A PROJECT REPORT

ON

"Balance Impairment Measurement using Margin of Stability"

Submitted to

Indian Institute of Technology Gandhinagar

In Partial Fulfilment of the Requirement for the Completion of

SUMMER RESEARCH INTERNSHIP PROGRAM
2017

BY

Gandhi Meet Bankim

UNDER THE GUIDANCE OF
Dr. Vineet Vashista

DEPARTMENT OF MECHANICAL ENGINEERING
Indian Institute of Technology Gandhinagar
PALAJ, GANDHINAGAR - 382355
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Department of Mechanical Engineering

PALAJ, GANDHINAGAR 382355

CERTIFICATE

This is certify that the project entitled

“BALANCE IMPAIRMENT MEASUREMENT USING MARGIN OF STABILITY“

submitted by

Gandhi Meet Bankim

is a record of bonafide work carried out by him, in the partial fulfilment of the requirement for the completion of Summer Research Internship Program at Indian Institute of Technology Gandhinagar. This work is done during year 2017, under our guidance.

Date: 11/07/2017

(Dr. Vineet Vashista)
Project Guide

(Prof. Manish Kumar)
SRIP Coordinator

(Prof. Manoj Gupta)
SRIP Coordinator

(Prof. Pedro Pombo)
SRIP Coordinator

External Examiner

Acknowledgements

I am profoundly grateful to **Dr. Vineet Vashista** for his expert guidance and continuous encouragement throughout to see that this project rights its target since its commencement to its completion.

I would like to express deepest appreciation towards **Prof. Manish Kumar**, **Prof. Manoj Gupta** and **Prof. Pedro Pombo**; Indian Institute of Technology Gandhinagar Summer Research Internship Program 2017 Coordinators whose invaluable guidance supported me in completing this project.

At last I must express my sincere heartfelt gratitude to all the members of Rehabilitation Robotics Lab and Sri Lankan interns from **University of Jaffna: Neethan Ratnakumar and Nidershan Suguneswaran** who helped me directly or indirectly during this course of work.

University of Jaffna, Sri Lanka

Gandhi Meet Bankim
IIT GANDHINAGAR

STATEMENT OF EXPERIENCE

Summer Research Internship Program at Indian Institute of Technology Gandhinagar was my initial step into how research is done in academic institutions in India. I attended this program immediately after completing my second year at IITGN. I expected from this research internship to learn a lot and I did. Throughout my Internship I learnt various softwares and most importantly how experiments are carried out in the field of STEM. Moreover I got introduction to the system of Motion Capture and how the process of Motion Capture is used in the field of Clinical Sciences, Entertainment, Sports and Object Tracking. Also I installed the Vicon Vero Motion Capture System in our Rehabilitation Robotics Lab at IITGN which gave me practical knowledge of how Motion Capture Camera needs to be aimed, focused and calibrated for suitable workspace area for experiments. In a nutshell, I got to know about minutes of how Motion Capture System works and needs to be operated. This Internship also made me familiar to working with MATLAB which is so common among the people in STEM. Now talking about my advisor Dr. Vineet Vashista or as he likes to be called as just Vineet, not to just brag but thinking logically he endowed his full trust in me. I can say that because Vineet trusted me with playing with Vicon Vero Motion Capture System purchased by IITGN on request of Vineet. This System roughly accounts to approximately 2 crores INR as per my knowledge. So I am very grateful to Vineet for trusting me. Also during the internship I got help from two interns from University of Jaffna, Sri Lanka name Neethan Ratnakumar and Nidershan Suguneswaran. They will be graduating this year and hence I got to learn a lot from them. But the thing that I want to focus on here is that working with them not only I got to learn technological stuff but also I personally restored the faith that I had lost in

Humanity. Both of them, Neethan and Nidershan are very humane individuals. In India, from childhood we are thrown into the pool of competitions. Hence Indians always try to compete with their peers however these two Sri-Lankan humane individuals believe in working together and being there whenever needed without any hint of jealousy or competition among peers. Hence I learnt a lesson on Ethics in addition to all the technological details too. Lastly the talks organized by the coordinators were very thought-provoking. The thing that I enjoyed the most was the final Poster Session. As I am very eager to learn new things, this Poster Session was full of knowledge of different fields of STEM. I got very excited about the topic of Machine Learning from some of the Posters presented in the session and hence in future will be looking forward to taking a project in the field of Machine Learning. So Thank You for Summer Research Internship Program at IITGN.

ABSTRACT

SRIP Project Balance Impairment Measurement using Margin of Stability serves as an initial phase of the project Sensorized Passive Prosthetic Limb. This SRIP Project involves studying the human gait which is the study of different patterns of human walking. For studying the human gait, we require to know the dynamics of human gait and hence the kinetics and kinematics of human gait. For studying the kinematics of human gait, Vicon Vero Motion Capture System and associated Software named Vicon Nexus was used in this project. Hence this project involved setting up of Vicon Vero Motion Capture Cameras, aiming the cameras and also calibrating them to generate a virtual workspace. After the workspace has been generated, next comes preparing the subject which involves taking different measurements of subject like weight, height, leg length and so on. Subject Preparation also involves placing Vicon Vero Motion Capture Markers on different joints of subjects body. After subject preparation, Static Trial is taken to verify that all the markers are recognized by the Vicon Nexus Software and to create a skeleton template which is unique for each subject. After Static Trial, Dynamic Trial is taken which is when the subject is walking on a treadmill. After recording the Dynamic Trial, the recorded data is processed and then that data is worked on using MATLAB and other softwares to get different human gait parameters. The data that is recorded in our project contains marker trajectories, velocities and accelerations. Using these data, different gait parameters were calculated. Once all the things were ready, the project involved taking data of an able-bodied person i.e. without any amputation walking normally and the same subjects human gait is recorded by introducing some constraint like no rotation of knee or ankle. When knee joint is restricted then it is similar to realizing a Transtibial Lower Limb Amputation or Below Knee Amputation. When both knee and ankle joint are constrained then it is similar to realizing a Transfemoral Amputation or Above Knee Amputation.

For our project we focused on restricting the ankle movement by making the subject wear an ankle brace and then recording the human gait using Motion Capture. Thereafter using both the data i.e. normal walking by an able-bodied subject and walking wearing an ankle brace of that same subject, project involved comparing the gait parameters and determining which parameter to be used to give feedback control loop from the prosthesis to the residual limb of the subject. The gait parameter that our project discusses is Margin of Stability. For Margin of

Stability, one need to understand the related parameters Base of Support and Extrapolated Center of Mass. Base of Support according to our project is the contact area of the feet with the ground at any instant of the gait cycle. Extrapolated Center of Mass is the projection of Body Center of Mass on the ground in addition to Body Center of Mass velocity multiplied by a constant factor. Hence using Margin of Stability as a varying gait parameter in the next phase of our final project we intend to create a feedback control loop using the Margin of Stability.

Keywords: Vicon Vero Motion Capture System, Base of Support, Extrapolated Center of Mass, Margin of Stability

Contents

Chapter 1

Dynamic Analysis of Human Gait

1.1 Simple Single Leg Dynamic

1.1.1 Problem Statement

It was required to develop a predictive dynamic model for human gait.

1.1.2 Objectives

The task was to develop a dynamic model of human walking so that predictions can be done by altering segment mass and inertial properties as well as by changing the swing and stance periods of a gait cycle or by locking joints. A well developed dynamic model can be used to understand amputee gait by analyzing the model under different circumstances and in comparison to the motion capture system based experimental outcomes.

1.1.3 Scope and limitations

This single leg dynamic model requires anthropometric measurements from the subject or assumed average measurements, marker trajectory data, GRF (Ground Reaction Force) data and on top of these it requires global coordinate based COP (Center of Pressure) positions as well to calculate the moments of the ankle, knee and hip.

In case of unavailability of GRF data some generalized values have to be assumed. The analysis of synchronization between both legs is not possible by the usage of this model as only one leg is considered. A more sophisticated two leg model will be required for these purposes.

1.1.4 Biomechanical Model

A biomechanical model of a lower limb consisting of three segments was considered for the analysis, the segments are considered to be connected by revolute joints. The model is taking only the sagittal plane into consideration for its calculations.

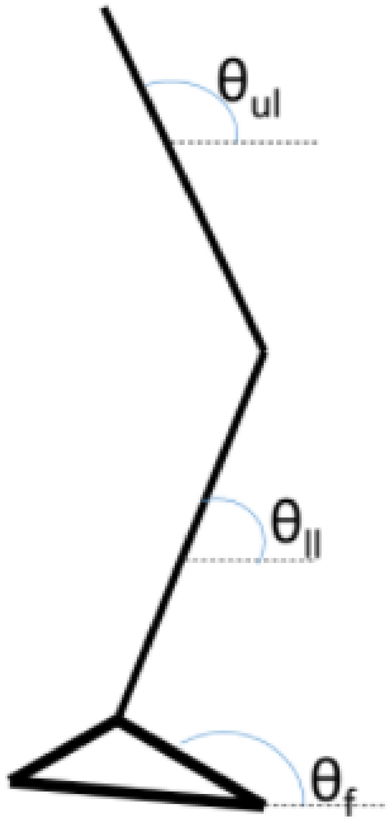


Figure 1: The Model considered

A method of simple inverse dynamics is adopted for this purpose as described in Research Methods in Biomechanics by D. Gordon E. Robertson. The method starts from the further most segments and solves for joint forces and moments.

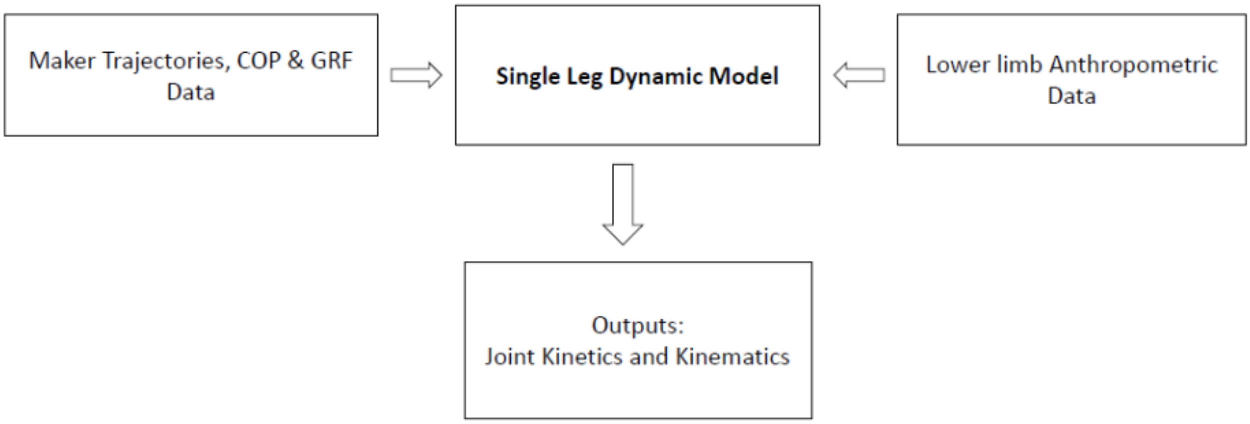


Figure 2: Required Inputs for Model

The following parameters are calculated from trajectory data by using the methods described by the equations.

Velocities (Central Difference):

$$v_i = \frac{s_{i+2} - s_{i-2}}{4\Delta t}$$

Here, i denotes the number of frame considered, s the displacement and t is the time between frames.

Angular Velocities (Central Difference):

$$\omega_i = \frac{\theta_{i+2} - \theta_{i-2}}{4\Delta t}$$

Here, is the angular displacement.

Accelerations and Angular Accelerations:

$$a_i = \frac{v_{i+2} - v_{i-2}}{4\Delta t} \qquad \alpha_i = \frac{\omega_{i+2} - \omega_{i-2}}{4\Delta t}$$

Moment of Inertias about COM: Using the anthropometry presented in Table1, the following equations can be used.

$$I_f = M_f(0.475L_f)^2 \qquad I_{leg} = M_{leg}(0.302L_{leg})^2 \qquad I_{th} = M_{th}(0.323L_{th})^2$$

Segment	Definition	Segment Weight/ Total Body Weight	Center of Mass/ Segment Length (From Proximal End)	Radius of Gyration/ Segment Length (About COM)
Foot	Lateral Malleolus / 2nd Metatorsal	0.0145	0.5	0.475
Leg	Femoral Condyles / Medial Malleolus	0.0465	0.433	0.302
Thigh	Greater Trochanter / Femoral Condyles	0.1000	0.433	0.323

Table 1: Anthropometric Data Required

Anthropometric measurements for this model are taken from Biomechanics of Human Locomotion (2009) by D. A. Winter and are given in Table 1.

The position of Ground Reaction Force acting on the foot (COP in X direction) was also taken from the same source. Using Newton Euler Equations we can write equations for each segment as shown in the following pages: The equations of motion for an unconstrained rigid body in space can be written as:

$$\sum F + Mg = Ma$$

$$\sum N = I\alpha$$

Here,

F – Force

M – Segment Mass

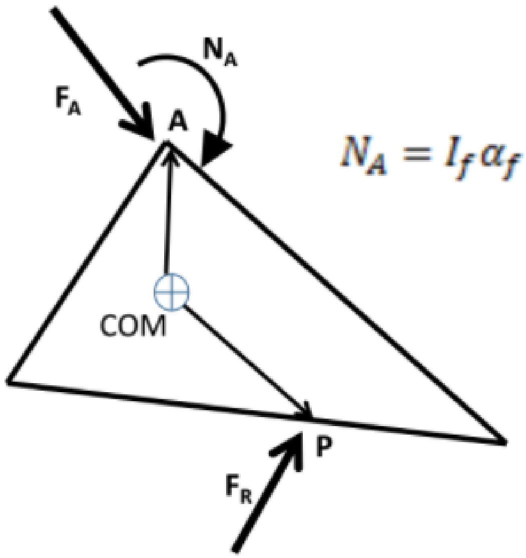
N – Moment

I – Moment of Inertia

a, α – Linear and Angular Acceleration

g – Gravitational Acceleration

1.1.5 Foot Segment



$$F_A = M_f(a_f - g) - F_R$$

$$N_A = I_f \alpha_f - (r_{COM} - r_P) \times F_R - (r_{COM} - r_A) \times F_A$$

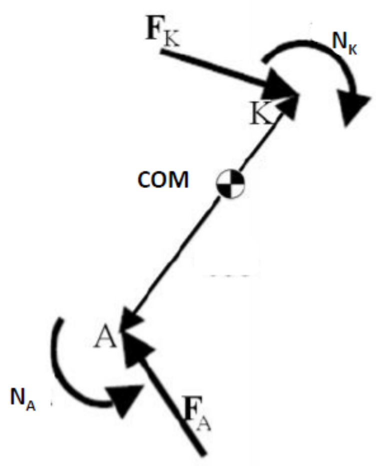
Here the directions of the forces acting are only randomly shown. The position denoted as COM is the center of mass of that segment. All vectors denoted by simple r are position vectors for each respective point. And N denotes moments acting at joints.

Therefore considering the vertical and horizontal components we can get the following equations of motion:

RxpAn = (Mf*AnAccX) - GRFX;
RypAn = Mf*AnAccY - GRFY + (Mf*9.81);
MpAn = If*AnAlpha + (RxpAn*cos(f-90)*COGf) - ((GRFX)*COMfY) + (RypAn*sin(f -90)*COGf) + ((GRFY)*(COMfX-COPX));

Here GRFX, GRFY are the horizontal and vertical ground reaction forces, COMfX, COMfY are the global coordinates of foot Center of Mass, MpAn is the moment at the ankle, COGf is the distance from proximal joint to COM and RxpAn and RypAn are horizontal and vertical components of force acting at the joint. Further AnAccX, AnAccY and AnAlpha represent respectively the Accelerations and angular acceleration of the segment.

1.1.6 Leg Segment



$$F_K = M_{leg}(a_{leg} - g) - F_A$$

$$N_K = I_{leg}\alpha_{leg} - (r_{COM} - r_K) \times F_R - (r_{COM} - r_A) \times F_A + N_A$$

The symbols used here are similar to the foot segment. Consideration of vertical and horizontal components results in the following equations.

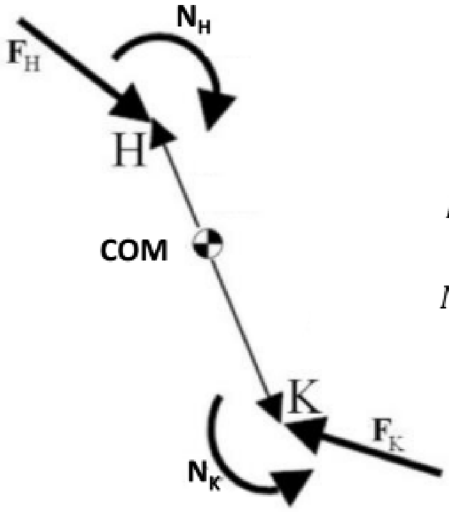
RxpLl = (Mll*LlAccX) + RxpAn;

RypLl = (Mll*LlAccY) + RypAn + (Mll*9.81);

MpLl = (Ill*LlAlpha) + MpAn + (RxpAn*sin(ll)*(Lll-COGll)) - (RypAn*cos(ll)*(Lll-COGll)) + (RxpLl*sin(ll)*(COGll)) - (RypLl*cos(ll)*(COGll));

The ll notation denotes that the segment is the lower-leg/ shank.

1.1.7 Thigh Segment



$$F_H = M_{th}(a_{th} - g) - F_K$$

$$N_H = I_{th}\alpha_{th} - (r_{COM} - r_H) \times F_H - (r_{COM} - r_K) \times F_K + N_K$$

The symbols used here are similar to the foot segment. Consideration of vertical and horizontal components results in the following equations.

RxpUl = (Mul*UlAccX) + RxpLl;

RypUl = Mul*UlAccY + RypLl + (Mul*9.81);

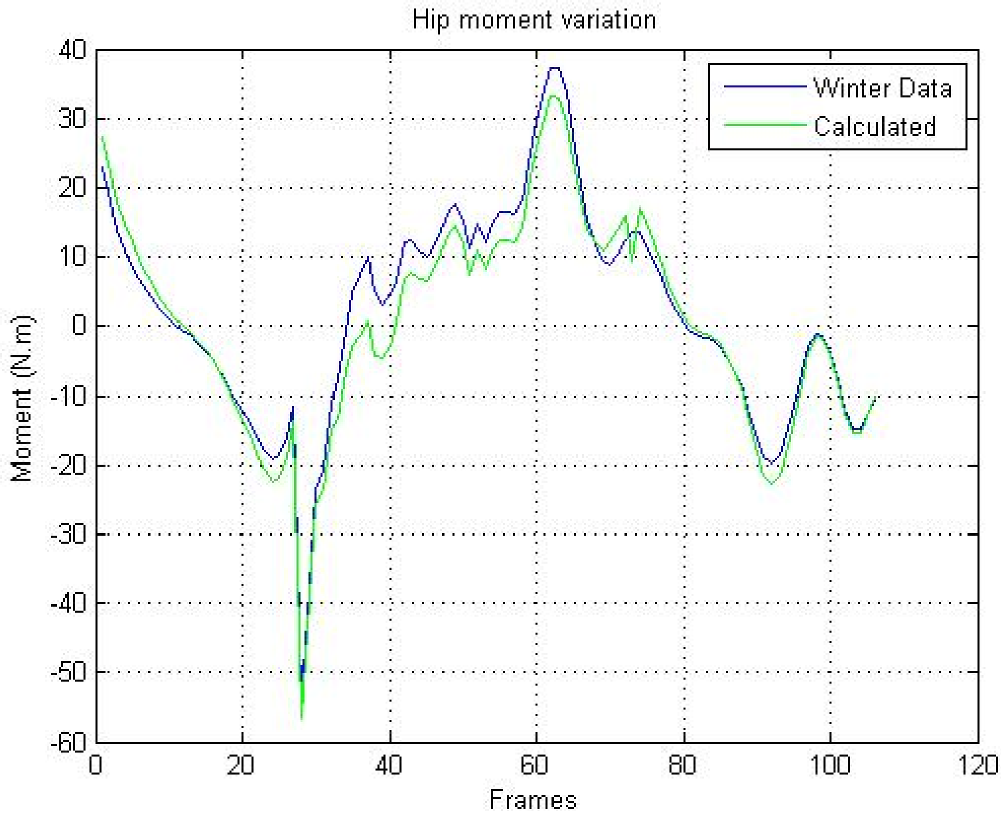
MpUl= Iul*UlAlpha + MpLl + (RxpUl*cos(ul-90)*COGul) + (RxpLl*cos(ul-90)*(Lul-COGul)) + (RypUl*sin(ul-90)*COGul) + RypLl*sin(ul-90)*(Lul-COGul);

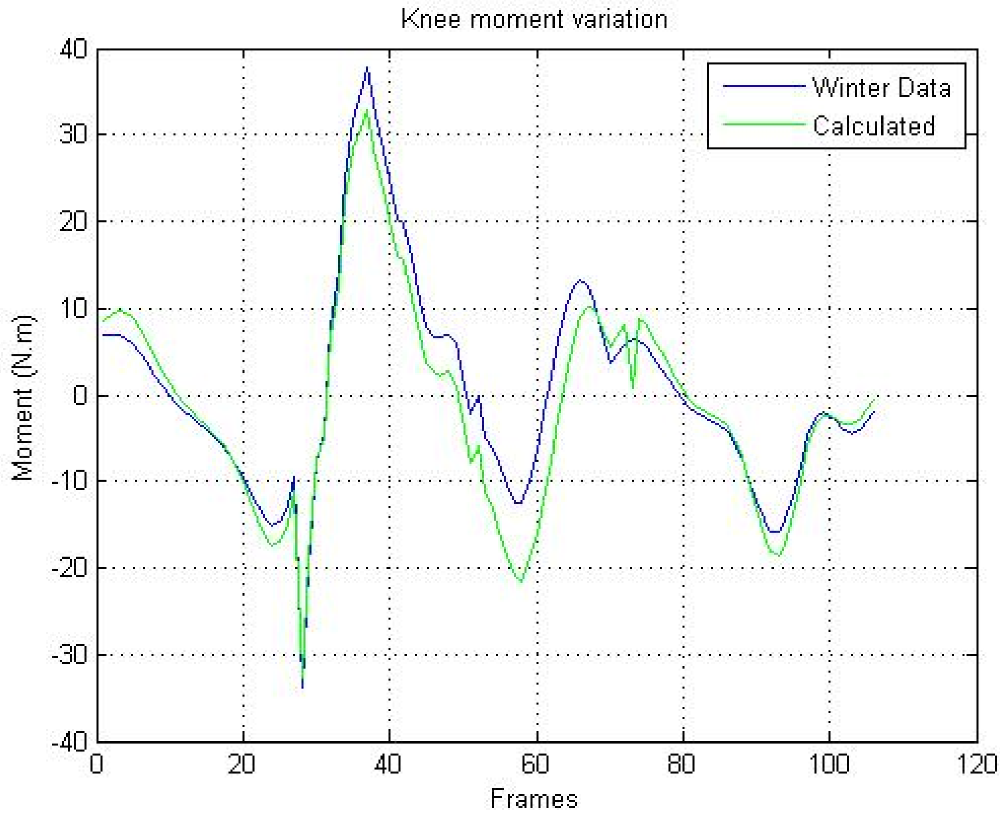
The ul notation denotes that the segment is the upper-leg thigh.

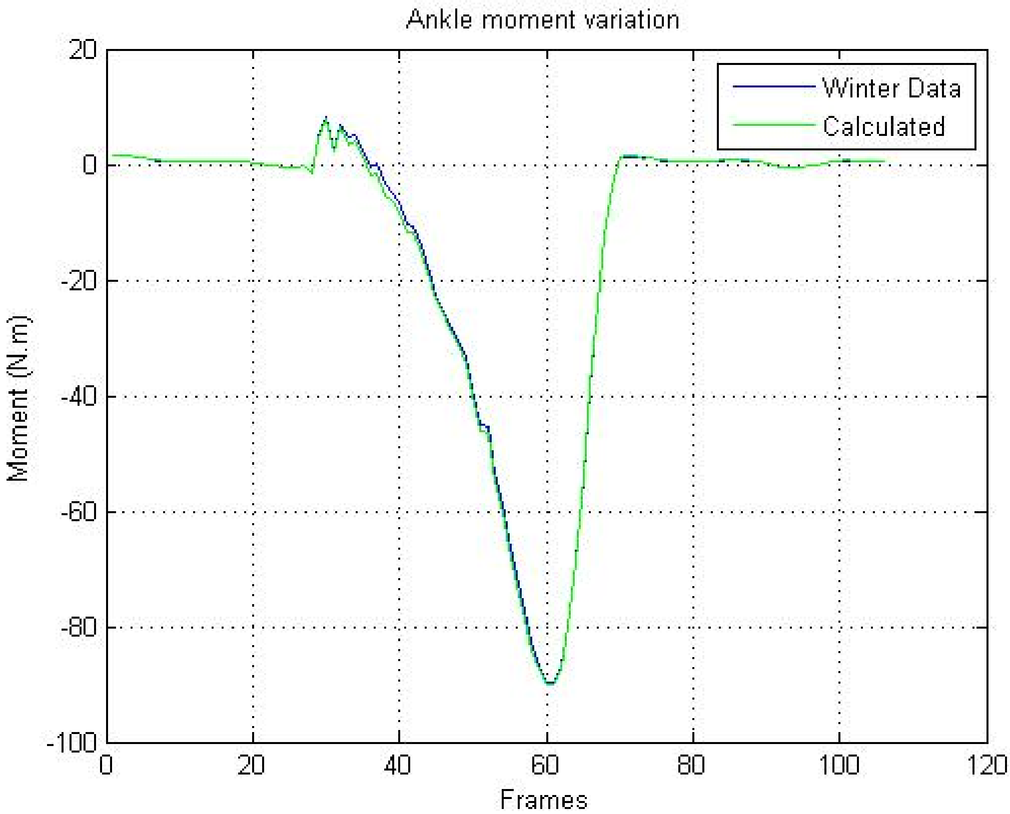
1.1.8 Model Outputs

Trajectory, GRF, COP, angle data was taken from Appendix A of Biomechanics of Human locomotion (2009) by D. A. Winter and the moments were calculated using this model.

The results were compared with the moment values given in the Appendix of the textbook. The results are plotted below:


Hip moment variation
Winter Data
Calculated
Moment (N.m)
Frames
40
30
20
10
0
-10
-20
-30
-40
-50
-60
0
20
40
60
80
100
120


Knee moment variation
Winter Data
Calculated
Moment (N.m)
Frames
40
30
20
10
0
-10
-20
-30
-40
0
20
40
60
80
100
120


Ankle moment variation
Winter Data
Calculated
Moment (N.m)
Frames
20
0
-20
-40
-60
-80
-100
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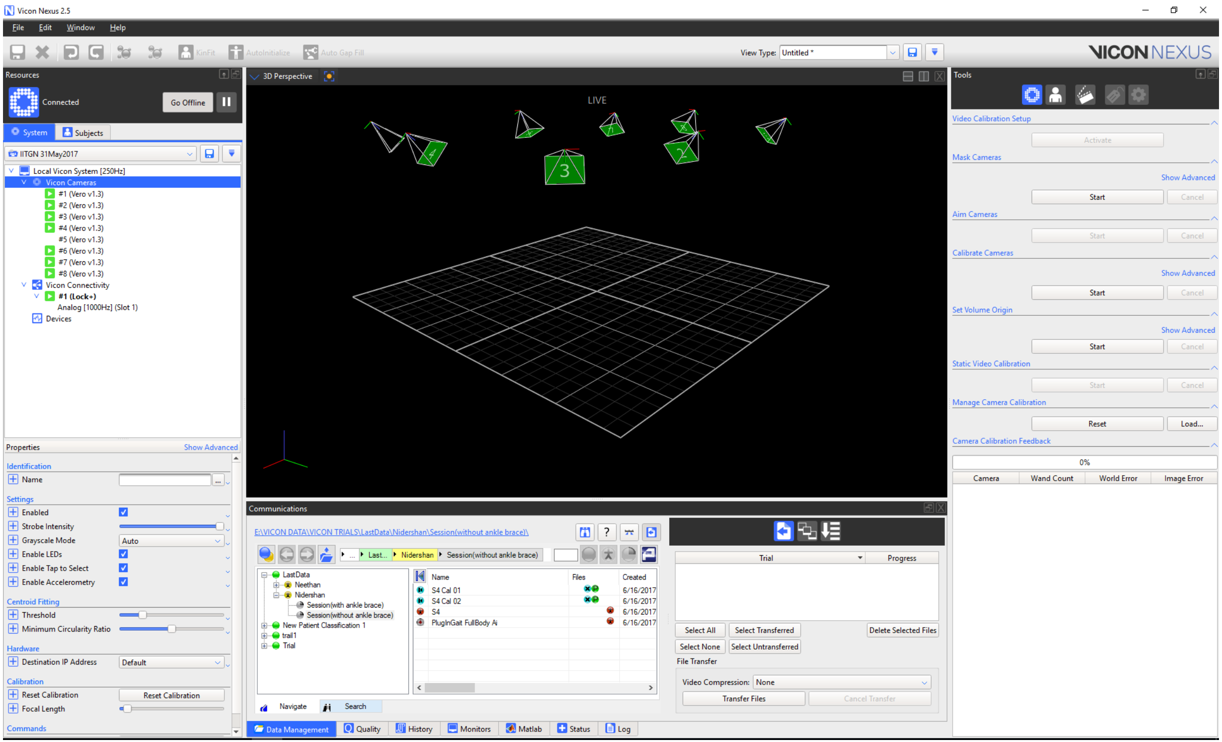
20
40
60
80
100
120

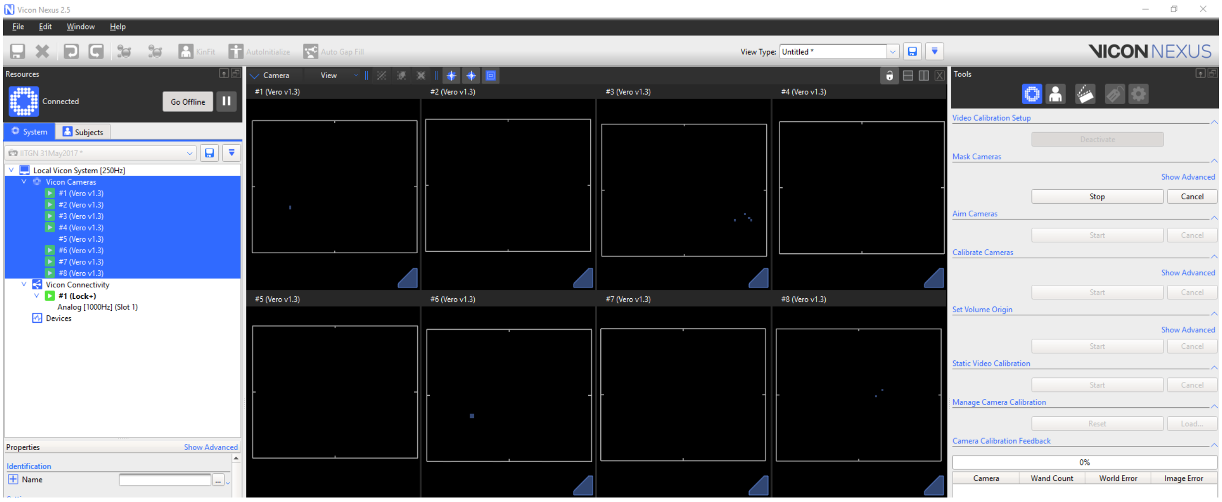
Chapter 2

Vicon Vero Motion Capture System

2.1 Vicon Nexus Software in Live Mode

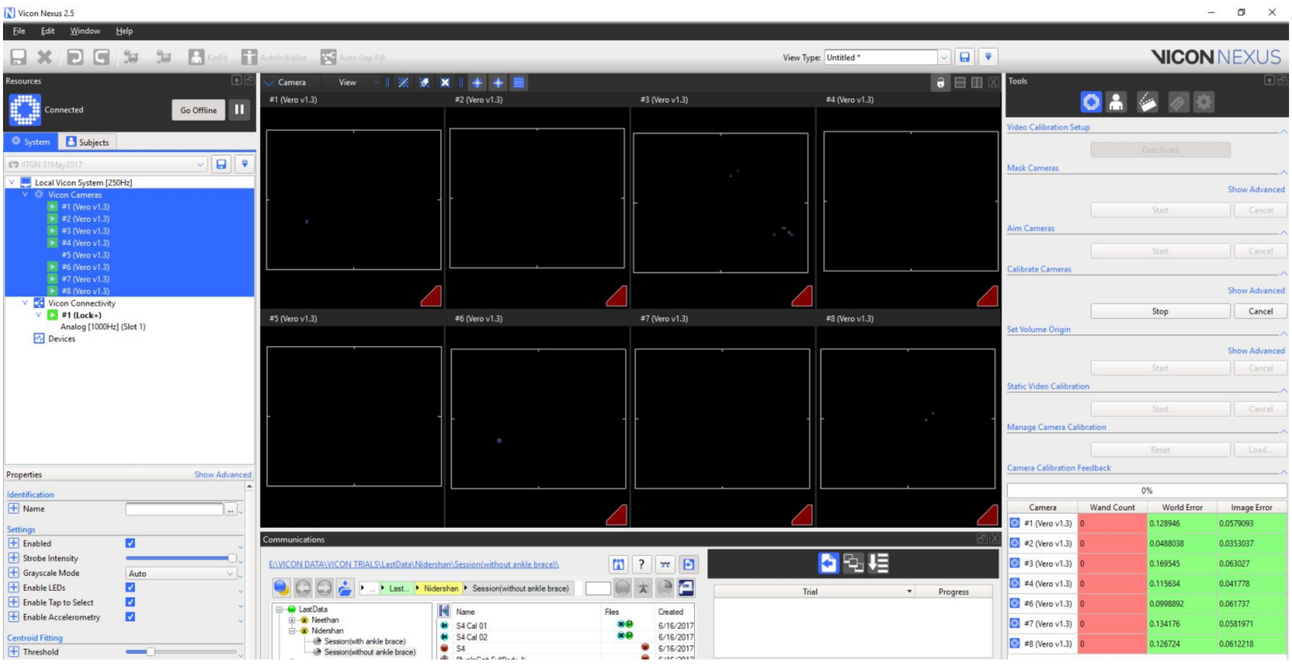


2.2 Masking Cameras

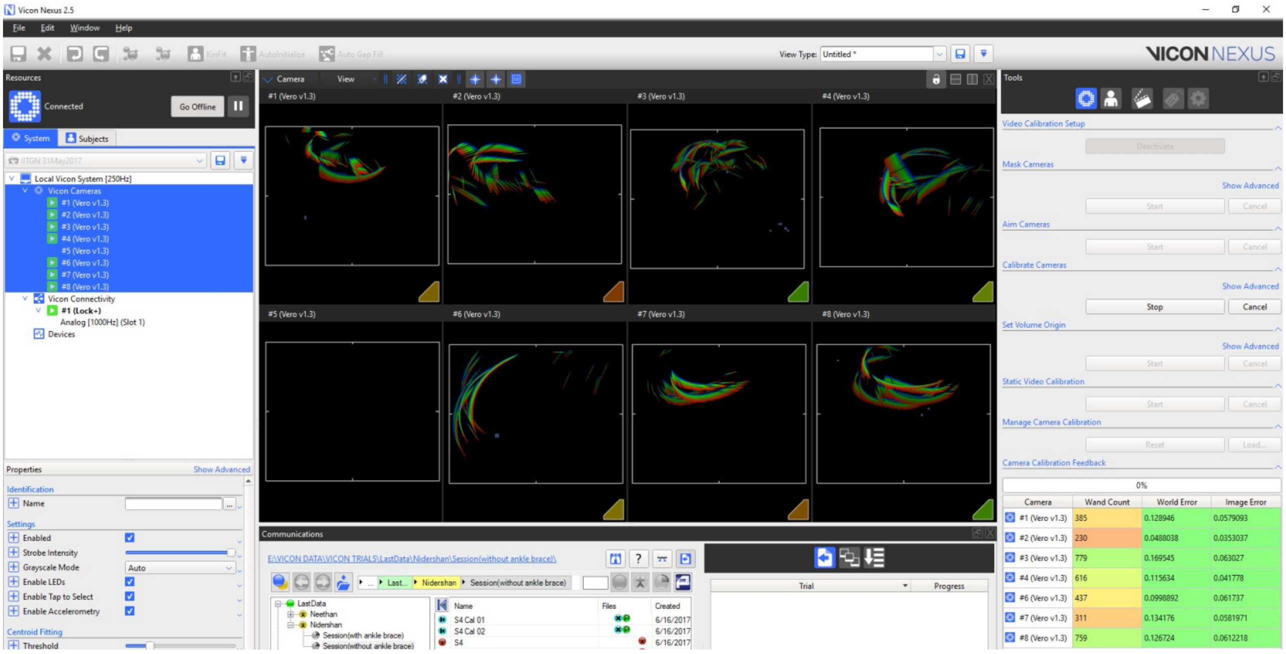


2.3 Vicon Vero Camera System Calibration Process

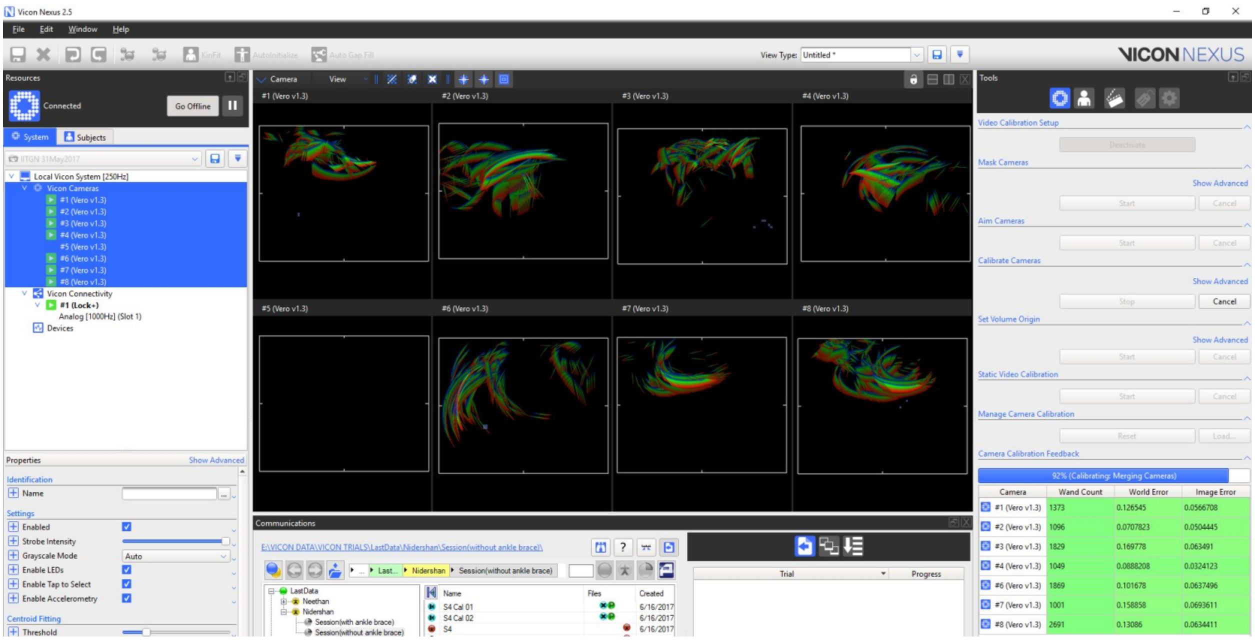
2.3.1 Before the process of calibration starts



2.3.2 Midway through the process of calibration



2.3.3 Completion of Camera Calibration Process



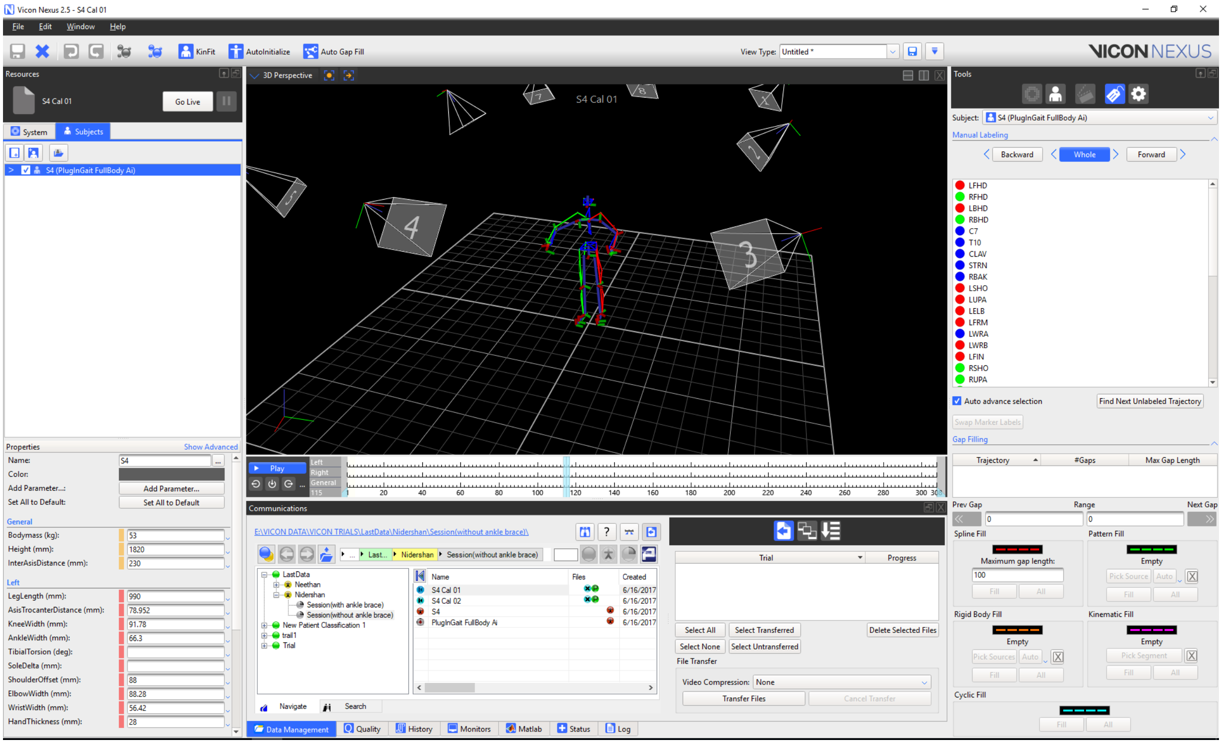
2.4 Marker Placement on Subject for Plug-in Gait Full Body Model

Anterior View

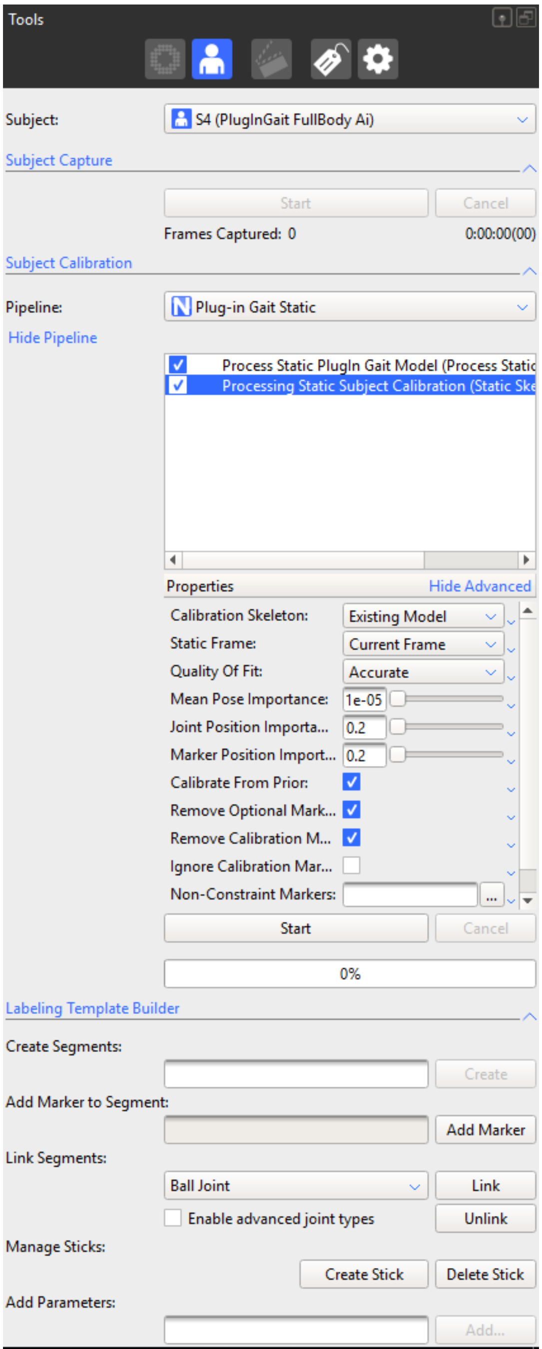
Lateral View

Posterior View

2.5 Static Trial

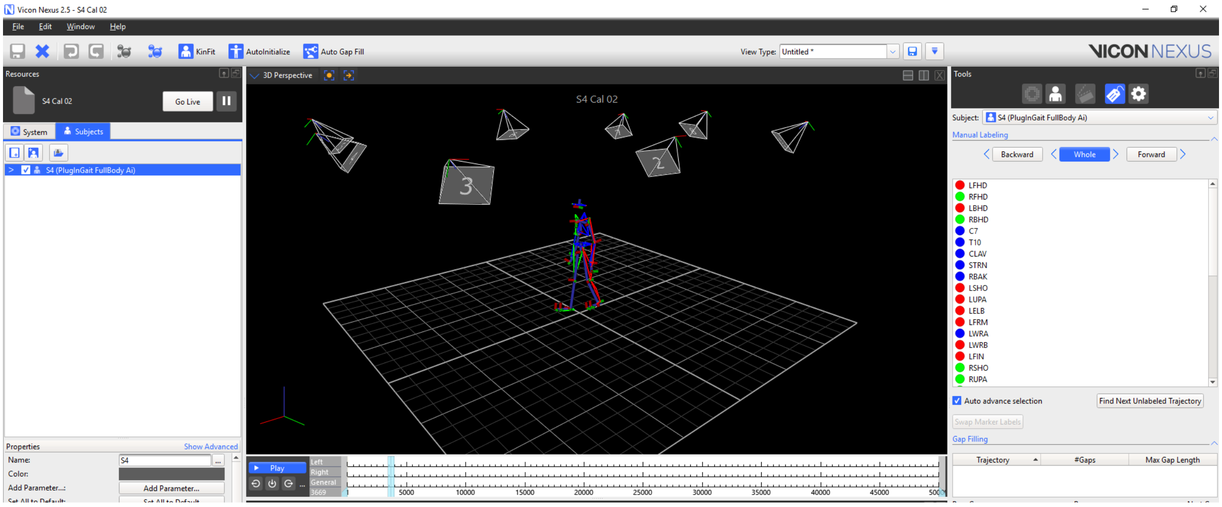


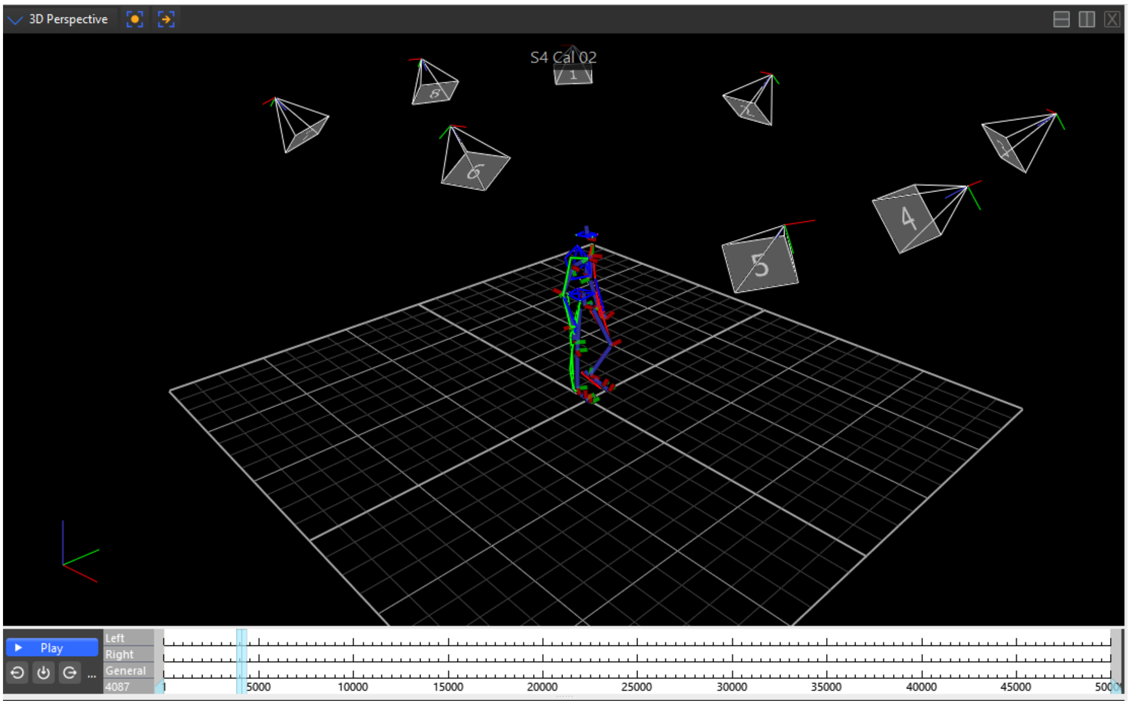
2.6 Static Trial Subject Calibration Pipeline and Plug-in Gait Static Pipeline

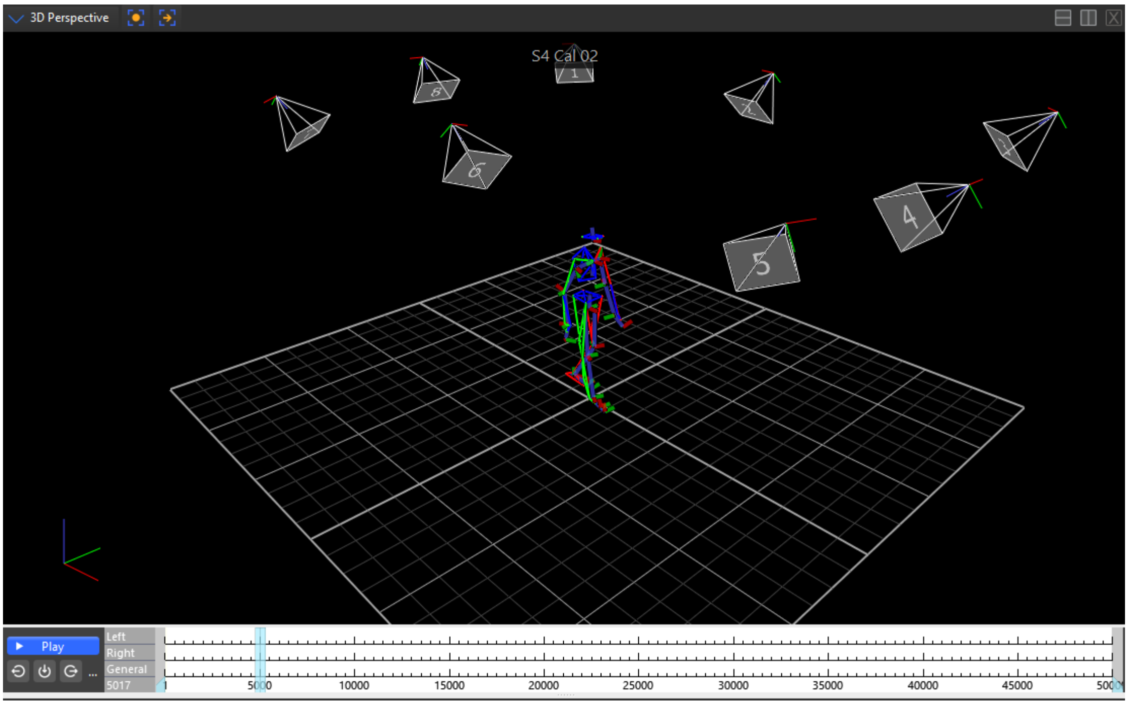


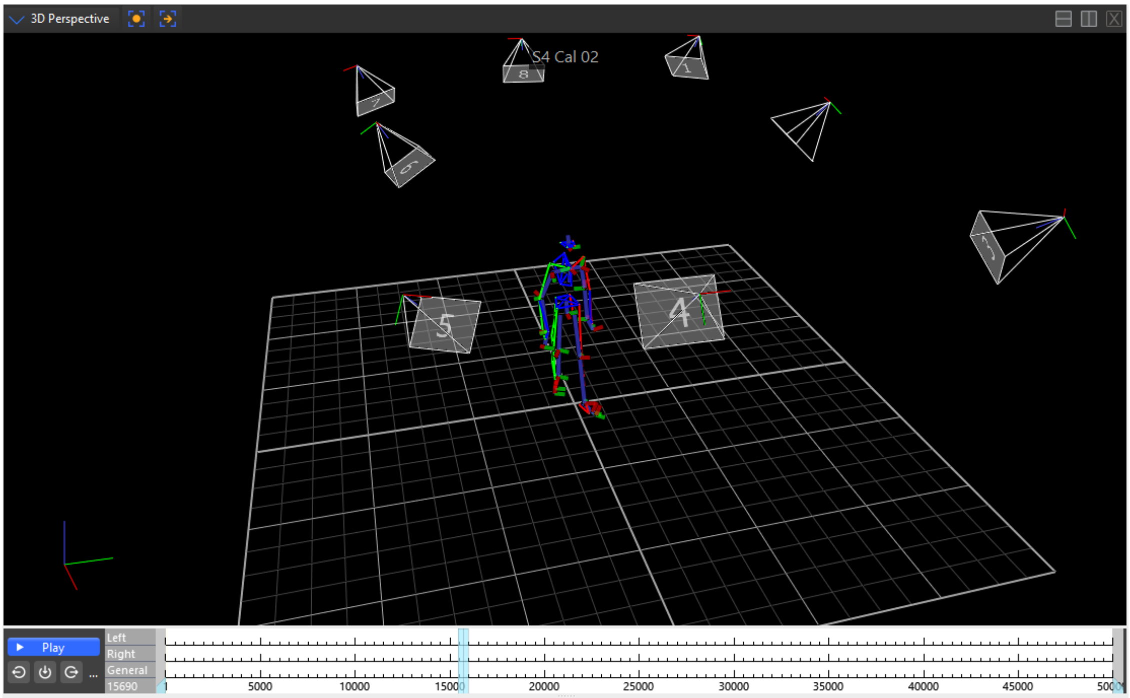
2.7 Subject walking on a treadmill with ankle brace on right foot for Dynamic Trial

2.8 Dynamic Trials






3D Perspective
S4 Cal 02
Play
Left
Right
General
5017
5000
10000
15000
20000
25000
30000
35000
40000
45000


3D Perspective
S4 Cal 02
Play
Left
Right
General
15690
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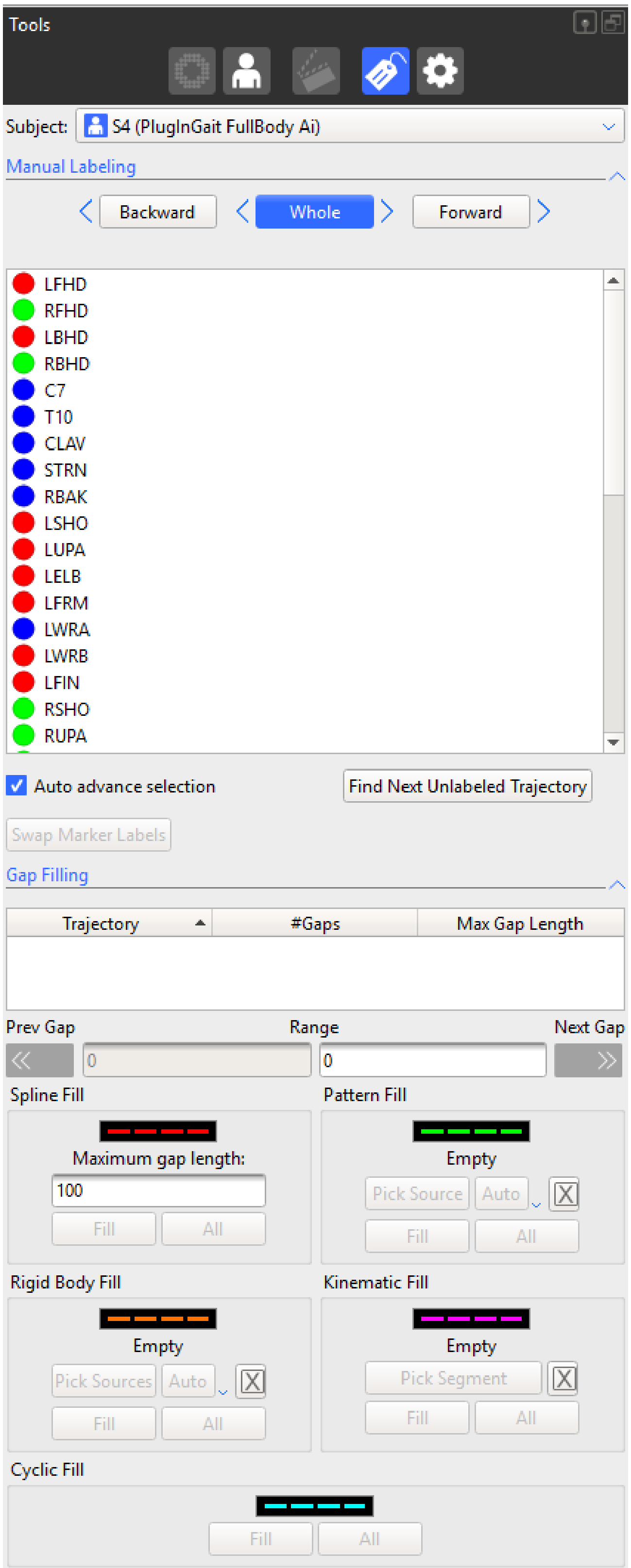
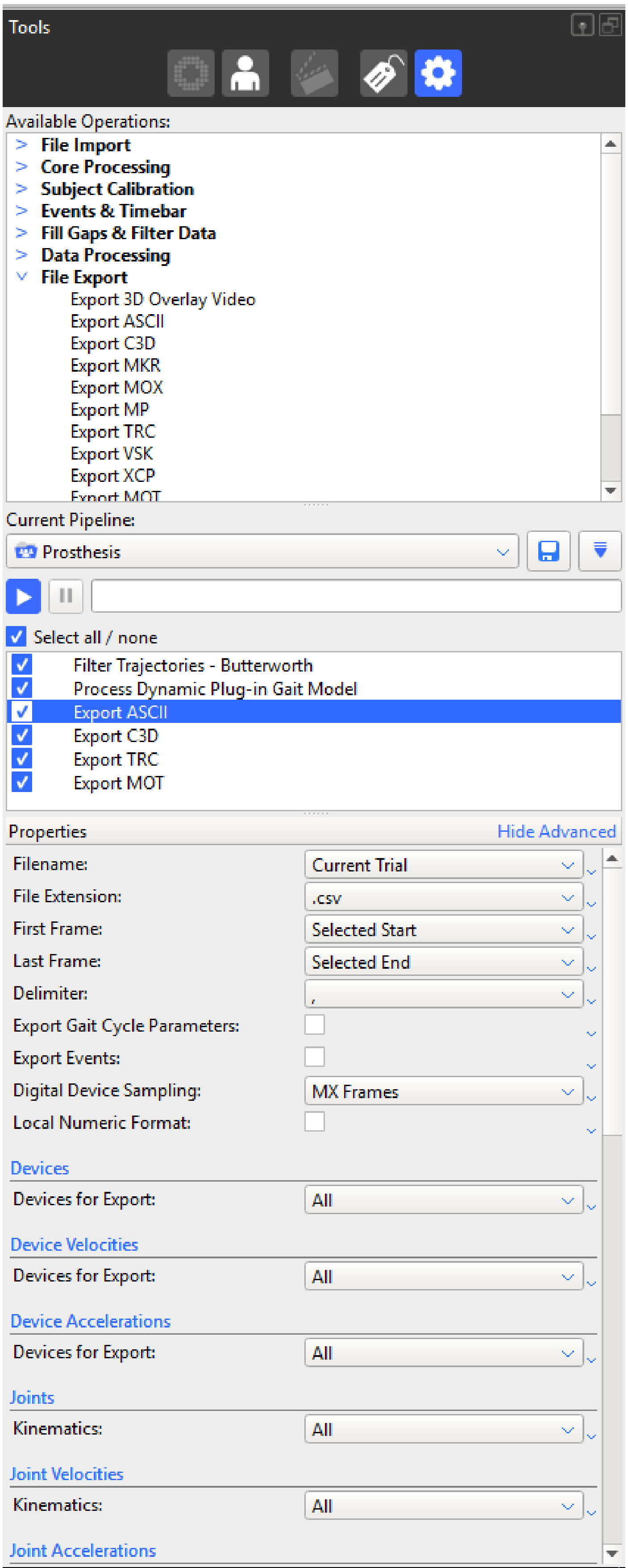
10000
20000
25000
30000
35000
40000
45000

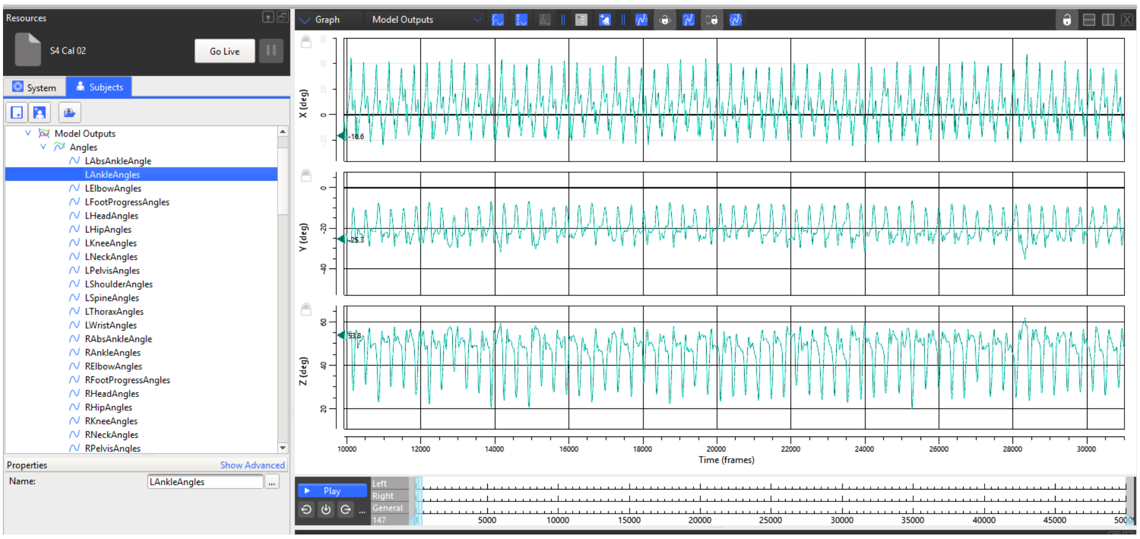
2.9 Data Processing: No Gaps



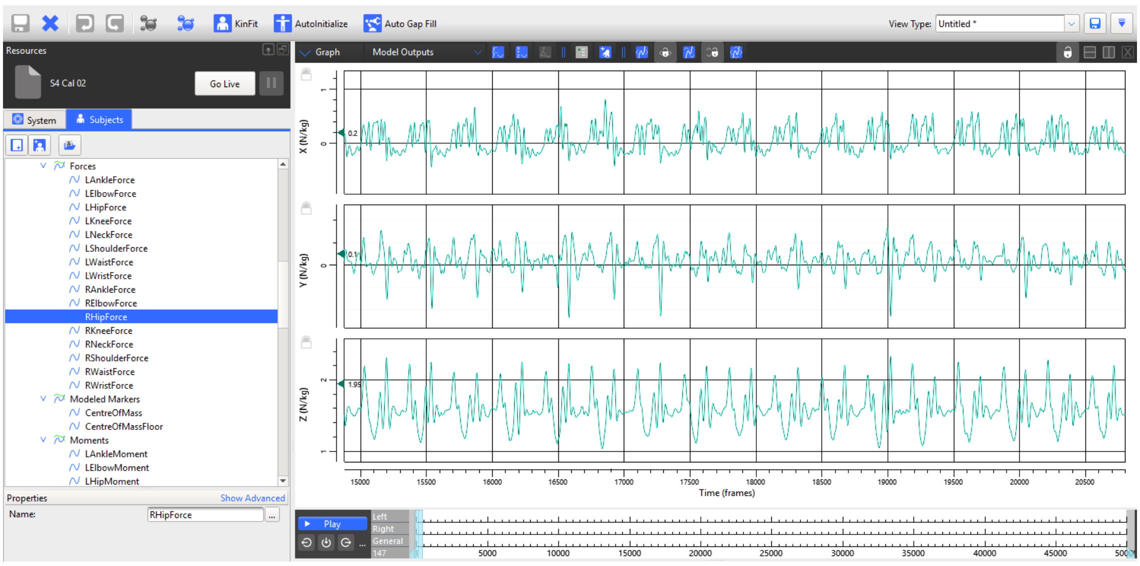
2.10 Custom made Prosthesis Pipeline



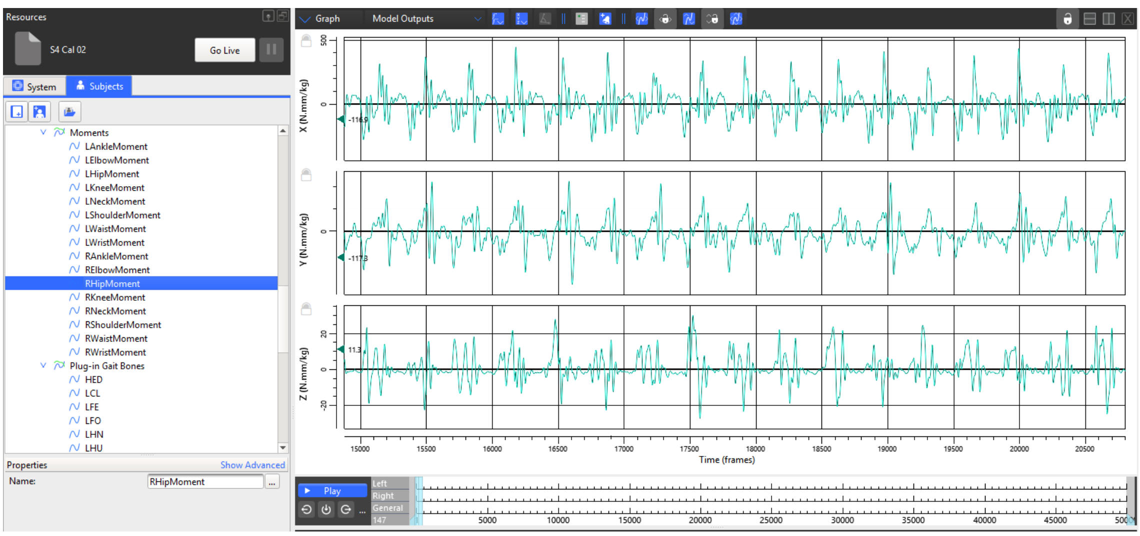
2.11 Model Outputs from Plug-in Gait Full Body Model



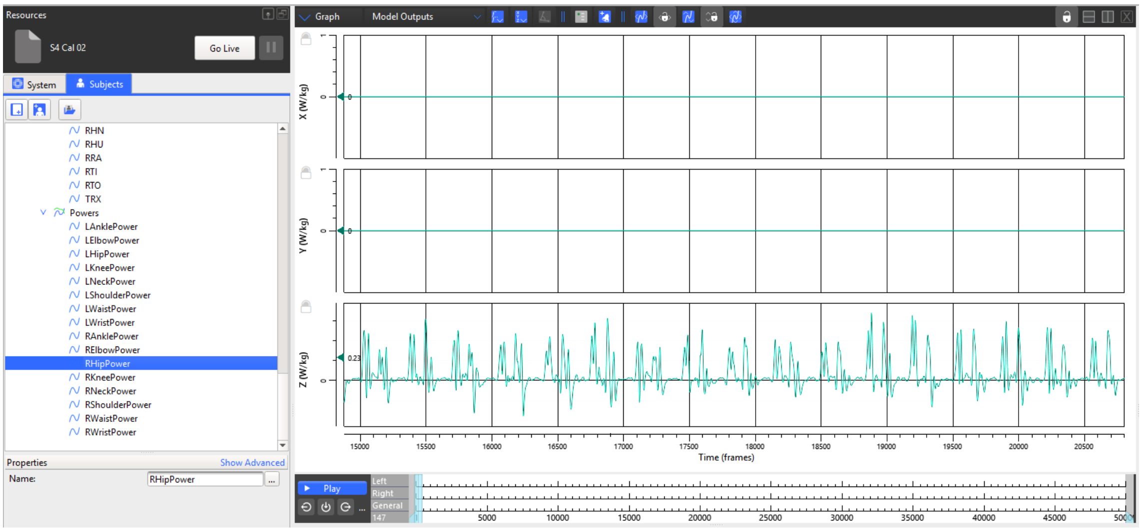
Left Ankle Angle Variation



Right Hip Force Variation



Right Hip Moment Variation



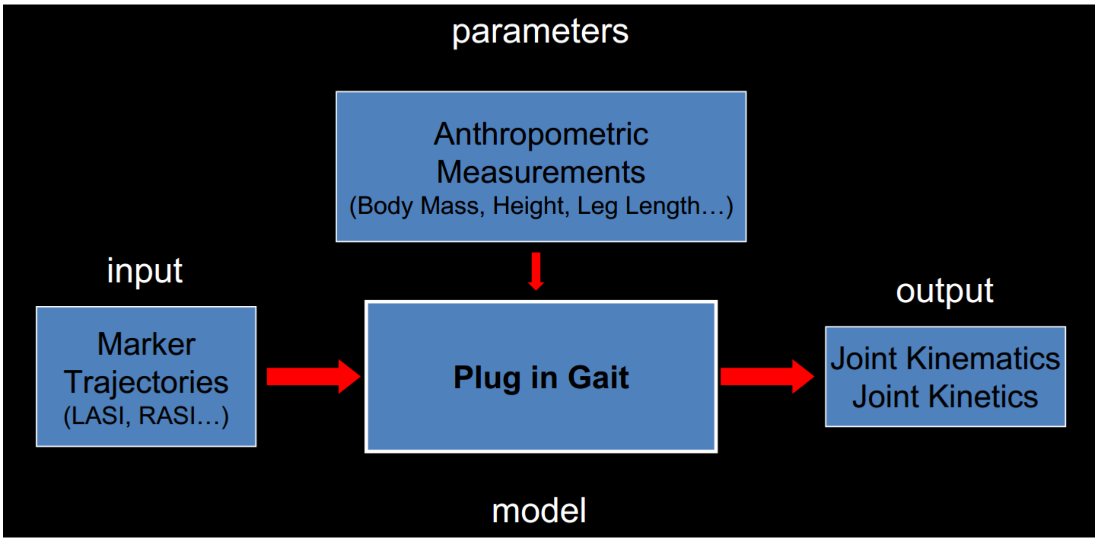
Right Hip Power Variation

Chapter 3

Plug-in Gait Full Body Model

3.1 Introduction

Plug-in Gait is pre-installed Vicon Nexus Model which forms the skeleton template for each subject automatically based on the Static Trial and Subject Measurements entered into Vicon Nexus Software. Theoretically Plug-in Gait Model is based on Conventional Gait Model or CGM developed by Kadaba, Davis and the Helen Hayes Hospital.



Plug-in Gait Full Body Model Input and Output

Plug-in Gait Model in Vicon Nexus Software contains four modeling modules

1) Lower Body Kinematic Model

2) Upper Body Kinematic Model

3) Lower Body Kinetic Model

4) Upper Body Kinetic Model

1) and 2) outputs Local Coordinate Axis of Rigid Body Segments, Joint Centers and Joint Angles.

3) and 4) outputs Joint Forces and Joint Moments by calculating Moment of Inertia.

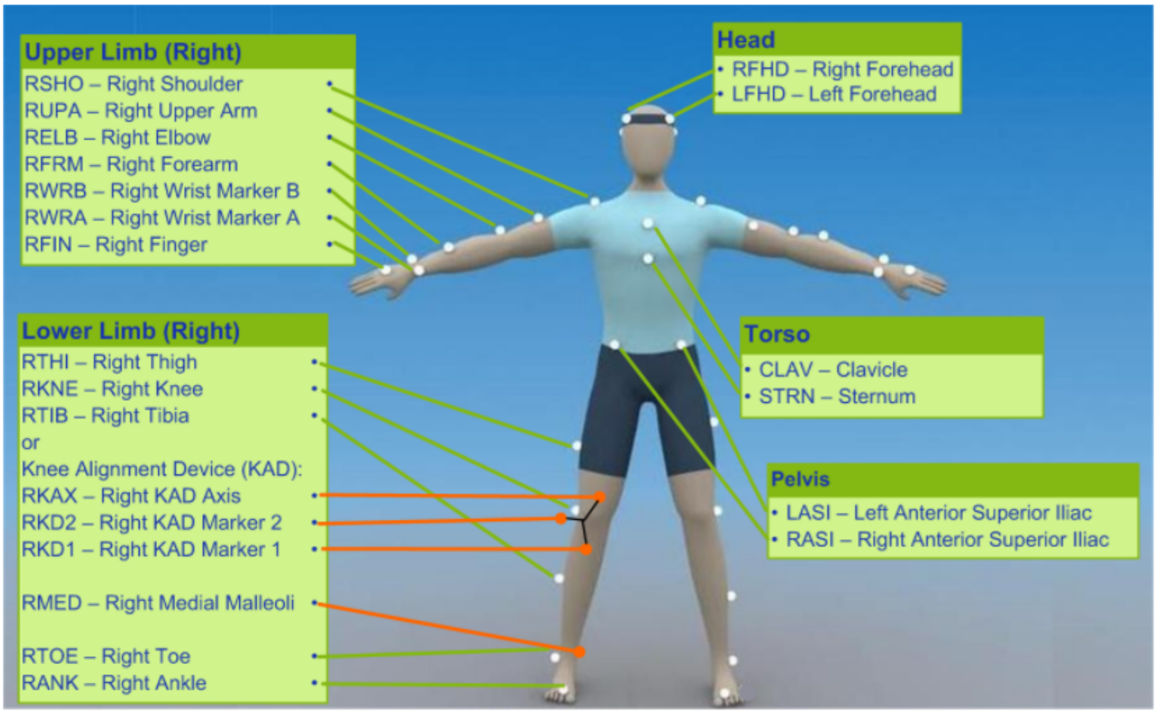
3.2 Kinematic Modeling

Rigid Segments can be formed using Physical markers and Virtual Markers determined using Physical Markers as well as the subject measurements added to the software before any trials.
Rigid Segments are defined based on frame to frame basis.

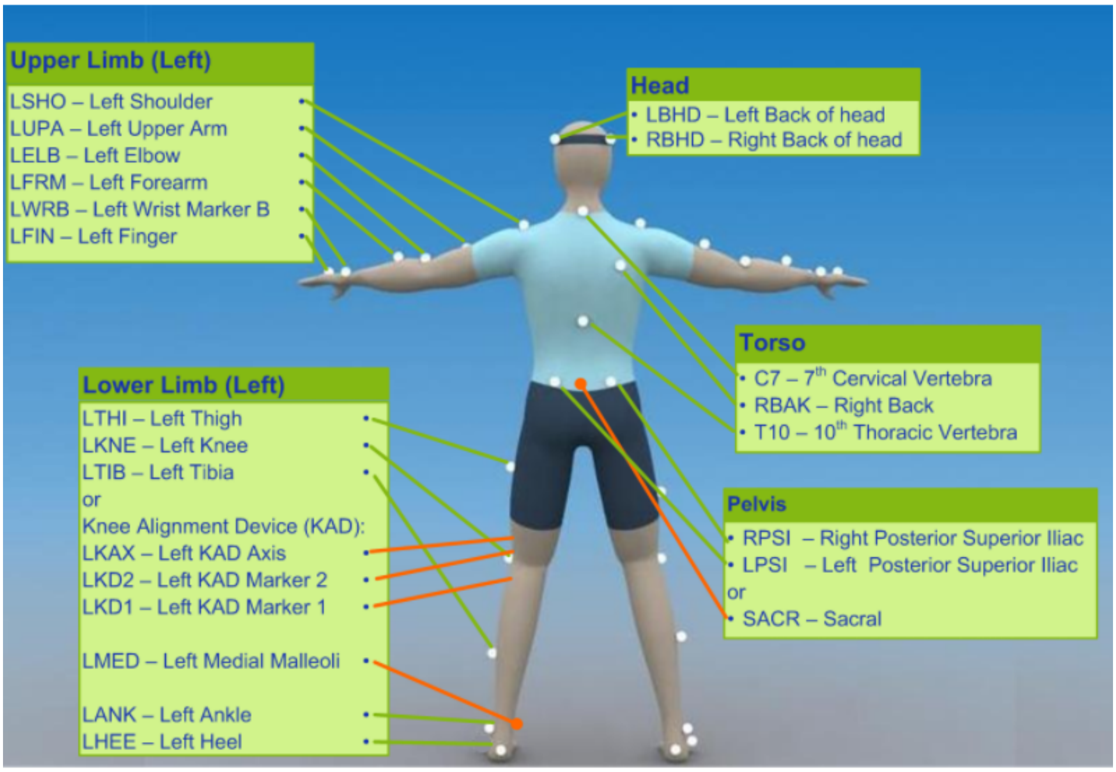
3.3 Kinetic Modeling

Joint Kinetics i.e. Joint forces and moments are determined using Inverse Dynamics Procedure.
Force Plate Readings i.e. Ground Reaction Force data is necessary for determining Joint Kinetics; however if no GRF data is present then also Joint Kinetics is calculated in Plug-in Gait Model however it is valid only during the swing phase of the Gait Cycle.

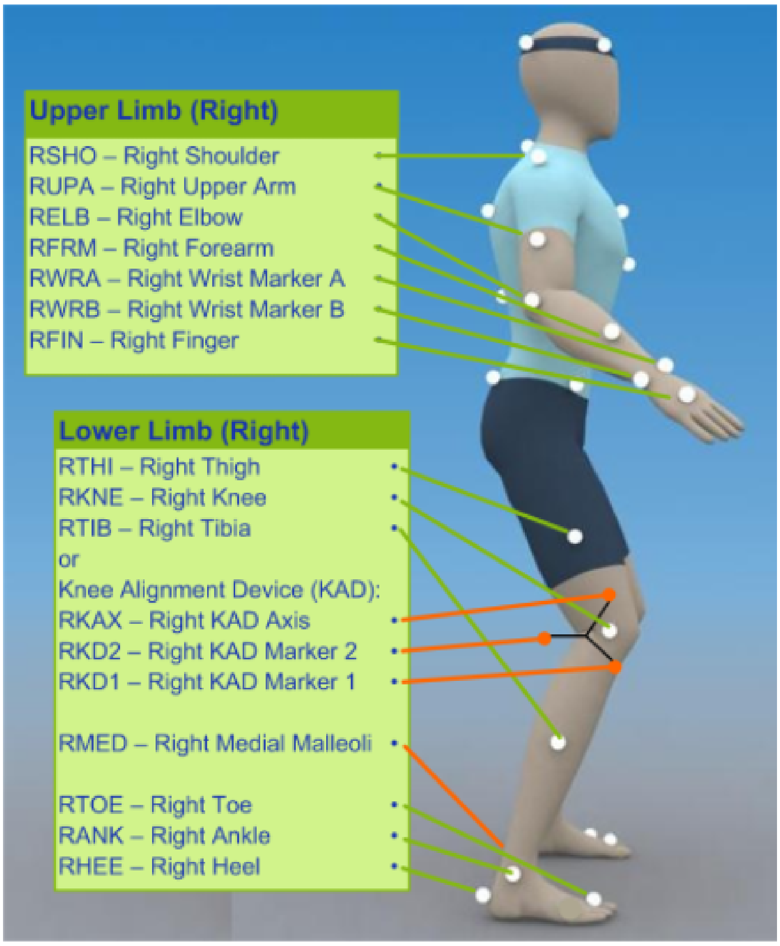
3.4 Marker Set for Plug-in Gait Full Body Model of Vicon Nexus



Anterior View



Posterior View



Lateral View

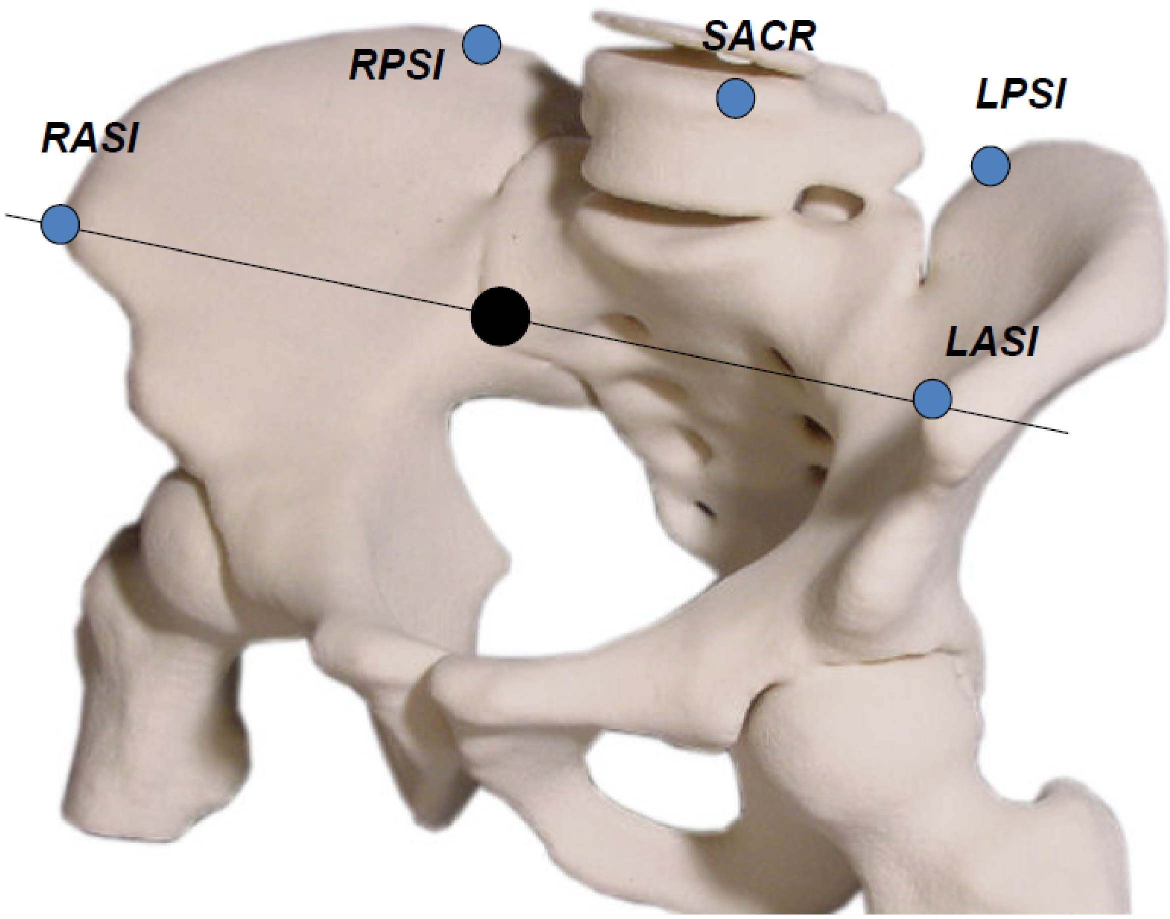
3.5 Plug-in Gait Full Body Model Input

Subject Measurements and Minimum number of markers as mentioned above should be present in Static as well as Dynamic Trial. For Plug-in Gait Full Body Model, minimum number of markers are 39 as shown above.

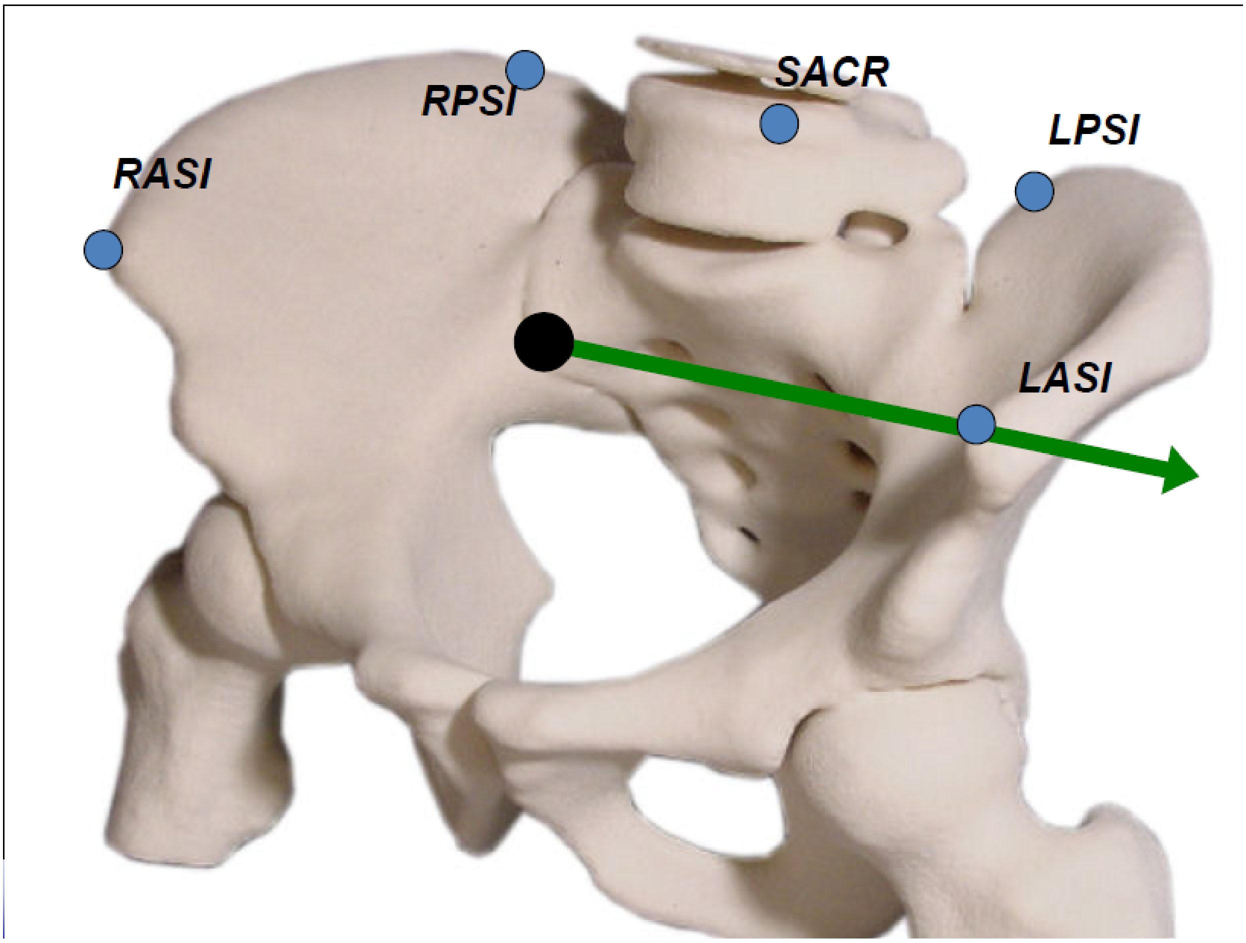
3.6 Plug-in Gait Full Body Model Output

Plug-in Gait outputs marker trajectories as a c3d file. It outputs X,Y and Z coordinates of every marker present in the Trial.

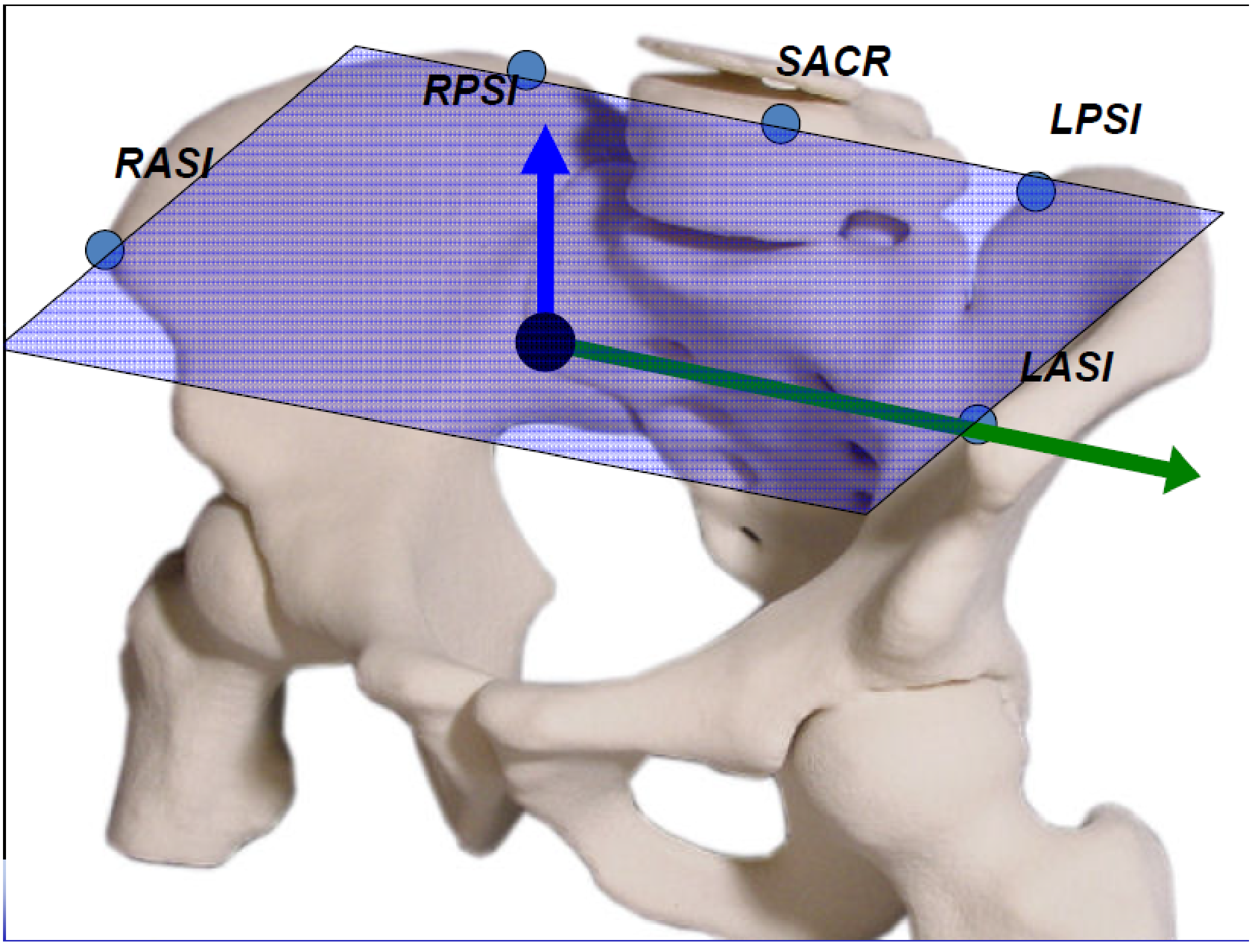
3.7 Pelvis Coordinate System



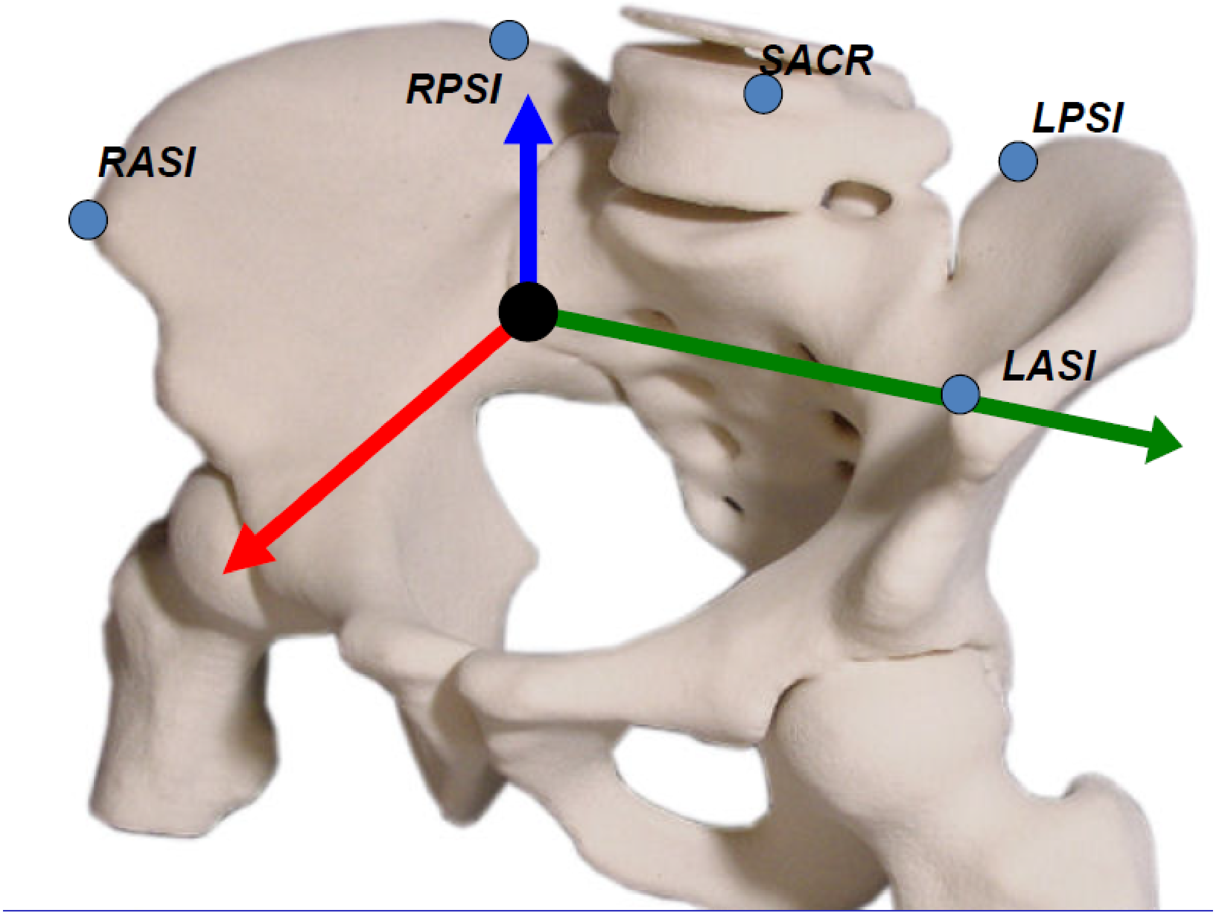
Origin is at the midpoint of RASI and LASI markers



Y-Axis from RASI to LASI



Z-axis is aligned perpendicular to the plane formed by RASI, LASI and SACR markers



X-axis is aligned in the direction determined by the cross product of Y-axis and Z-axis

3.8 Hip Coordinate System and Hip Joint Center Calculation

Hip coordinate system(R B. Davis et al)

$$HJC_x = C * \cos(\vartheta) * \sin(\beta) - (AsisTrocDist + mm) * \cos(\beta)$$

$$HJC_y = S(C * \sin(\vartheta) - aa)$$

$$HJC_z = -C * \cos(\vartheta) * \cos(\beta) - (AsisTrocDist + mm) * \sin(\beta)$$

$S = \pm 1$

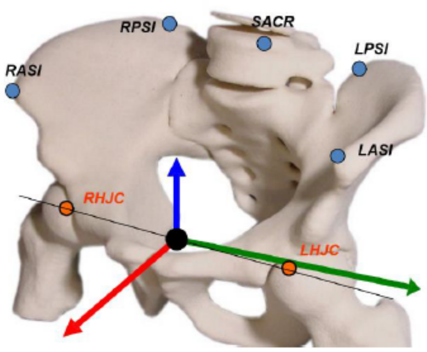
$\vartheta = 0.5 rad$

$\beta = 0.314 rad$

AsisTrocDist = 0.1288 * LegLength – 48.56 *

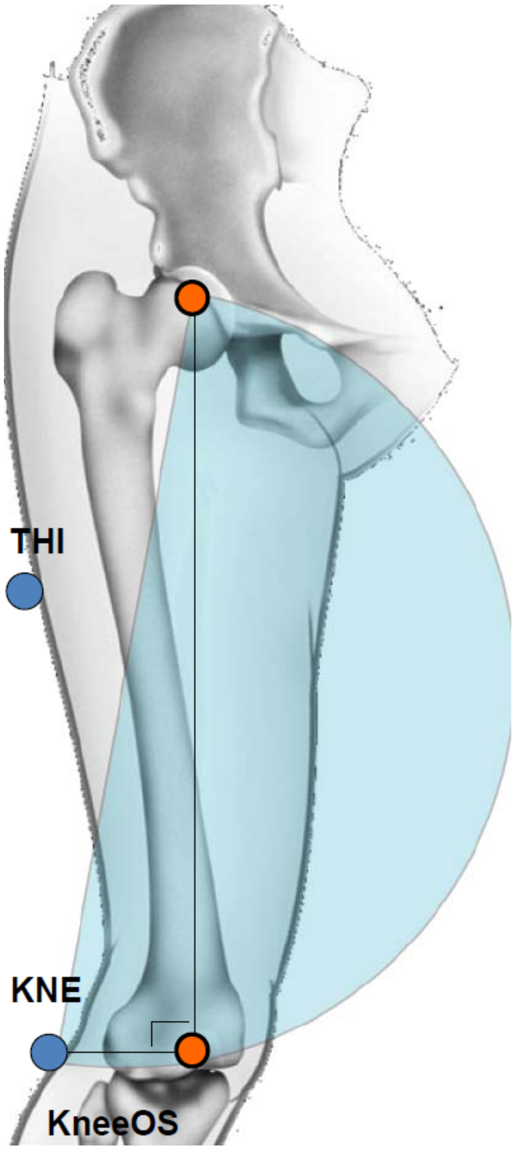
C = MeanLegLength*0.115 – 15.3

aa = (InterAsis)/2

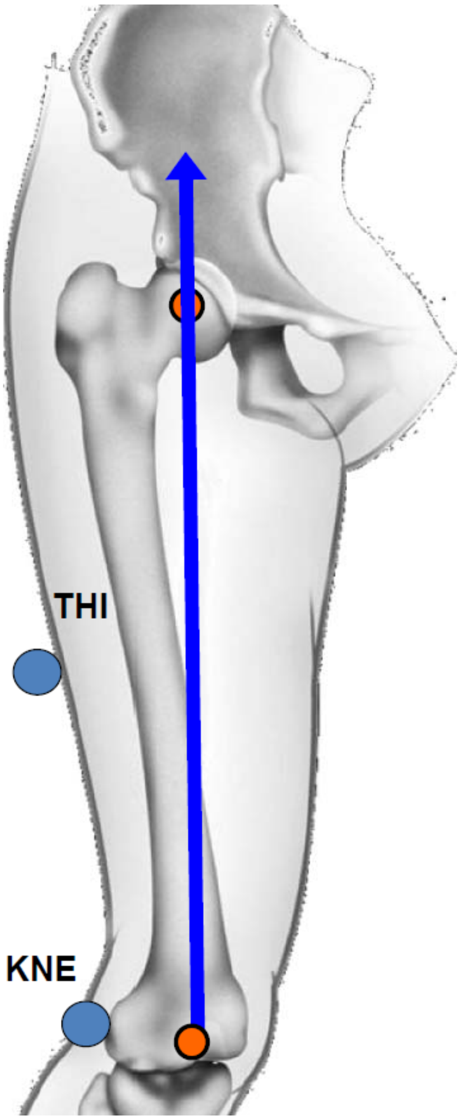


Once the Hip Joint Center is determined, the Hip Coordinate system is determined by shifting Pelvis Coordinate System such that Hip Joint center acts as the origin of Hip Coordinate System and there is no change in orientation of X, Y and Z axis from that of Pelvis Coordinate System.

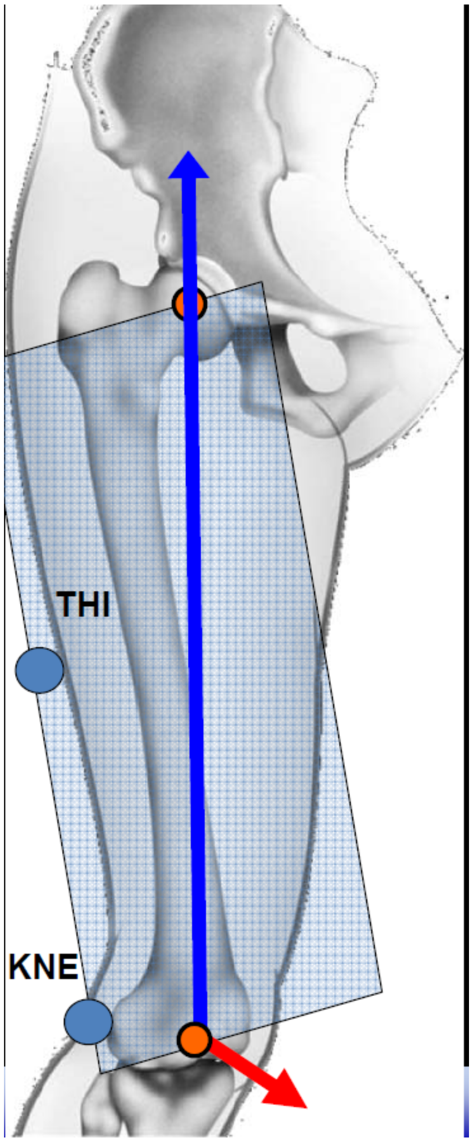
3.9 Thigh Coordinate System



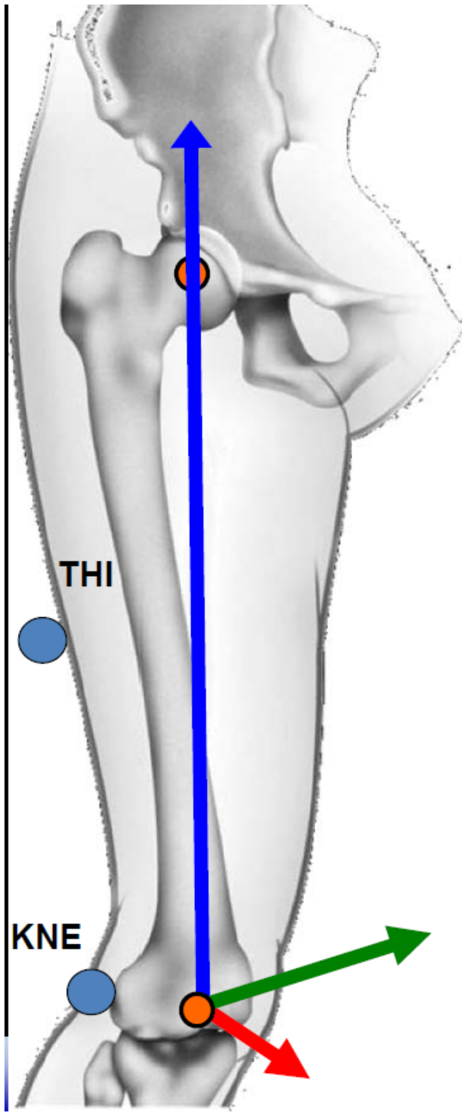
Knee Joint Center is defined as a Virtual Marker at a distance KneeOS from KNE marker in the plane defined by KNE, THI and HJC markers.
Also the angle KNE-KJC-HJC must be 90^o.
KneeOS = (Marker Diameter + Knee Width)/2.
Knee Width is entered during Subject Measurement Section.



Origin is taken at the KJC.
Z-axis is taken along the direction of KJC and HJC.

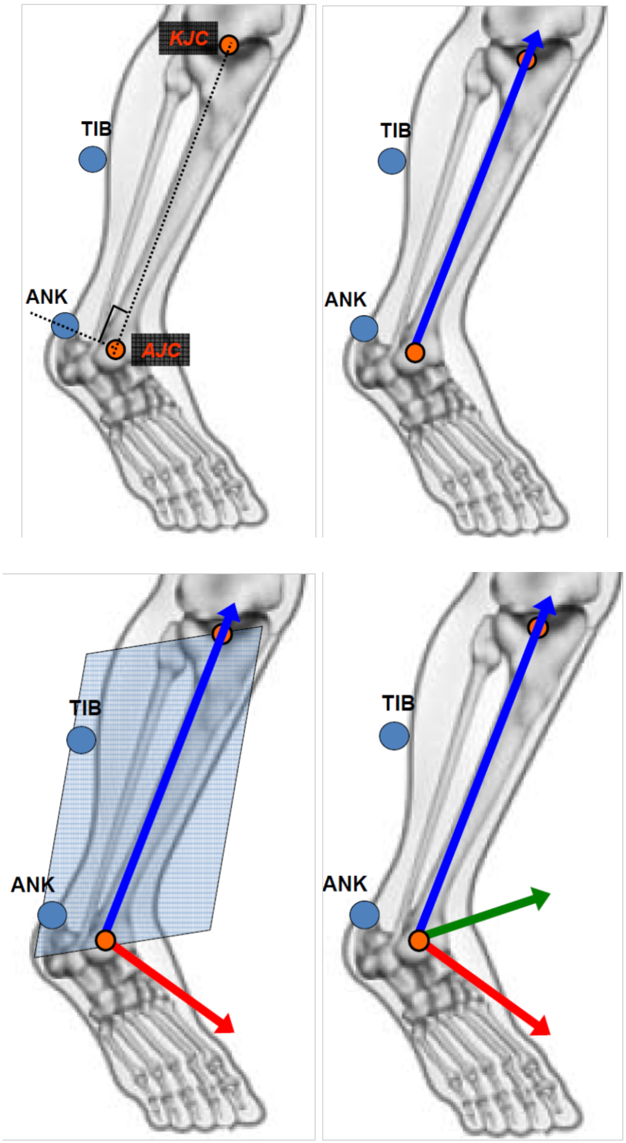


X-axis is aligned in the direction perpendicular to the plane formed by HJC, KNE and THI markers.



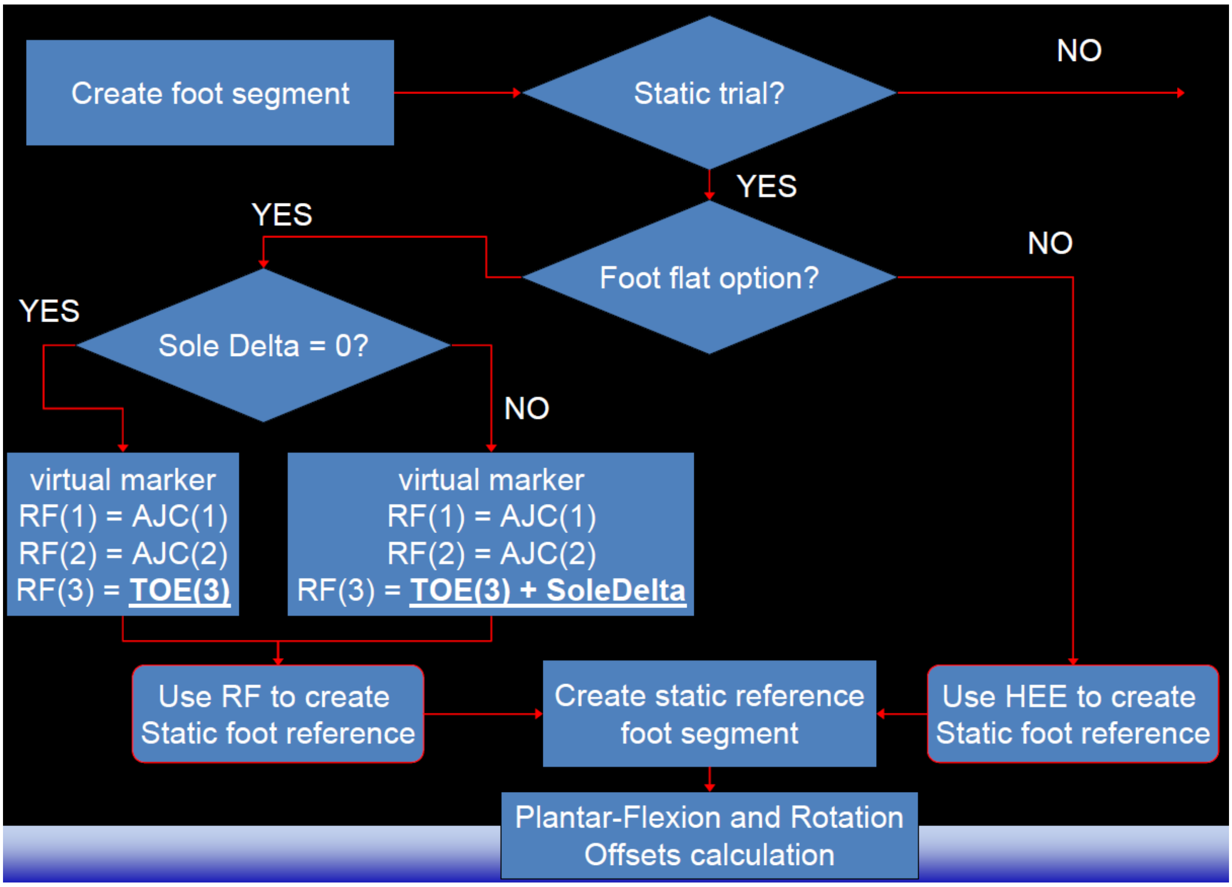
Y-axis is aligned in the direction determined by taking the cross product of Z and X axis.

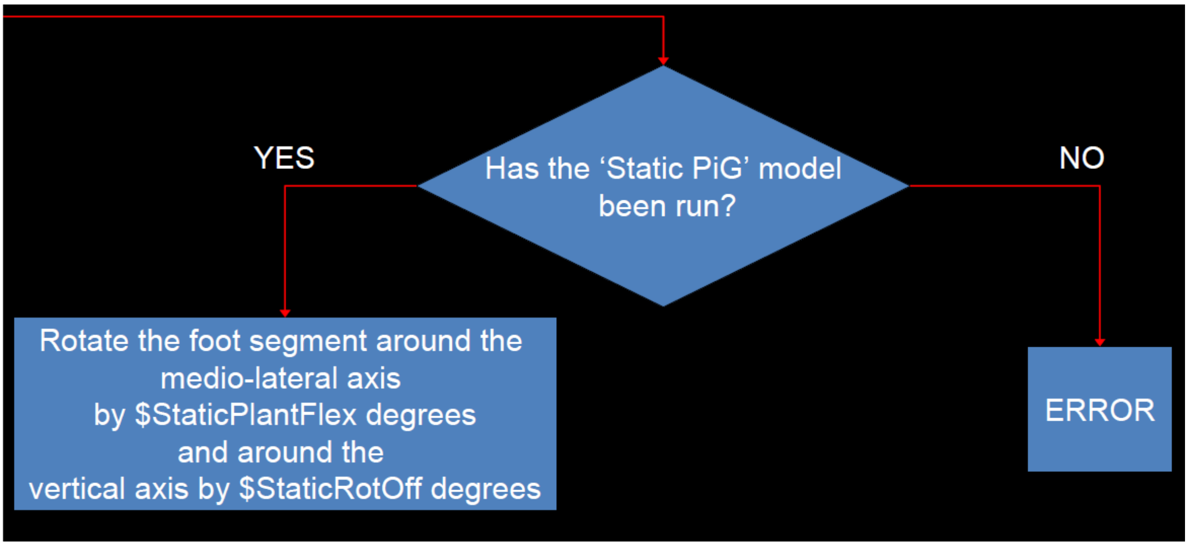
3.10 Shank Coordinate System

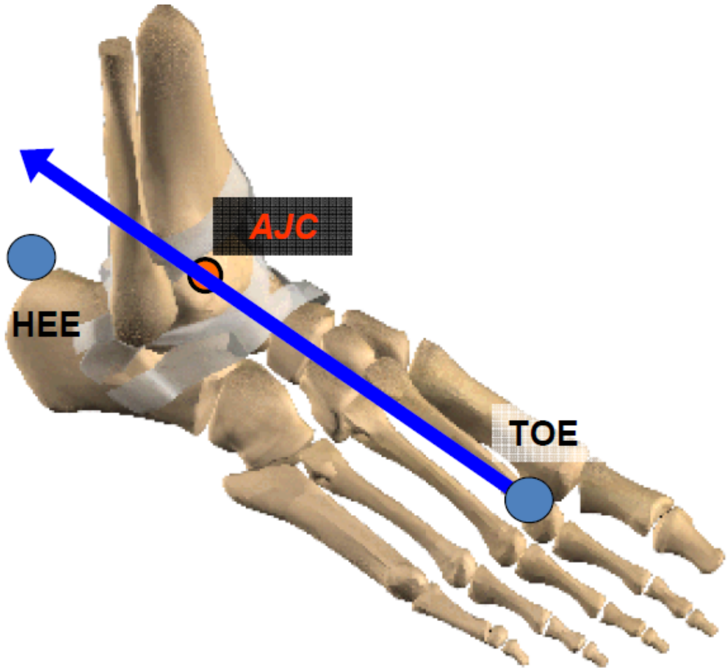


Similar Procedure is performed to determine Shank Coordinate System as done during determining Thigh Coordinate System.

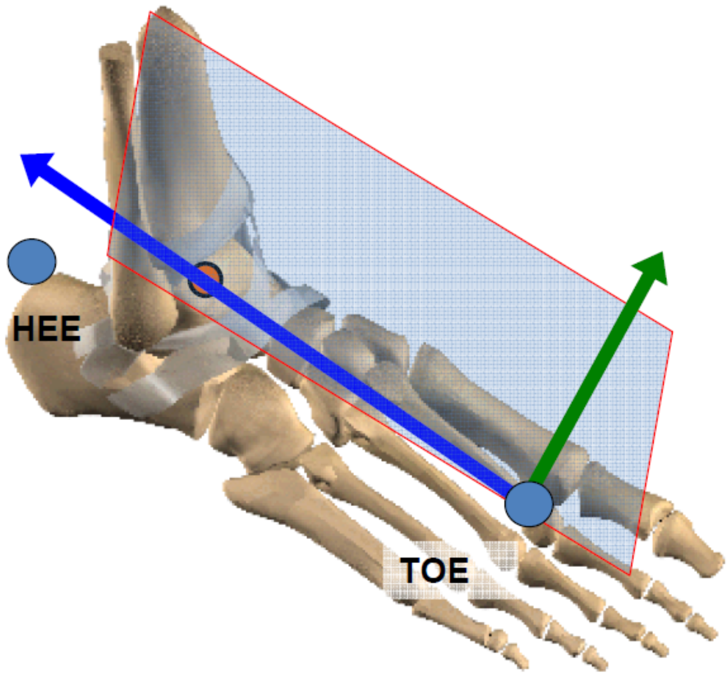
3.11 Foot Coordinate System Work Flow



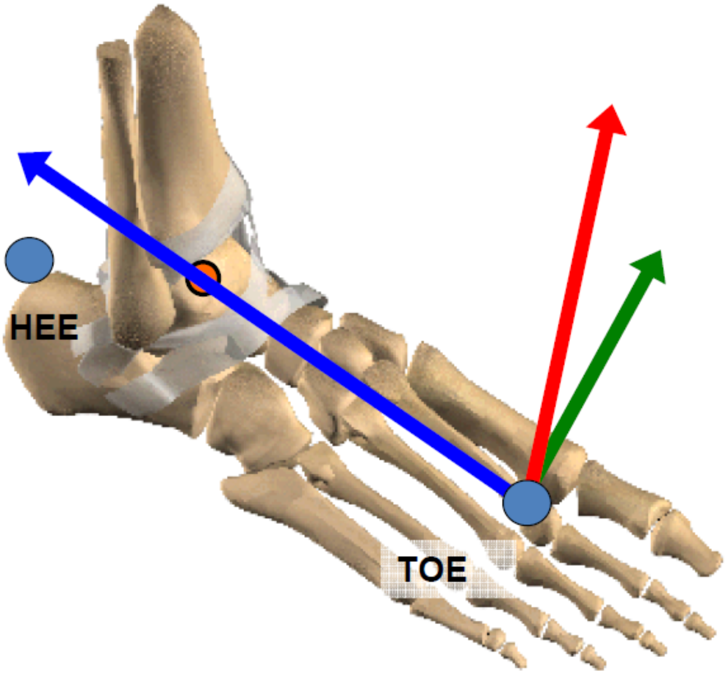




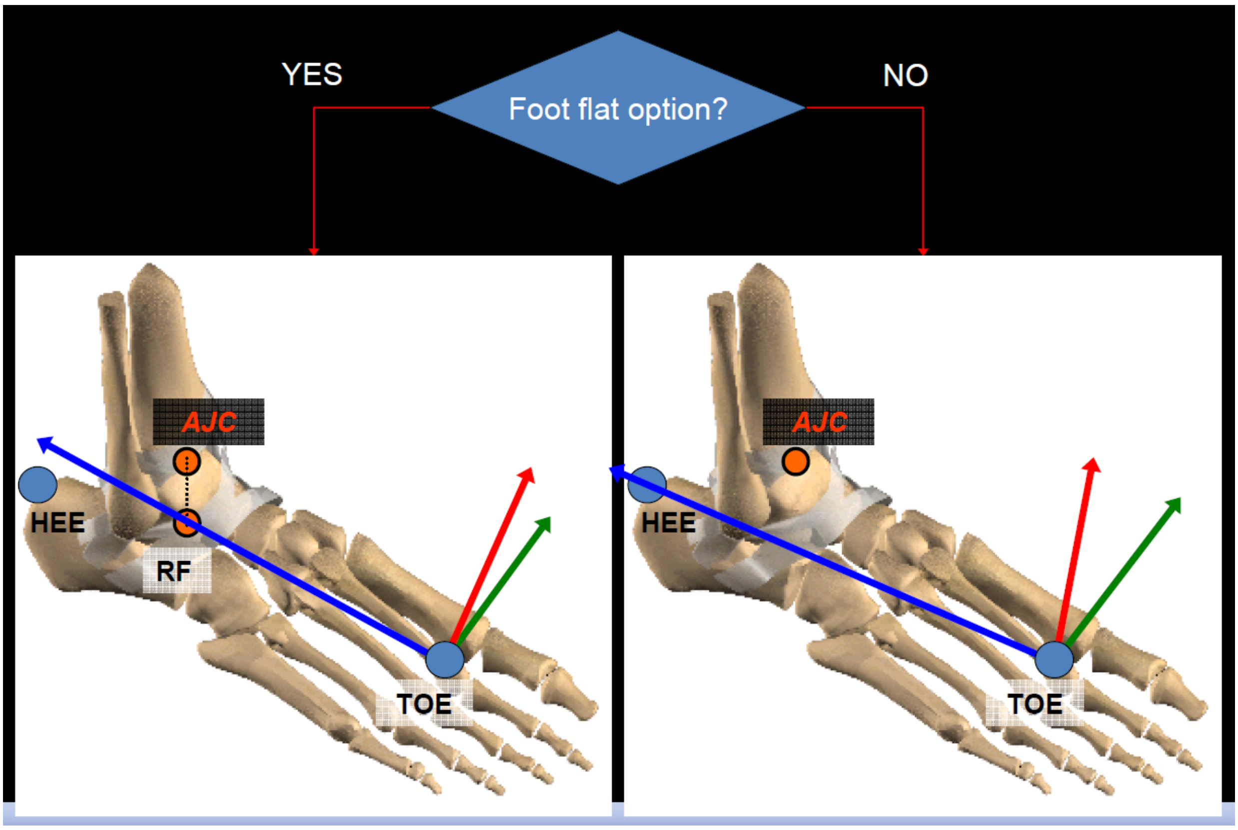
Origin is taken at TOE marker
Z-axis is aligned along the TOE-AJC marker direction

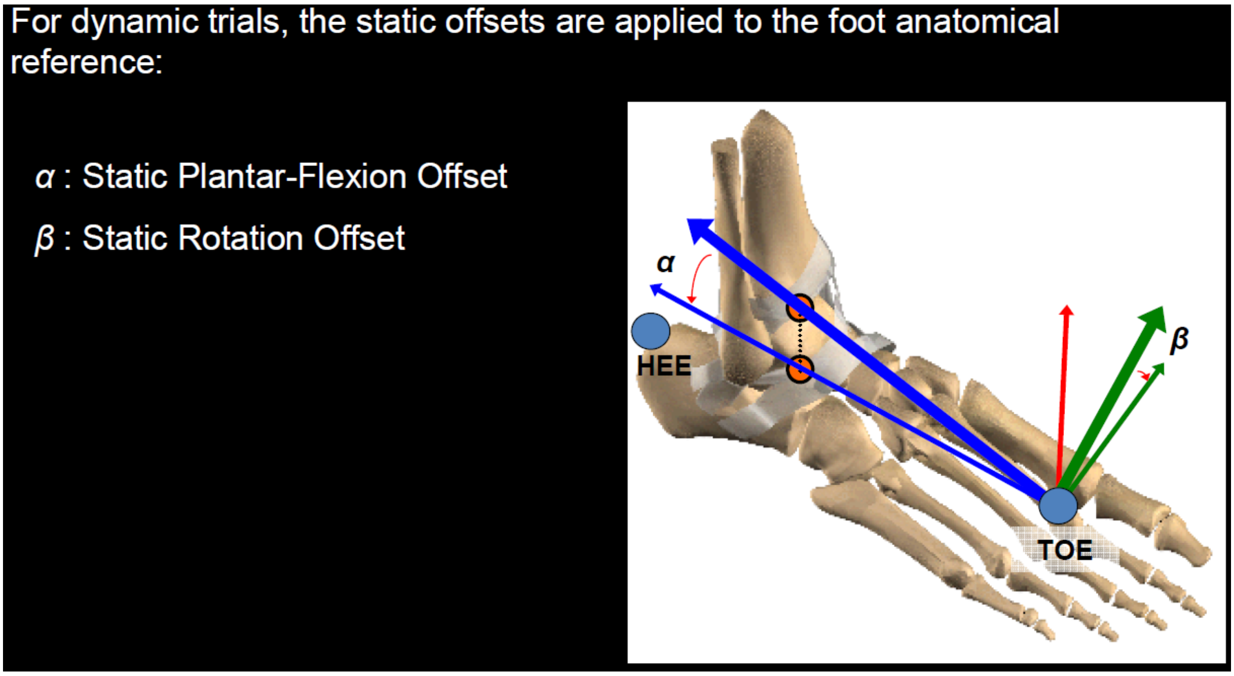


Y-axis is aligned in the direction perpendicular to the plane formed by TOE, AJC and KJC markers

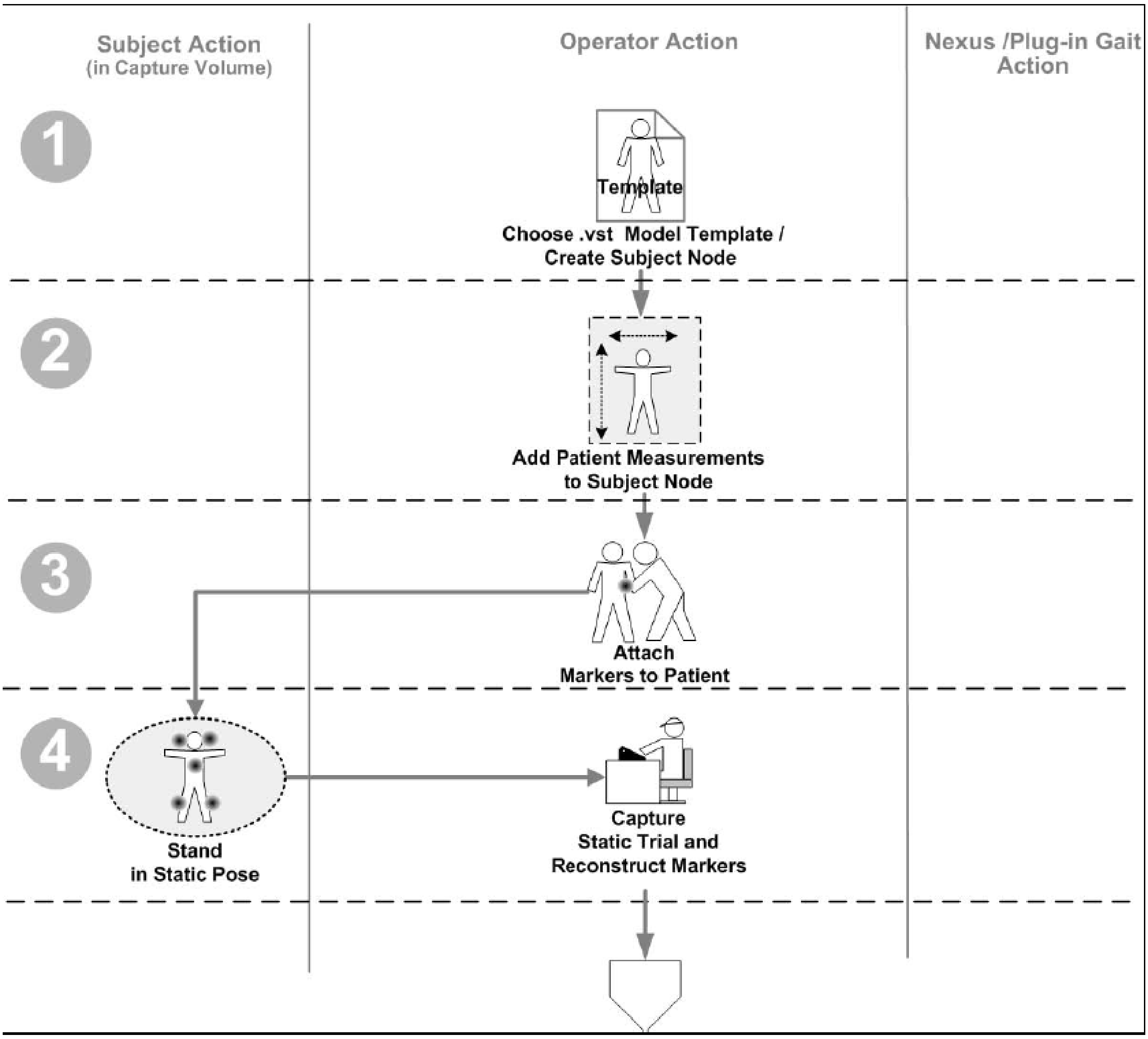


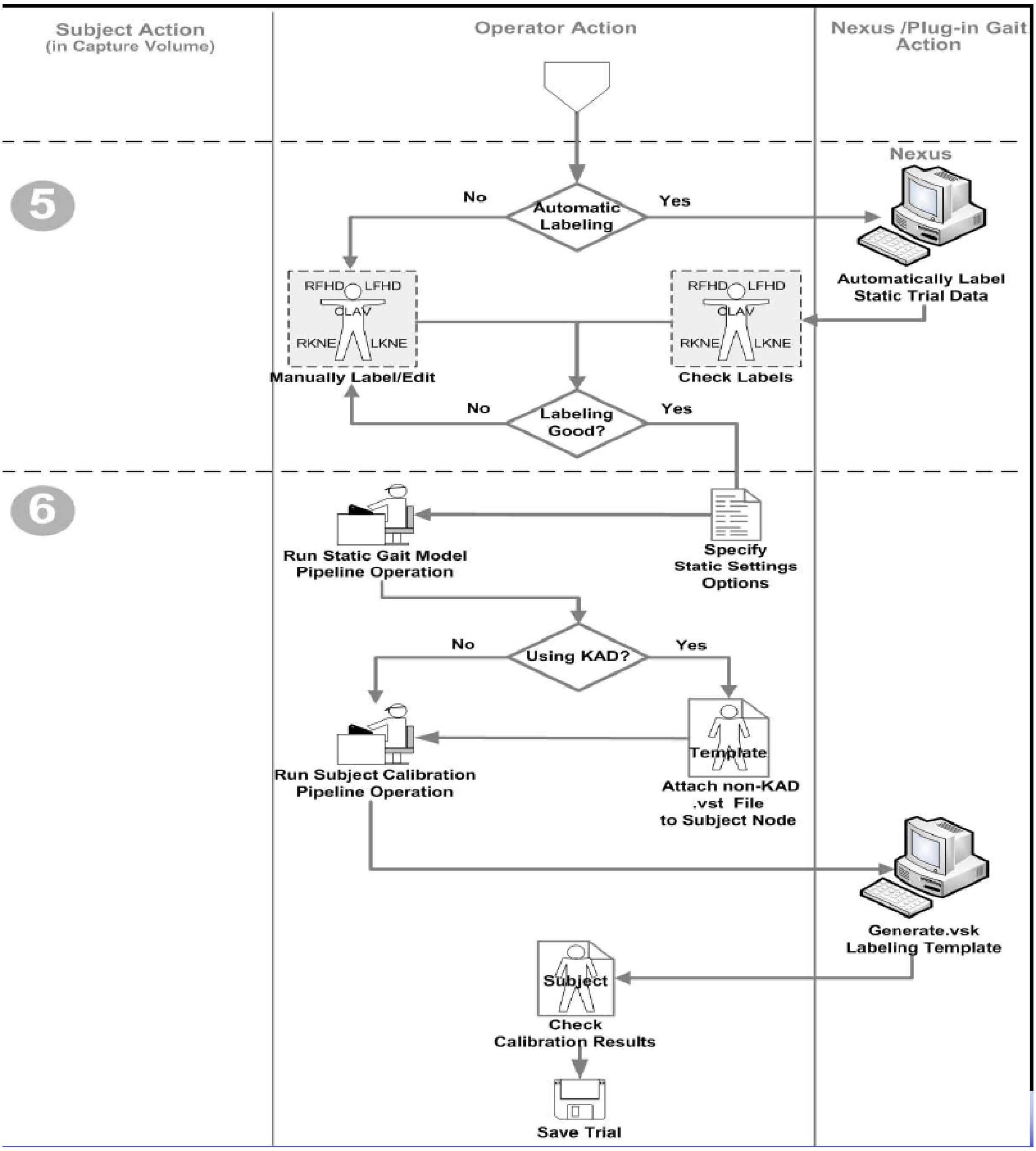
X-axis is taken in the direction determined by taking Cross Product of Y and Z axis




For dynamic trials, the static offsets are applied to the foot anatomical reference:
α : Static Plantar-Flexion Offset
β : Static Rotation Offset
α
HEE
β
TOE

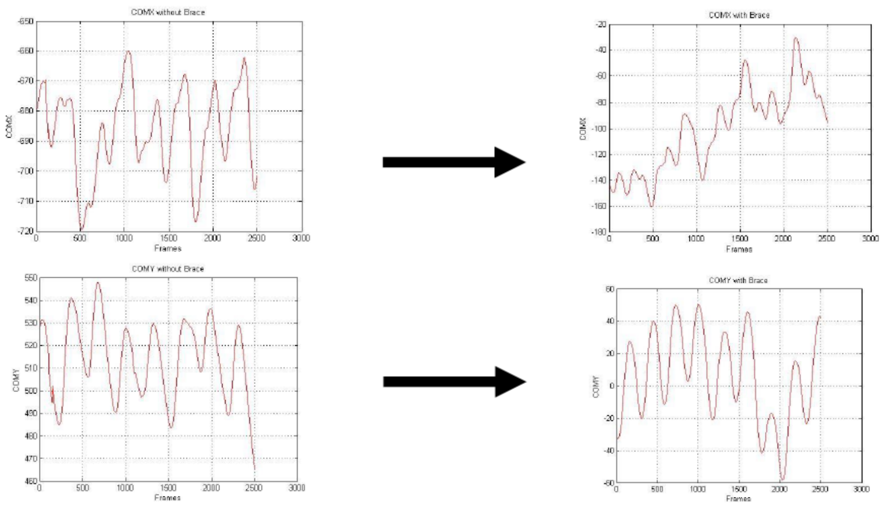
3.12 Plug-in Gait Work Flow



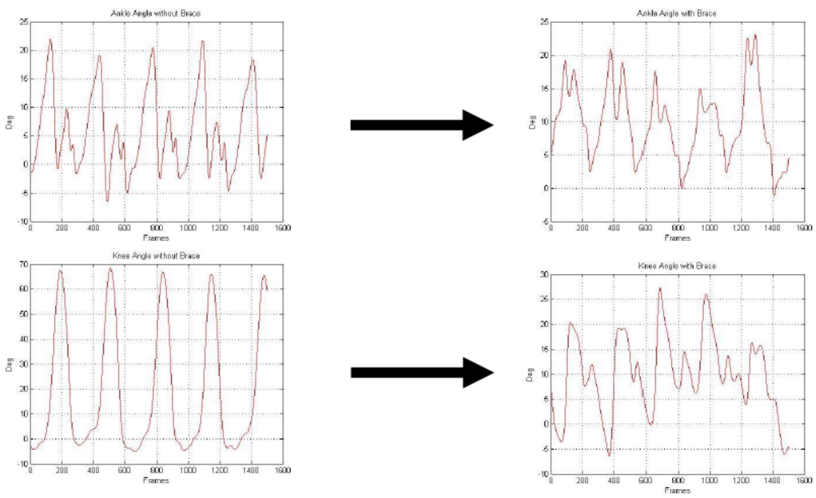

Subject Action
(in Capture Volume)
Operator Action
Nexus /Plug-in Gait Action
5
No
Automatic Labeling
Yes
Nexus
RFHD
LFHD
CLAV
RKNE
LKNE
Manually Label/Edit
Check Labels
Automatically Label Static Trial Data
No
Labeling Good?
Yes
6
Run Static Gait Model Pipeline Operation
Specify Static Settings Options
No
Using KAD?
Yes
Run Subject Calibration Pipeline Operation
Template
Attach non-KAD .vst File to Subject Node
Generate.vsk Labeling Template
Subject
Check Calibration Results
Save Trial

Motion Capture Results Plug-in Gait:

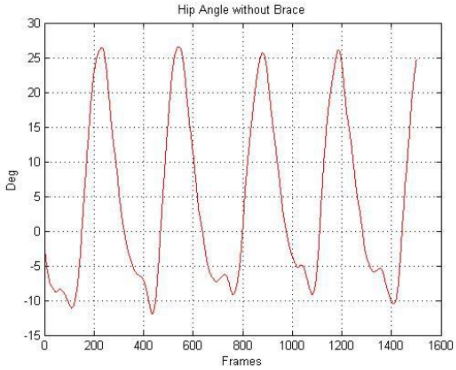
- Results for Center of Mass

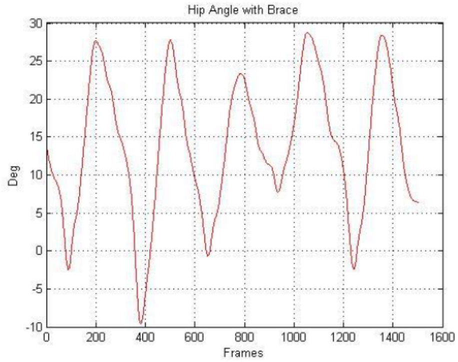


- Ankle and Knee Joint Angles



- Hip Joint Angles



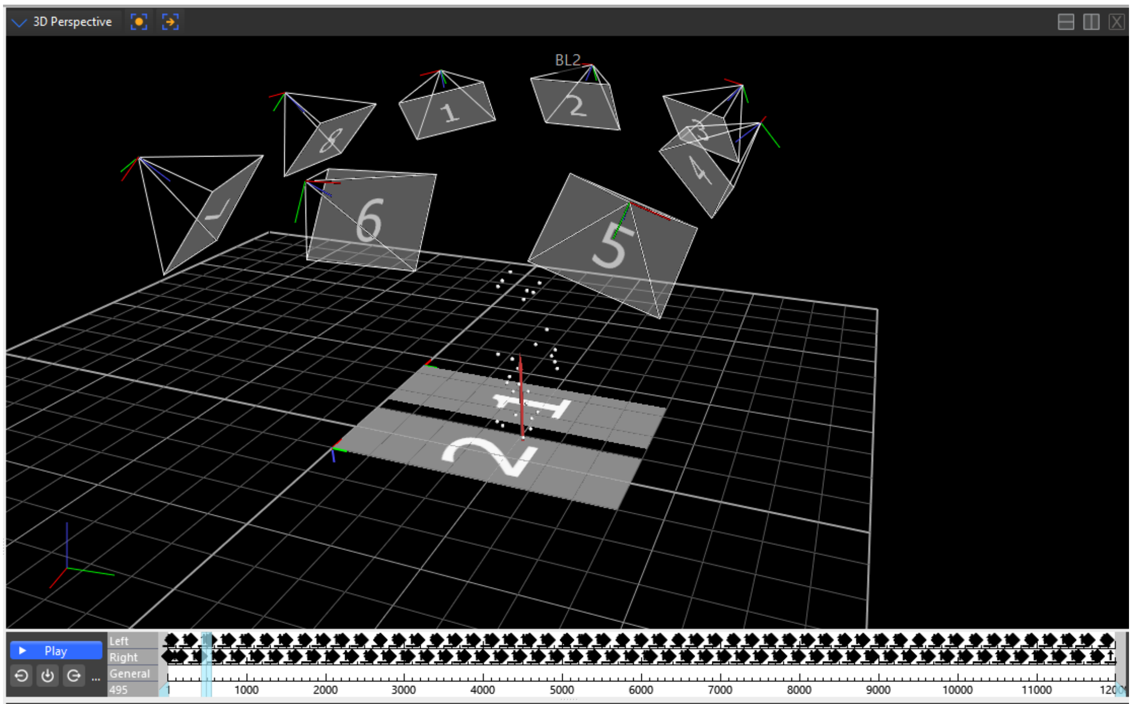


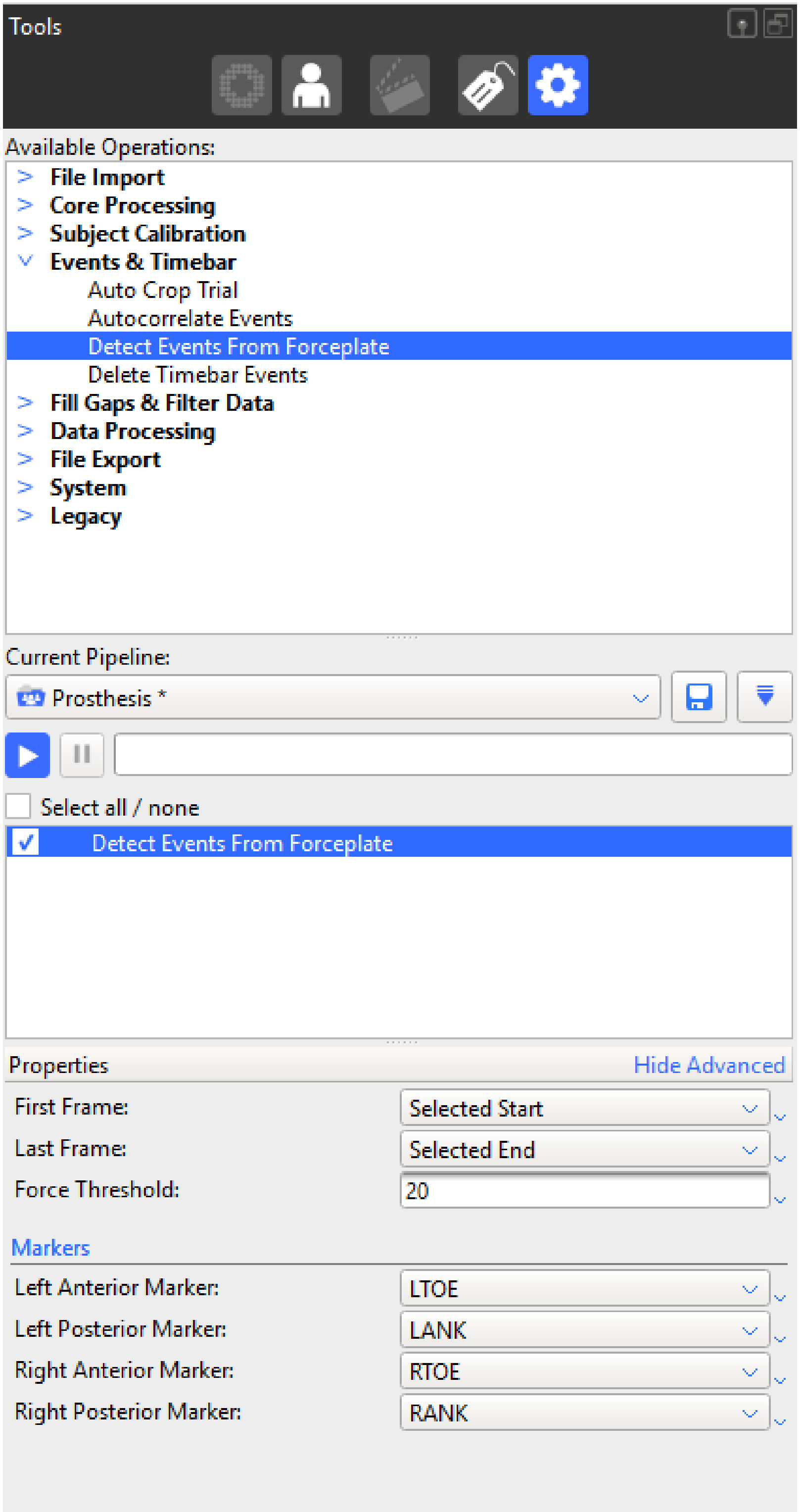
Chapter 4

Gait Parameters

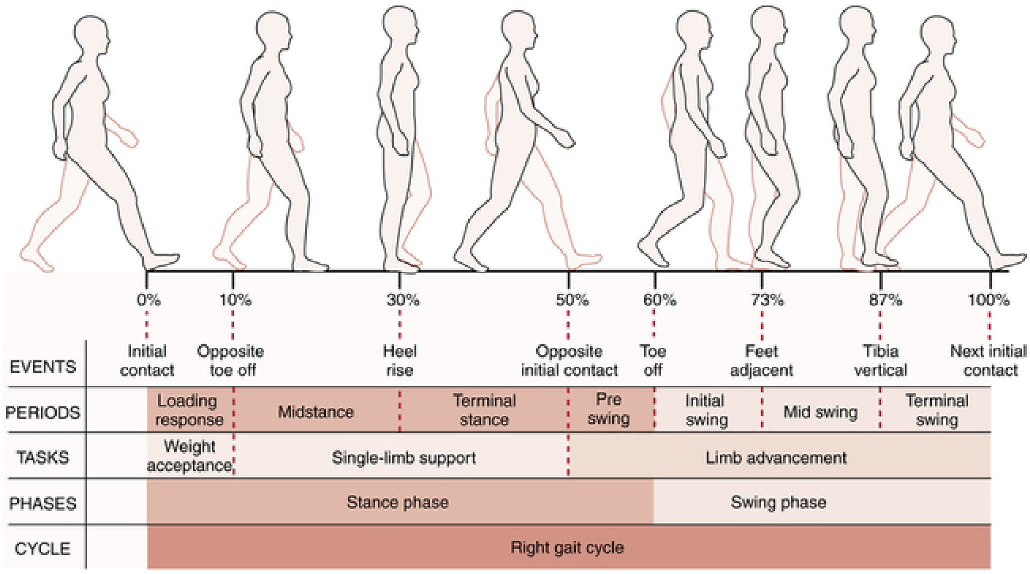
4.1 Gait Events

Gait Events can be detected through Vicon Nexus Software. Vicon Nexus uses Force Plate Data i.e. Ground Reaction Force data to detect Gait Events.





However in our SRIP Projects Workspace, Force Plate data was not available due to absence of Force Plates Equipment. Hence we used another method based on the kinematics of marker data that we recorded.



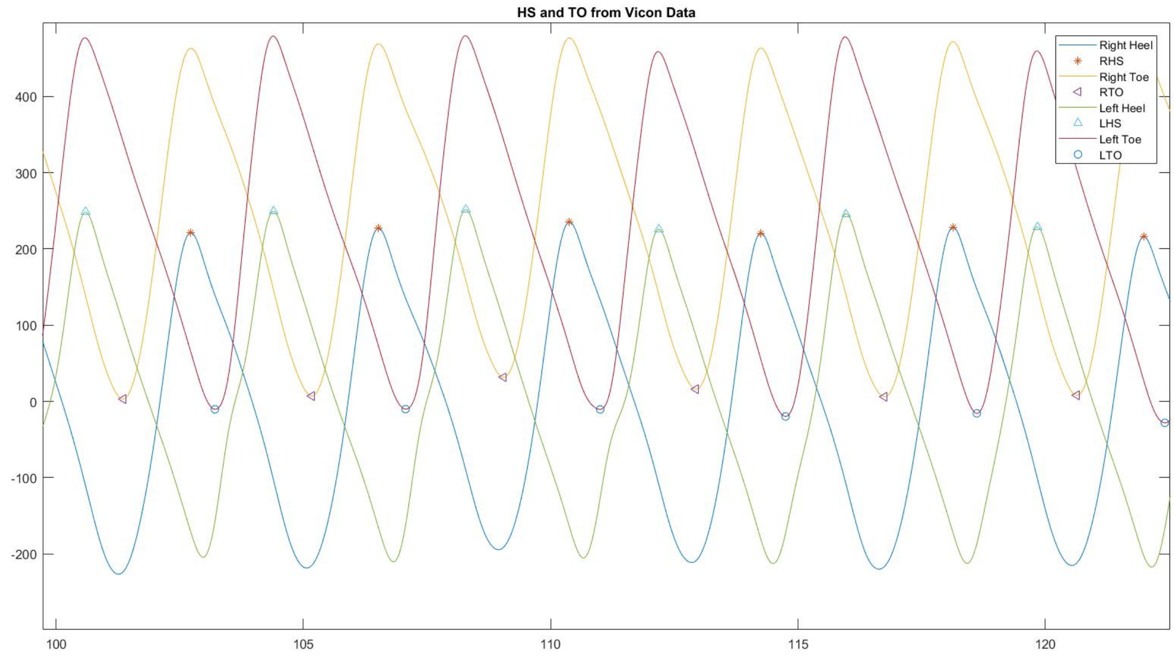
`https://clinicalgate.com/gait-2/`

Based on kinematics data, we can detect Gait Events by measuring the relative displacement of Heel Marker with respect to Sacrum Marker present at the midpoint of Pelvis.

Whenever the relative displacement is at its peak in positive direction, Heel strike of that particular foot occurs.

Similarly when the relative displacement of Toe marker with respect to the Sacrum Marker present at the midpoint of the Pelvis is at its peak in the negative direction, Toe Off of that particular foot occurs.

Below are the results of the MATLAB program that we programmed to detect Gait Events from kinematic data recorded of the markers using Vicon Vero Motion Capture System.



By determining these Gait Events we can determine gait parameters at different periods and phases of the Gait Cycle and also at different Percentages of Gait Cycle.

Also by determining Gait Events the entire kinematic data collected for some time period can be sequenced and analyzed efficiently.

4.2 Base of Support and Margin of Stability

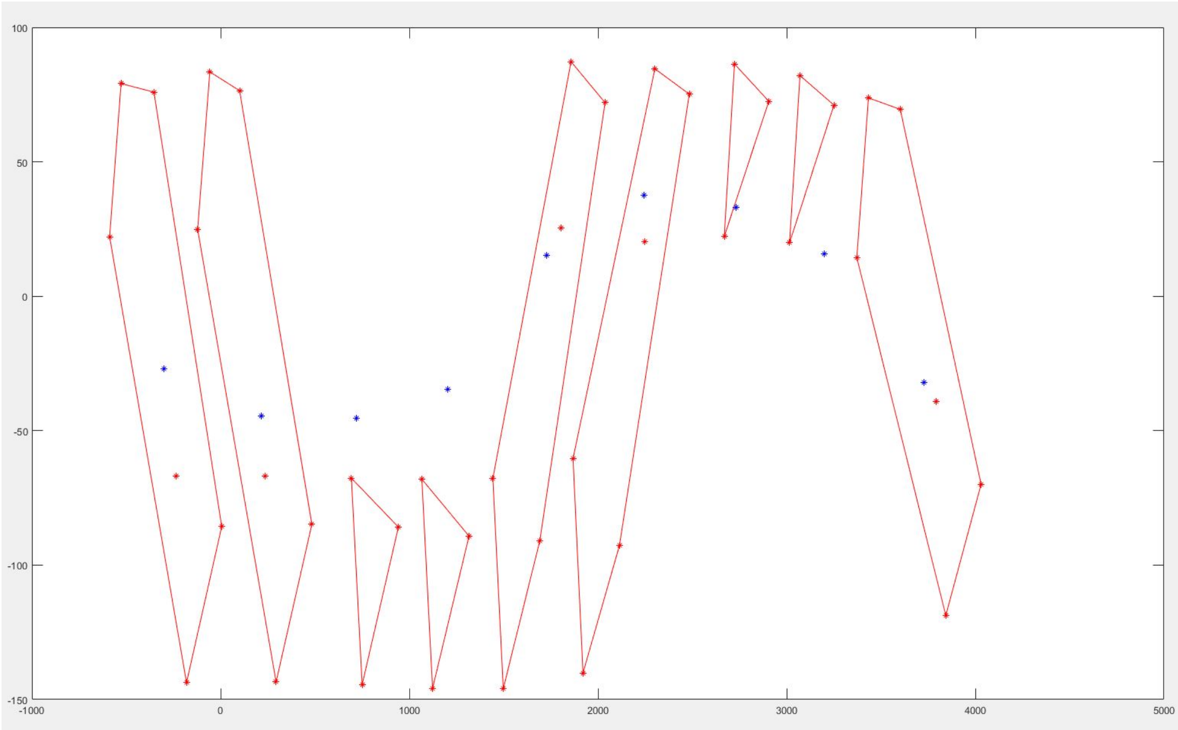
Base of Support according to our project is the surface area contact of both left and right feet at any instant of the Gait Cycle

OR

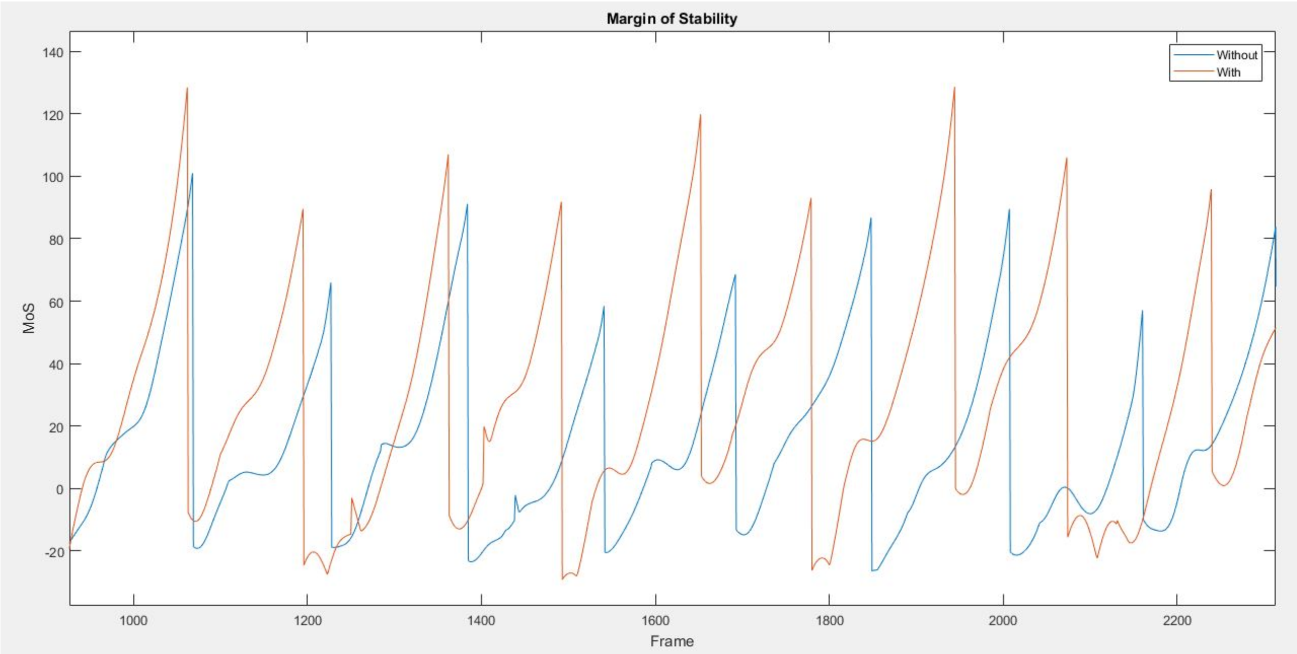
Base of Support is a convex polygon with minimum surface area encompassing all the feet markers at any instant of the Gait Cycle.

As the contact area changes during the Gait Cycle it was very important to detect the Gait Events initially then calculate Base of support.

Results of MATLAB code that we programmed to determine Base of Support at different events of the Gait Cycle is as follows:



Horizontal axis is the X-axis and Vertical axis is Y-axis.
Triangle in the bottom part is the projection of Right foot markers on the ground and Triangle in the top portion is the projection of Left Foot on the ground.
The markers in the same horizontal distance as compared to the third marker are HEEL and ANK markers whereas the third marker is the TOE marker.
Blue * label is the position of Extrapolated Center of Mass.
Extrapolated Center of Mass is the projection of Center of Mass on the ground in addition to Center of Mass velocity multiplied by a constant factor which is dependent on the distance between pelvis and ankle joint.
Margin of Stability according to our project is defined as the minimum distance of Extrapolated Center of Mass to any of the side of the Base of Support area.
From the kinematic data recorded for an able-bodied subject walking with and without ankle brace we were able to compare the Margin of Stability between both the cases using MATLAB code that we programmed.



Here positive MoS means that Extrapolated CoM is outside of the Base of Support Polygon.

Whereas negative MoS means that the Extrapolated CoM is inside the Base of Support Polygon.

As a result one can conclude from the above graph that when the subject was wearing ankle brace, the MoS was more positive in comparison to that when the subject was not wearing ankle brace.

As a result in the next phase of our Project Sensorized Passive Prosthetic Limb if we construct a feedback control loop from the prosthetic to the residual limb based on Margin of Stability gait parameter then we can increase the dynamic stability of the subject while wearing prosthesis and hence help in making the gait symmetric and using less human metabolic energy than earlier.

Chapter 5

Summary and Conclusion

SRIP Project Balance Impairment Measurement using Margin of Stability as mentioned earlier serves as an initial phase of the long term project titled Sensorized Passive Prosthetic Limb

Through this SRIP Project, we were able to learn and implement how to install Vicon Vero Motion Capture System which can be used in many areas like in Clinical Sciences, for Motion Capture in Video Games, in Movies for Animation and CGI. We learnt how to aim, mask and calibrate Vicon Vero Cameras so that we can create a desired workspace.

Also we learnt how to prepare a subject and take kinematic and kinetic data using Vicon Vero Motion Capture System and Vicon Nexus Software associated with that particular Motion Capture System.

We were also able to create a dynamic model in Vicon Nexus and play with it to get different Gait Events and hence different Gait Parameters.

To differentiate between a subject walking with and without ankle brace for realizing Transtibial Amputation or Below Knee Amputation, we used a gait parameter known as Margin of Stability.

Now in the next phase of our final project we aim to use this difference in Gait parameter: Margin of Stability in creating a feedback control loop from the Passive Prosthetic Limb to the residual limb.

Also in future we plan to buy Force plate so that we can also use Ground Reaction Force data.

In addition to that we also plan to buy Electromyography Sensor to measure the muscle force and incorporate a more realistic model using OpenSim, musculoskeletal human simulating software developed by people at Stanford University.

Below is somewhat similar to what we aim to create as a Feedback Control loop for Lower Limb Passive Prosthetic Limb to make it sensorized.

Vibrotactile based Feedback Control Loop for Lower Limb Passive Prosthesis

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