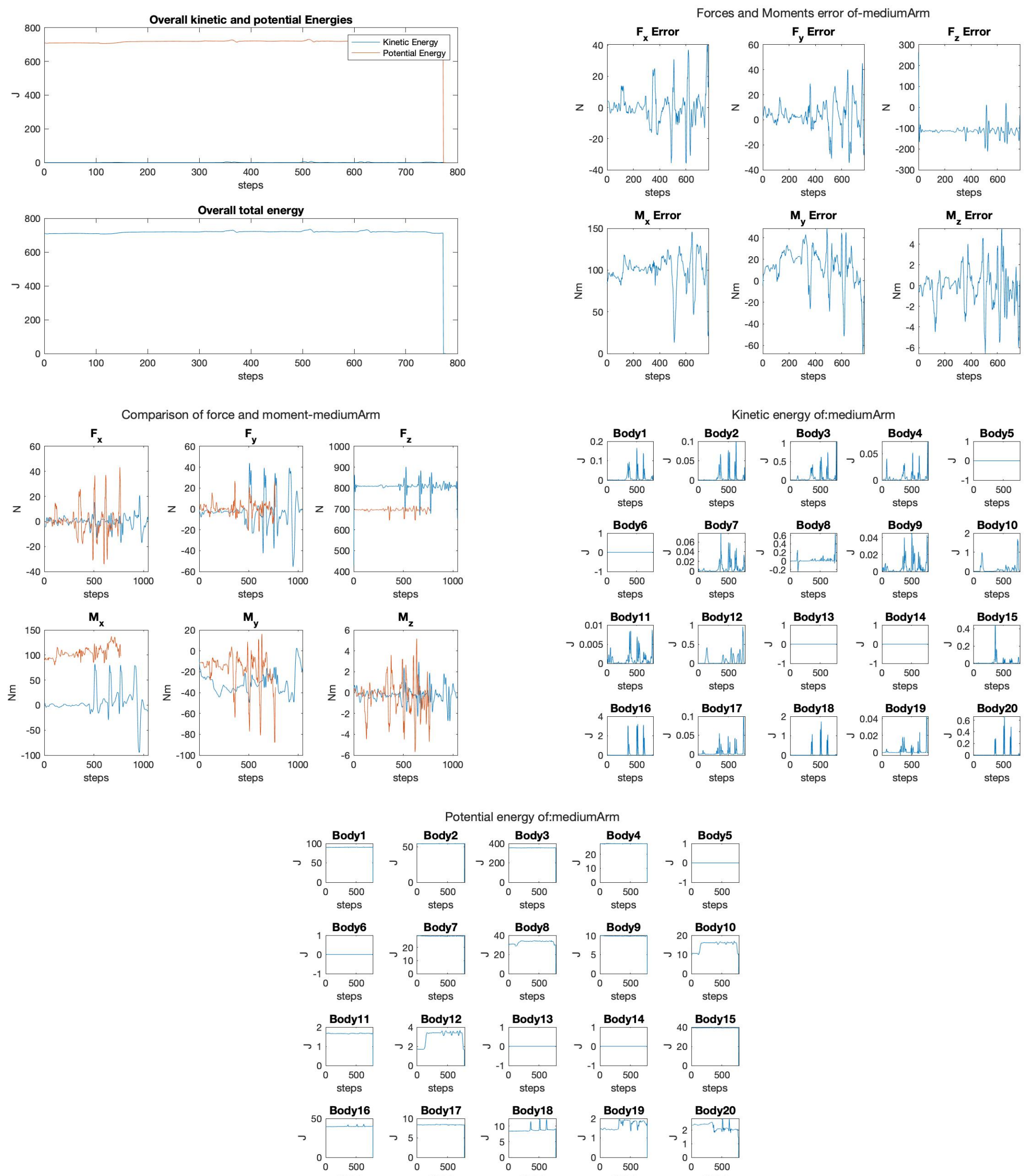

Figure 17: Medium Arm actions of each body i

5. Quick Jump actions are validated and plotted below:

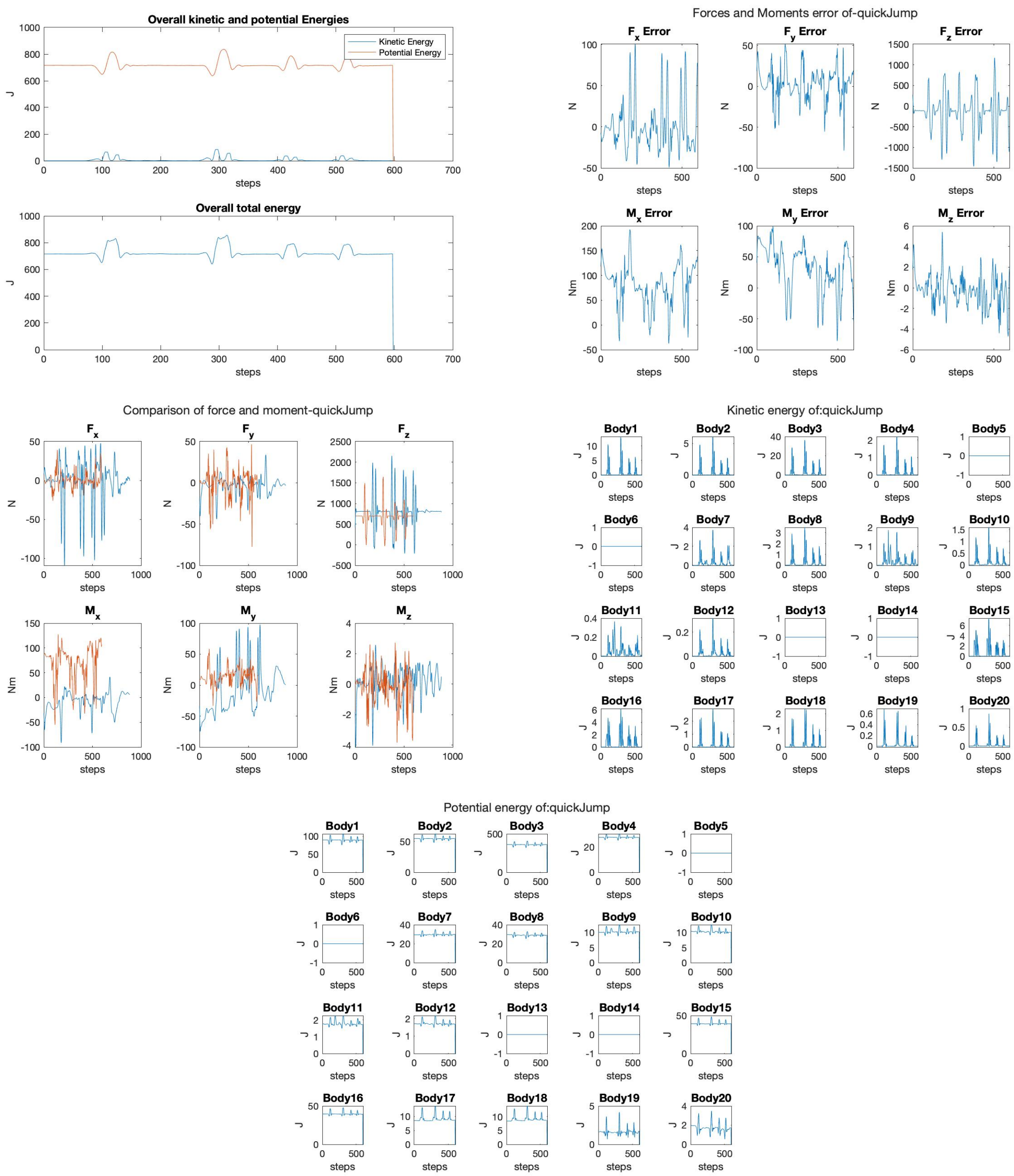

Figure 18: Quick Jump actions of each body i

CONCLUSION

The experiment and analysis of human motion is performed on MATLAB and are detailed in this report. The code for the experiment is available in GitHub repository at https://github.com/franklinselva/study-human-motion-newton-eulers.git.

APPENDIX

The Human Motion is validated and plotted for different actions for Kinematic energy, Potential energy, force and momentum along with the error plot. These plots are plotted and referred below in this section. Each of these plots are same as in *Validation and Results*.

1. Custom 2 actions are validated and plotted below:

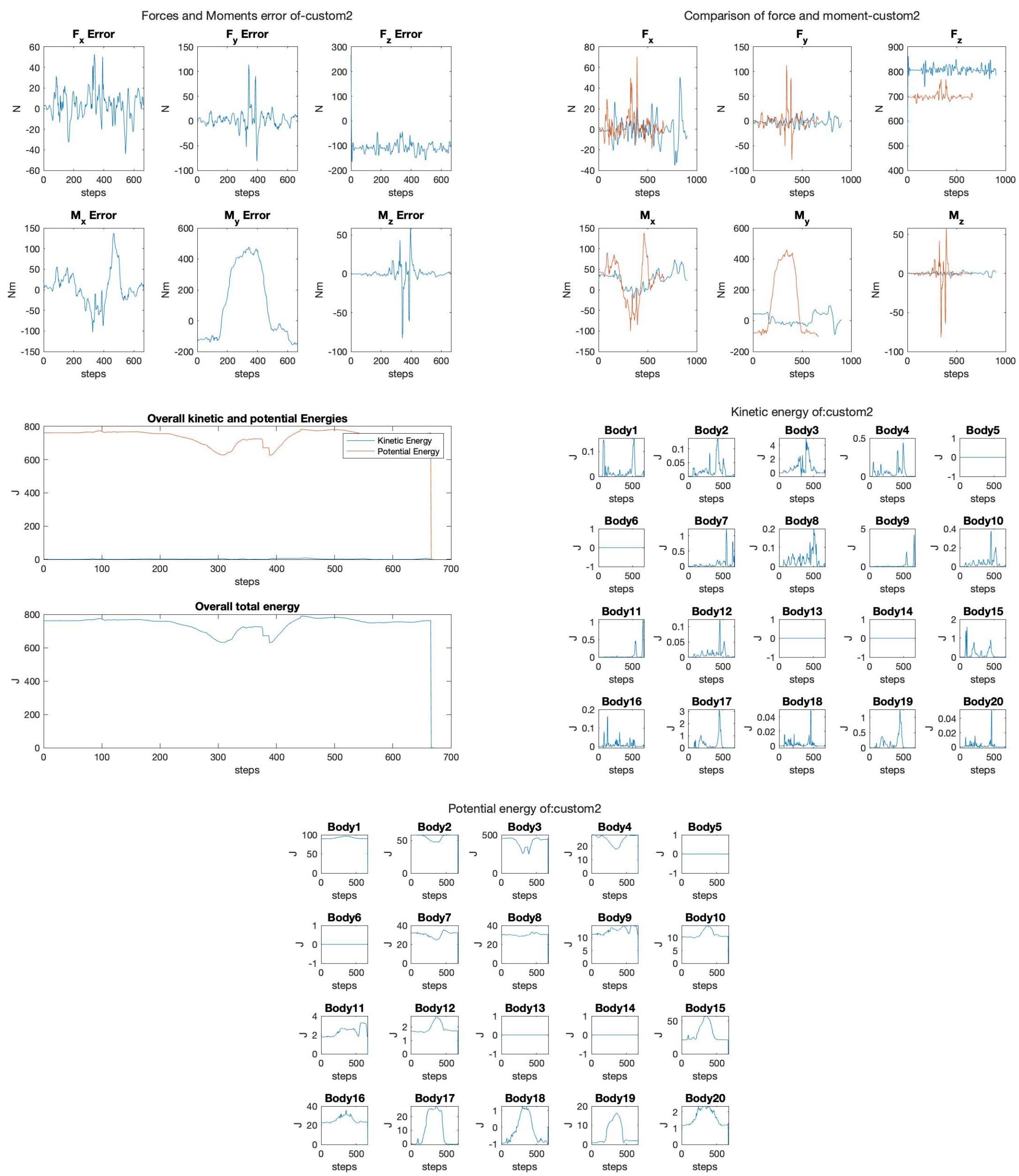

Figure 19: Custom 2 actions of each body

2. Custom L actions are validated and plotted below:

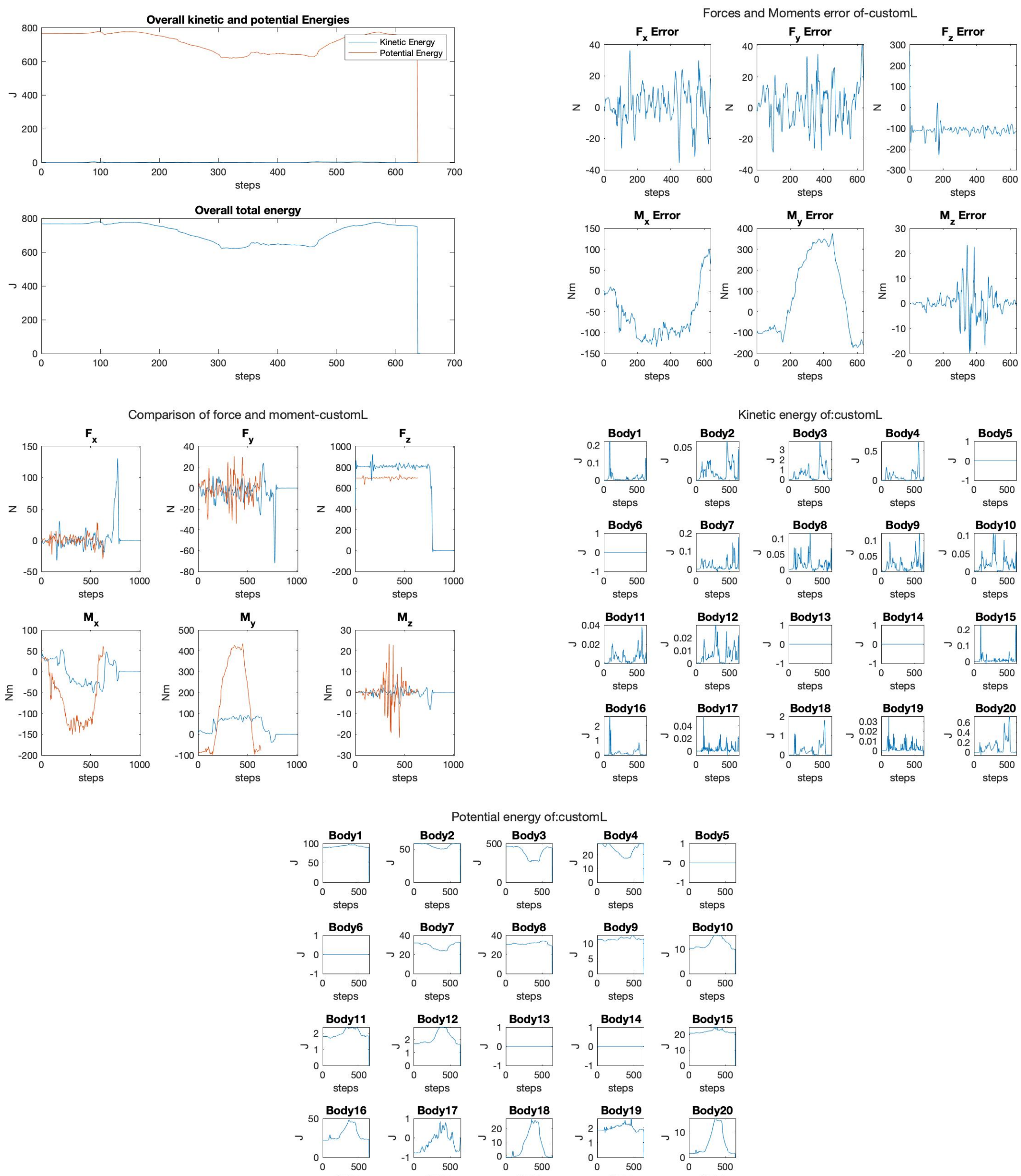

Figure 20: Custom L actions of each body

3. Fast Kick actions are validated and plotted below:

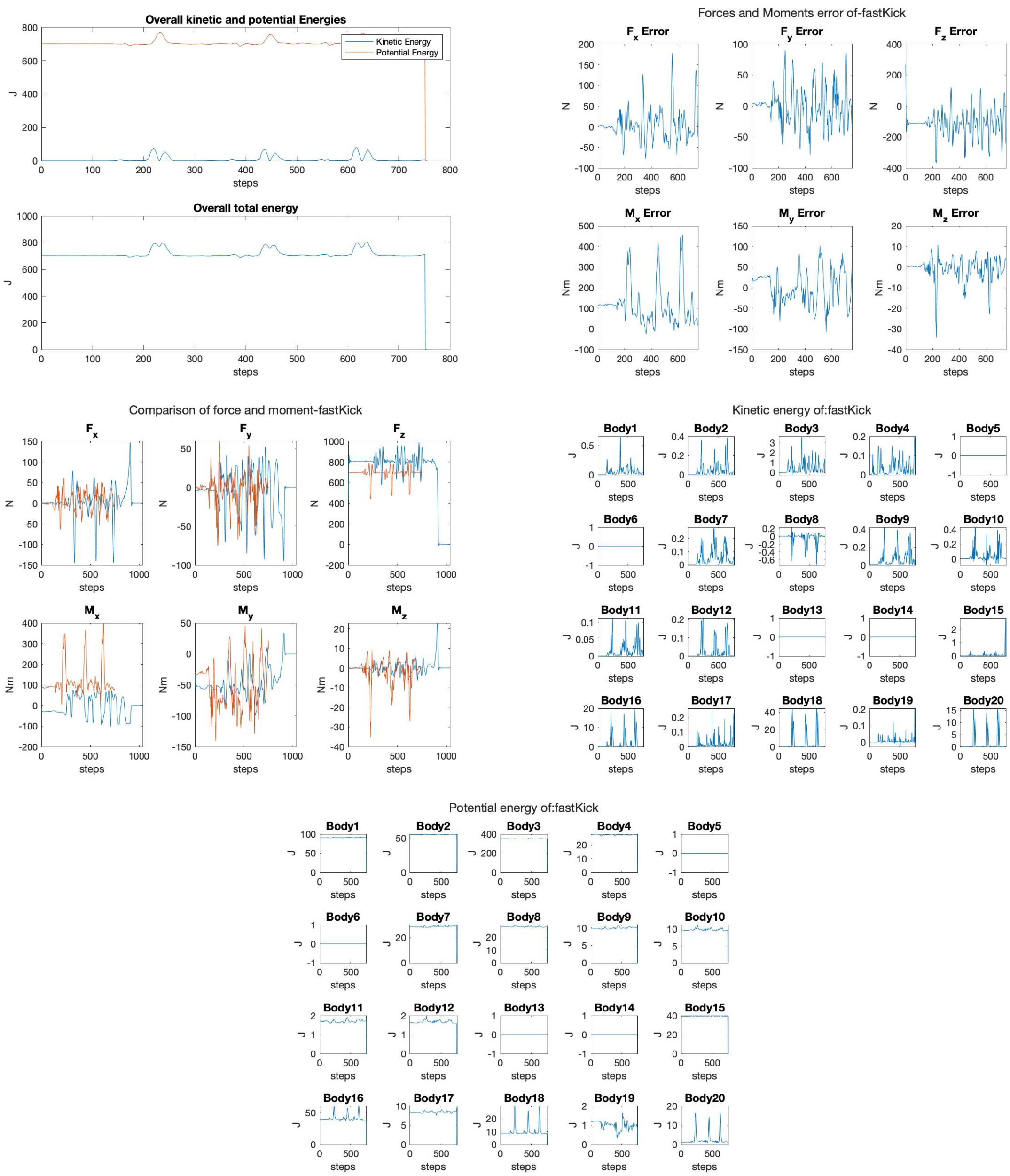

Figure 21: Fast Kick actions of each body

4. Fast Kick Arm actions are validated and plotted below:

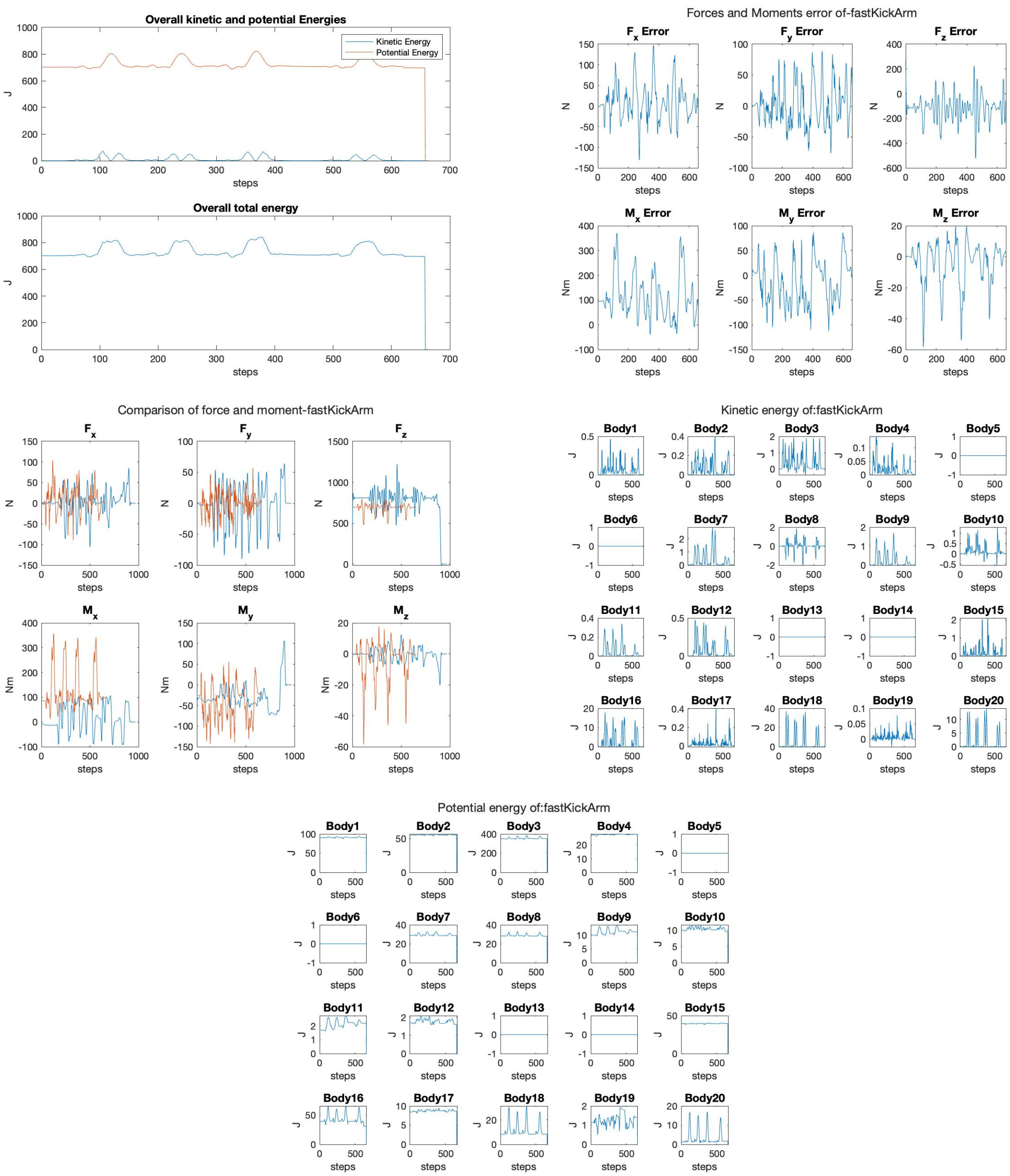

Figure 22: Fast Kick Arm actions of each body

5. Max Jump 2 actions are validated and plotted below:

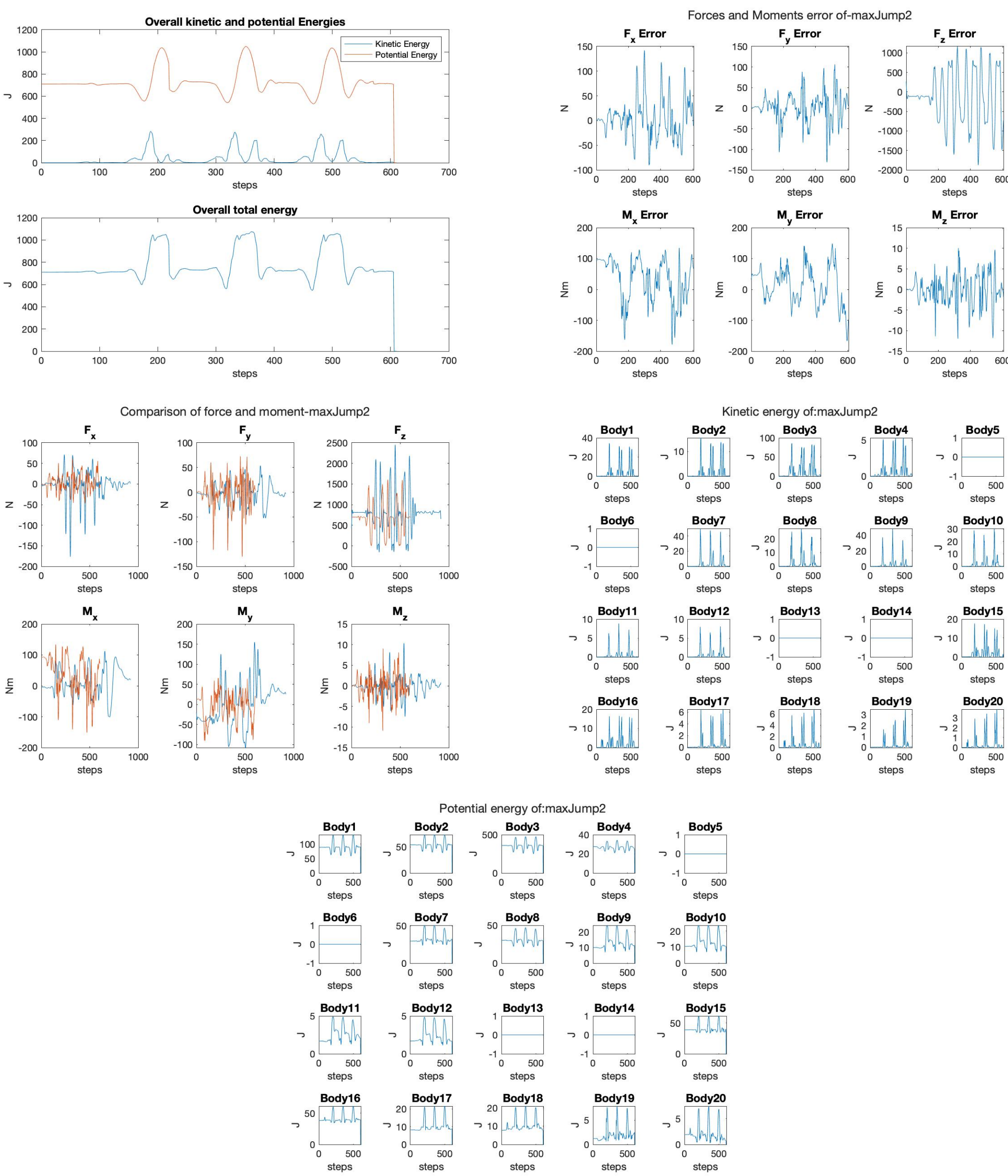

Figure 23: Max Jump 2 actions of each body

6. Medium Arm NOSTOMP actions are validated and plotted below:

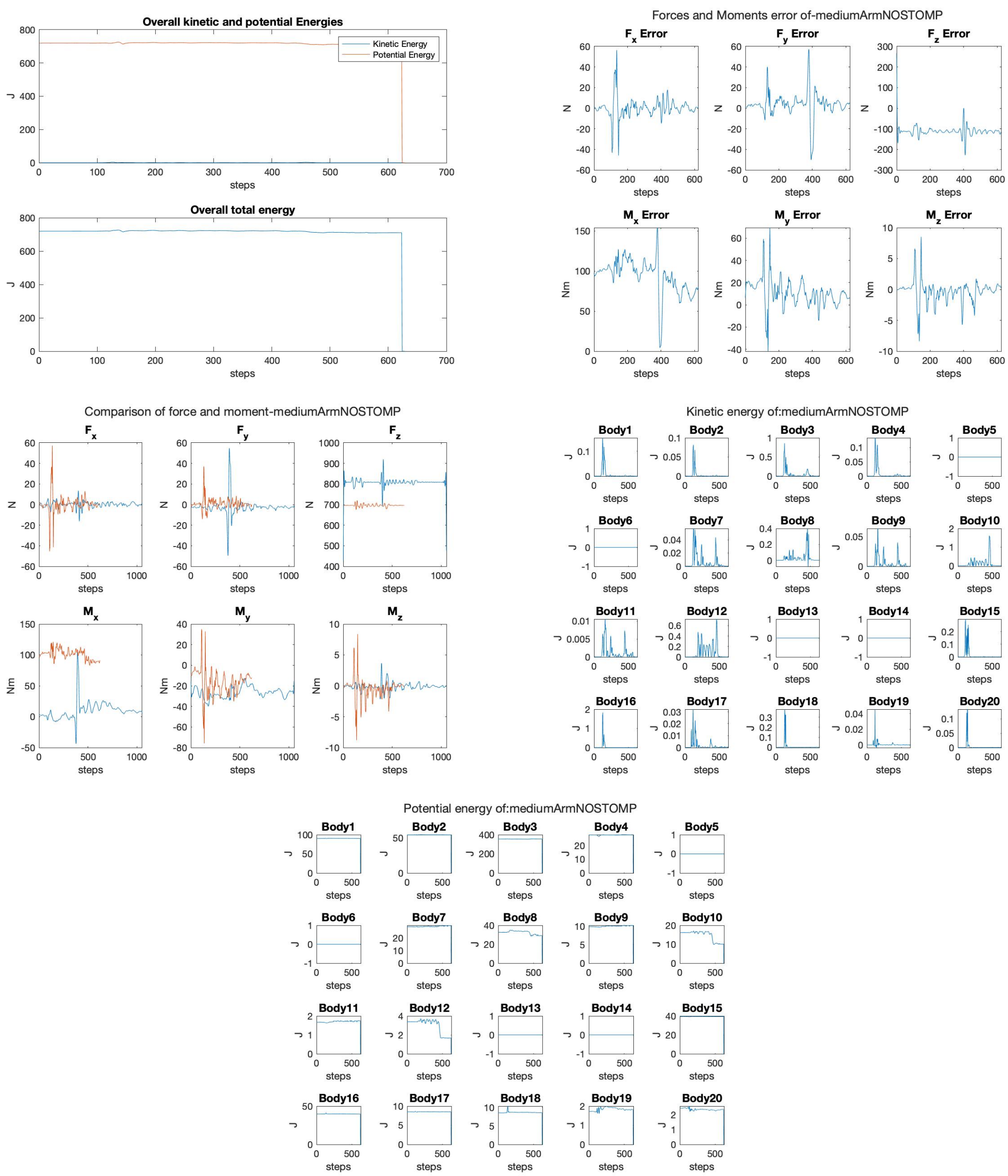

Figure 24: Medium Arm NOSTOMP actions of each body

7. Medium Kick actions are validated and plotted below:

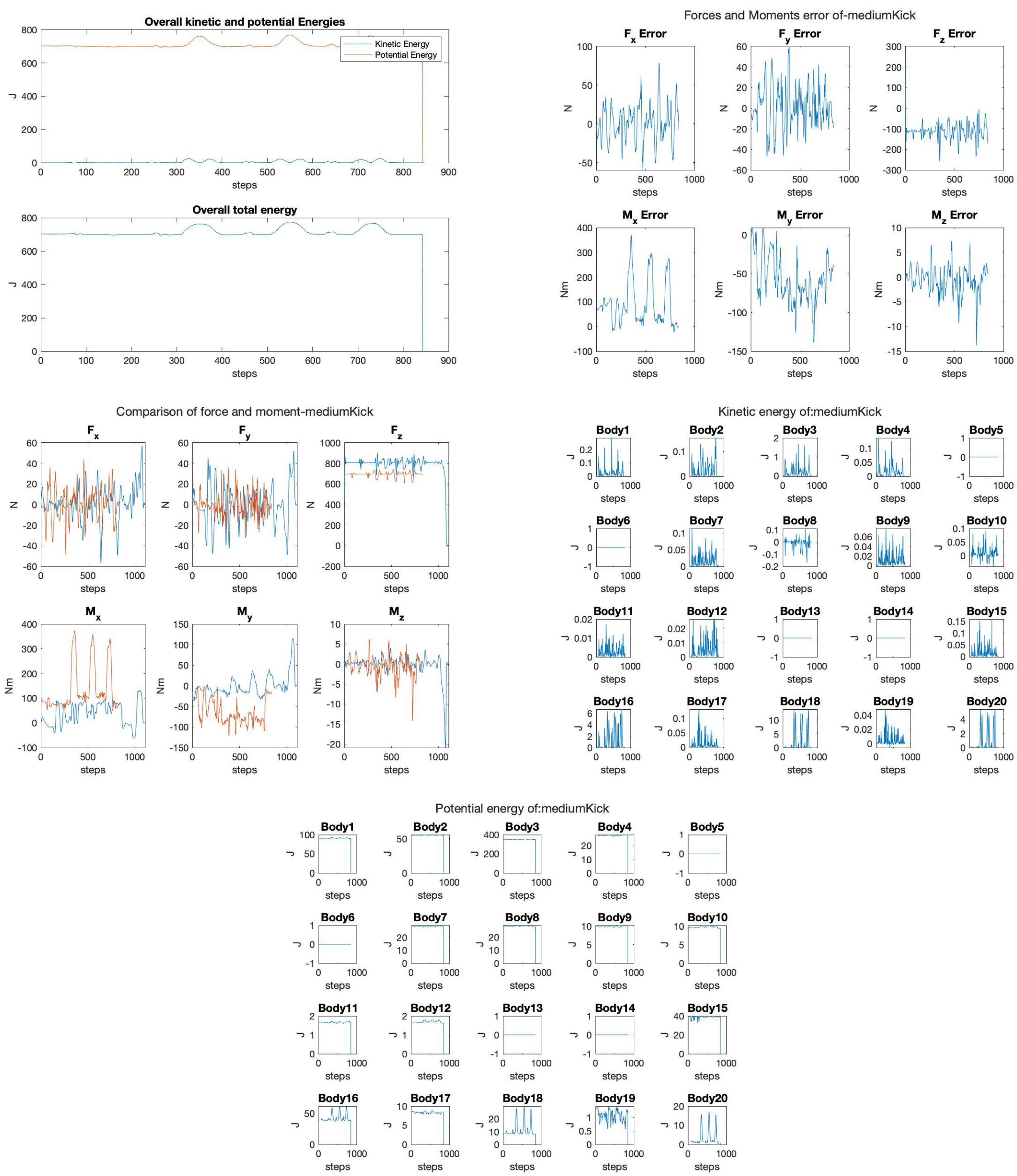

Figure 25: Medium Kick actions of each body

8. Medium Kick Arm actions are validated and plotted below:

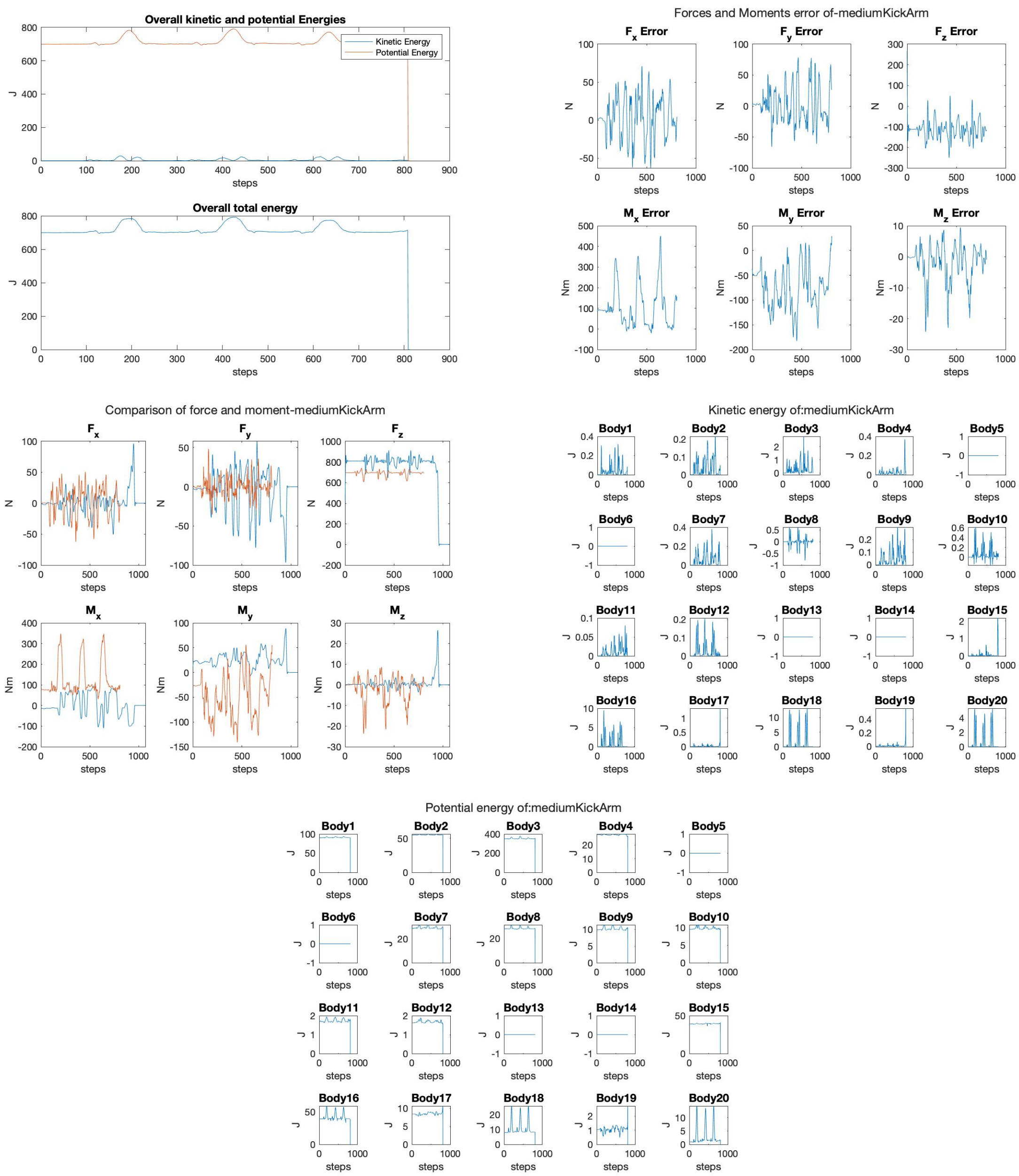

Figure 26: Medium Kick Arm actions of each body

9. MedJump actions are validated and plotted below:

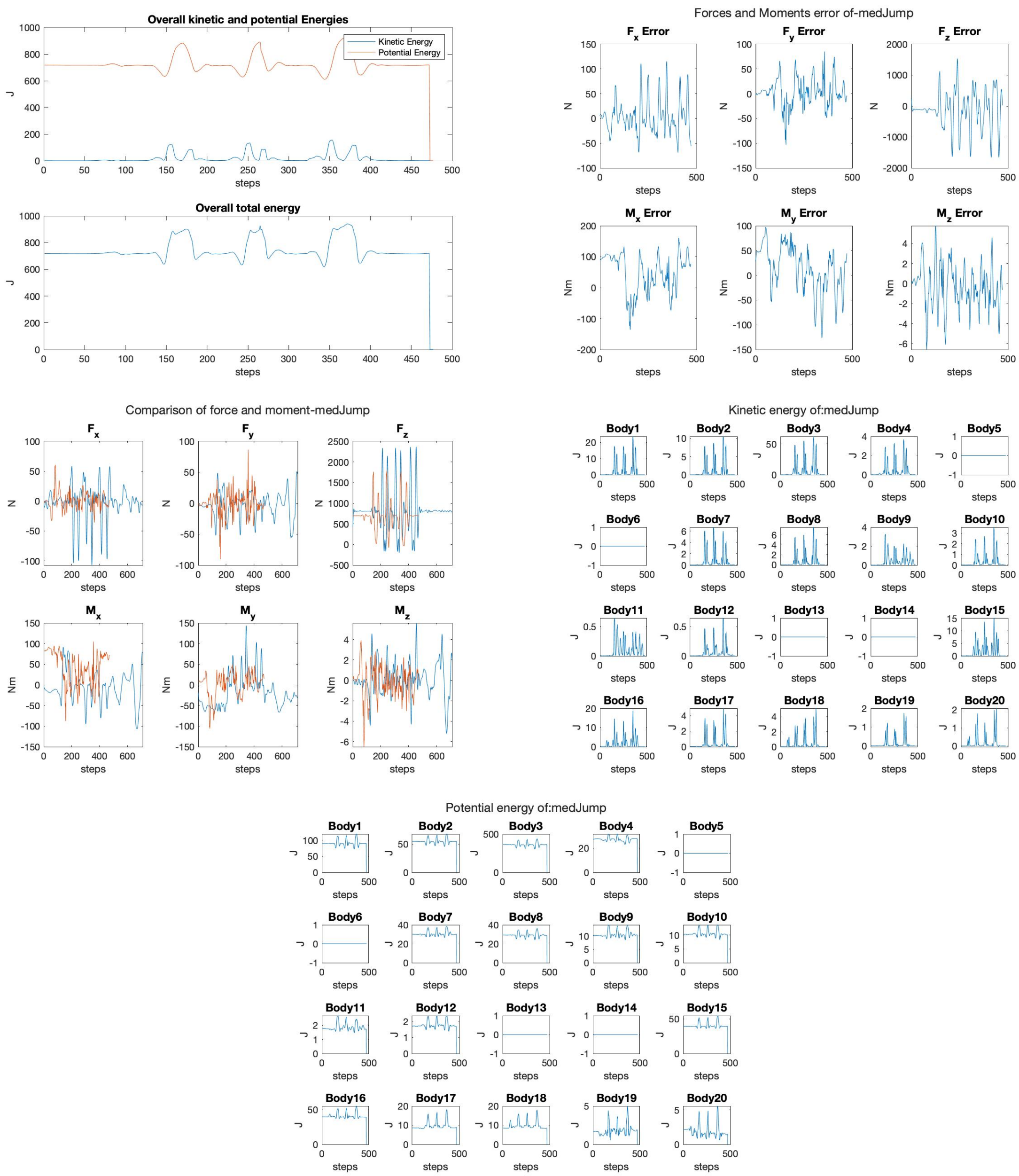

Figure 27: MedJump actions of each body

10. Slow Kick actions are validated and plotted below:

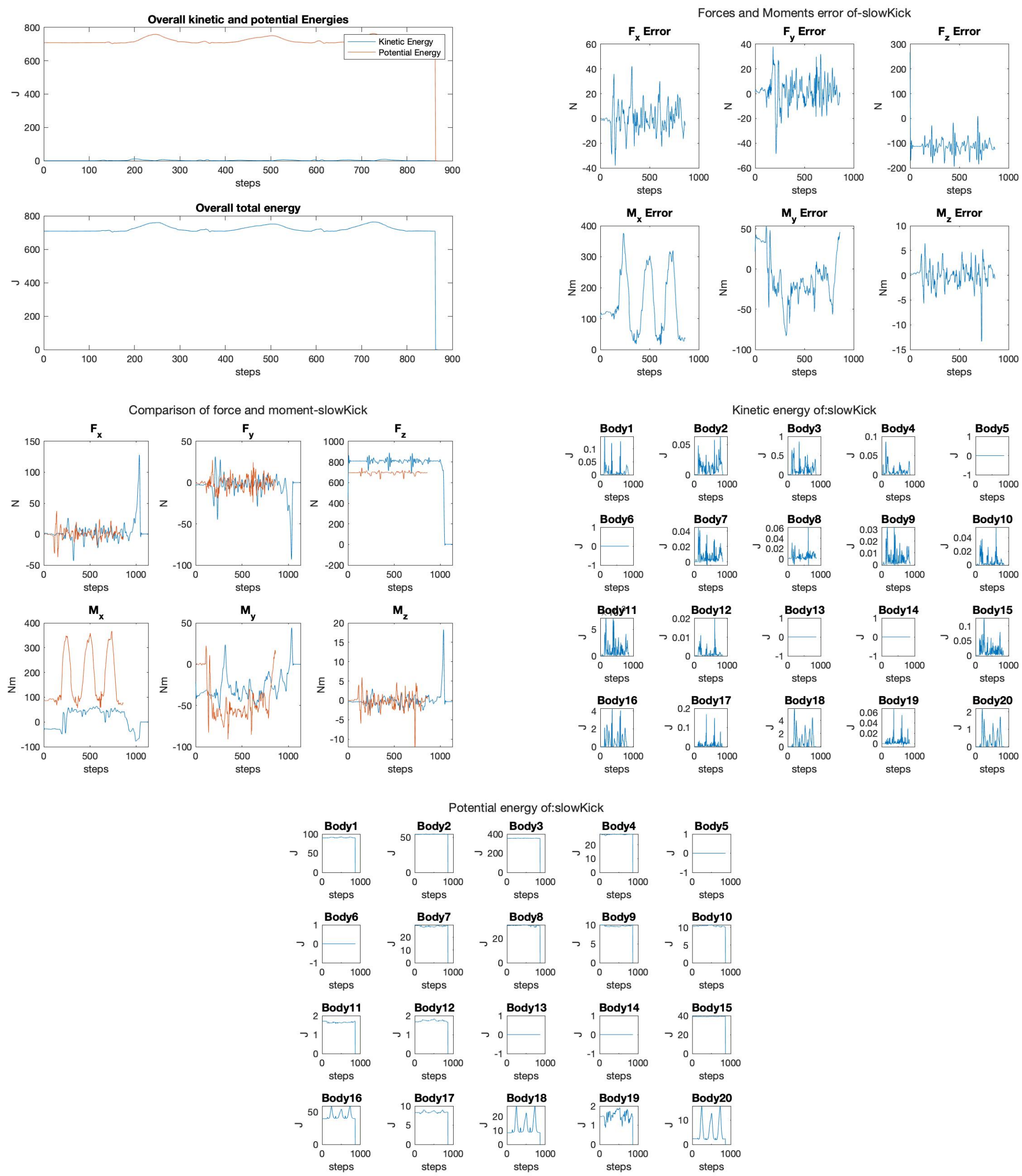

Figure 28: Slow Kick actions of each body

11. Slow Kick Arm actions are validated and plotted below:

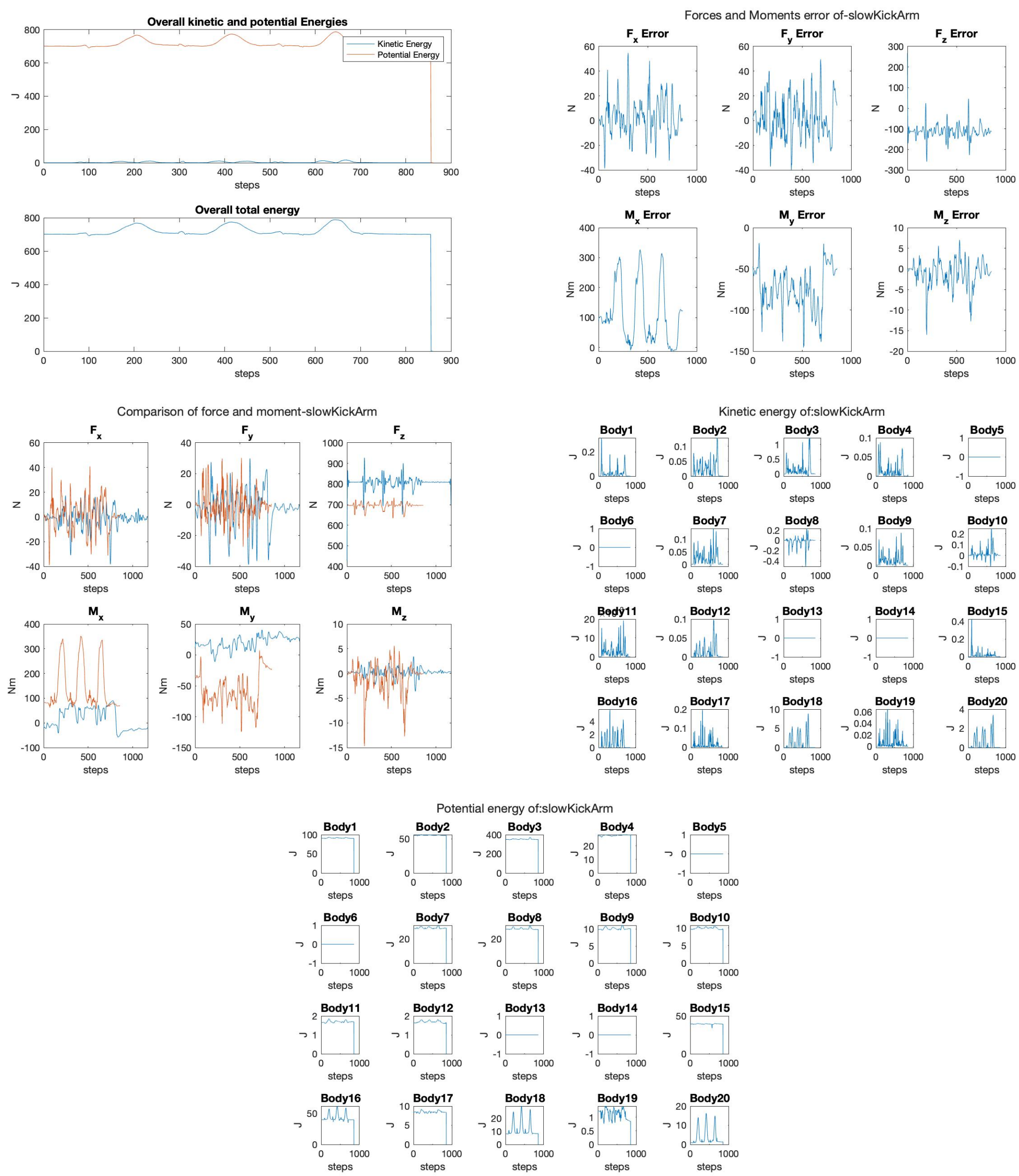

Figure 29: Slow Kick Arm actions of each body