

3DSuit Inertial Motion Capture Systems for Biomechanical, Sports Science and Rehabilitation Applications

Published March 2012

Intended Audience

A guide for researchers not familiar with latest features of the next generation 3DSuit inertial Motion Capture Systems, released in March 2012.

1. Introduction

When Inertial Labs introduced its gyroscopic inertial motion capture system in 2006, the only interface software that it was coupled with was designed for use by professional animation community who needed a less complex tool to capture data for Animation.

Mainly due to lack of demand, there was never any attempt by Inertial Labs to direct further development of the technology to address needs in the biomechanical community. This position changed in 2010 when Inertial Labs recognized there was an opportunity to help research facilities and Universities as well as the animation community.

By mid-2011, Inertial Labs was able to demonstrate its newly completed beta products to selected researchers who were extremely interested in helping to develop the next generation of inertial motion capture systems. This would include new IMU technology (Inertial Measurement Units) as well as a data acquisition pipelines covering some ground-breaking features. 3DSuit system released in March 2012 are the result of this collaboration.

This document will explain the 3DSuit systems thoroughly and help identify for the researcher in which exact tasks the Next-Gen 3DSuit systems can be employed where results will be on par with an optical system, and what quantitative tasks should not be delegated to them in the first place.



2. Gyroscopic inertial motion capture system vs. optical systems

2.1 Why compare the two systems.

Before any motion capture technology was ever commercially introduced, researchers used video cameras and high speed still cameras to capture images in calibrated angles of view and then attempt to line body segments to calculate joint angles. This was (crude and tedious but effective.

This process of arriving at joint angles from digitizing body segments is ingrained in the biomechanics community's understanding of how angle data is digitized. From this point of view, any system contending to be a biomechanical tool needs to be compared against the general optical system pipeline of collecting data.

When evaluated against optical systems, Gyroscopic system manufacturers have consistently failed to make a positive impression, even though they employ one of the most accurate sensors ever developed.

They have not helped their case by offering their systems as a 6 Degrees of Freedom (6DoF) alternative to optical systems since in such a configuration, with large tolerance positional data (either measured or calculated), the inertial systems tend to corrupt the accuracy of their rotational data.

The accurate rotational data when left alone can be a valuable tool for a wide selection of research projects.

The new 3DSuit systems don't compete with optical pipelines, but try to complement them.

In situations where it is the only candidate, it increases flexibility through its optional user configured (and reconfigurable in post) data file of exact subject segment lengths & orientations. This file also holds reconfigurable magnetic compensation settings for the Raw data – an industry first.

Seasoned optical system users have the best tool for capturing data indoors (lab conditions) and have experienced quality data. Those same users can now get similar data on a real bike, in a real car, on a sandy beach, in a kayak, at a house, or running on the grass and this is why we think they would be very interested in adding the 3DSuit system to their research tools.

2.2 Main system advantages and drawbacks

Some general attributes of inertial and optical motion capture systems are tabled below. Note that in the following table only high-end optical systems, as well as the Next-Gen 3DSuit systems are considered.

SYSTEMS COMPARISON		
	INERTIAL (3DSuit)	OPTICAL
Capture Area	Unlimited	Limited
Outdoor Capture	Easy	Very Difficult
Occlusion-free	Yes	No
Marker Swapping Free	Yes	No
Space Calibration	Not Needed	Needed
Data cleaning	Minimal	Automatic
Sensor placement routine	Sensors on Lycra Suit or Straps	Reflective markers on Lycra suit
Solo wearing sensor rig	Simple	Possible
Solo operation	Simple	Not Possible
Local motion accuracy	Tight	Very tight
Global motion Accuracy	Challenging	Very tight
Slop from S/W filters	No filters	None
Lag from s/ware Filters	No filters	Some Systems
Nuance preservation	High	High
Real-time events system	Ideal	Not Suitable
Rig worn under clothing	Yes	No
Install & mocap by an Expert	30 Minutes	2 to 4 Hours
Install & mocap -beginner	30 Minutes	Days
Rolling around on the floor	Yes	Challenging
Capture in Water	Yes	No
Replacement sensor cost	High	Very High
Actors hugging or touching	Possible	Easy
Multi person capture	Possible	Excellent
Capture fingers simultaneously	Yes	Yes
Sync system	Various types	TTL

Visual 2: Table of Optical v inertial motion capture system comparison

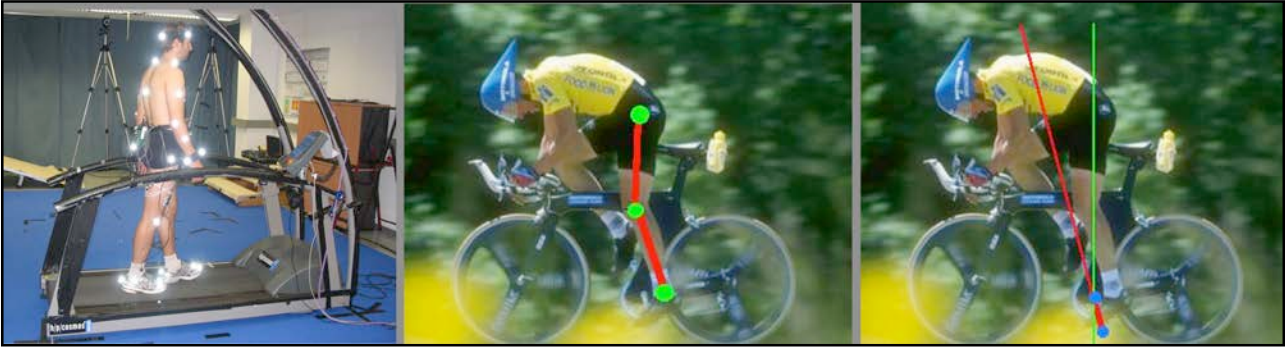
2.3 Shared challenges of the 2 systems

Regardless of the type of system used there remain a few challenges which the user needs to learn to mitigate if they want to maximise the accuracy of collected data.

1. Clothing artefact: clothes stretch and change position. The value of accurate sensors is negated if they move with clothes rather than the body
2. Tissue artefact: there are no solid spaces on the thighs and upper arms to place any markers or sensors. Markers/sensors placed on these segments will move when their distal segments move, even if the segment itself has not moved.
3. Skin artefact: sensors need to move with the body to provide accurate data. Sensors moving on loose skin will introduce data artefacts. The size and weight of sensor will reduce this effect, so this is more of a challenge for the inertial system, requiring the IMUs be the lightest and smallest possible size and weight.

4. Kinetic artefact: the momentum of a fist will move sensors/markers beyond their intended travel. This again, is more of a challenge for inertial systems (even though the IMUs are strapped on segments) so size and weight of IMUs are a significant factor in choosing a motion capture system.

2.4 Differences in the approach to data collection (Lines v dots)



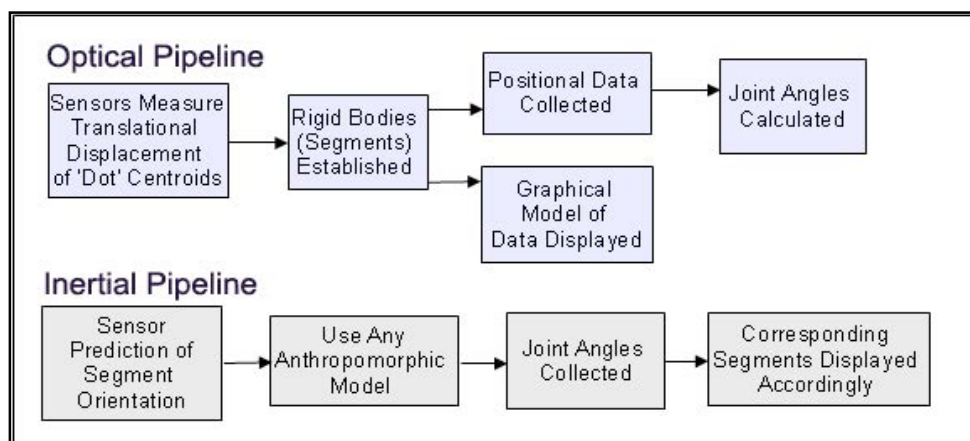
Visual 3: optical systems measure dots and inertial systems measure lines

Both systems are primarily used to collect joint angle data however they go about it in a very different way. Optical systems measure limb position displacement in reference to a user-designated origin, and thereafter calculate the angle of the said limb against the same origin (or another limb).

Inertial systems measure limb orientation displacement directly, bypassing the need for segment position data. An inertial system, however, needs an anthropomorphic model at the outset on which to display the motions.

The segment lengths of the said model do not alter the accuracy of angles between them (joint positions, however, would be arbitrary). With accurate segment lengths and orientations at the start, either measured manually or photographically, a layer of accuracy would apply to joint positions in addition to already accurate joint angles.

Both systems start off with global coordinates, 3DSuit uses Earth's magnetic field and gravity as reference and cameras designate an origin somewhere in the capture area (hence 3DSuit can have an extremely large capture area).



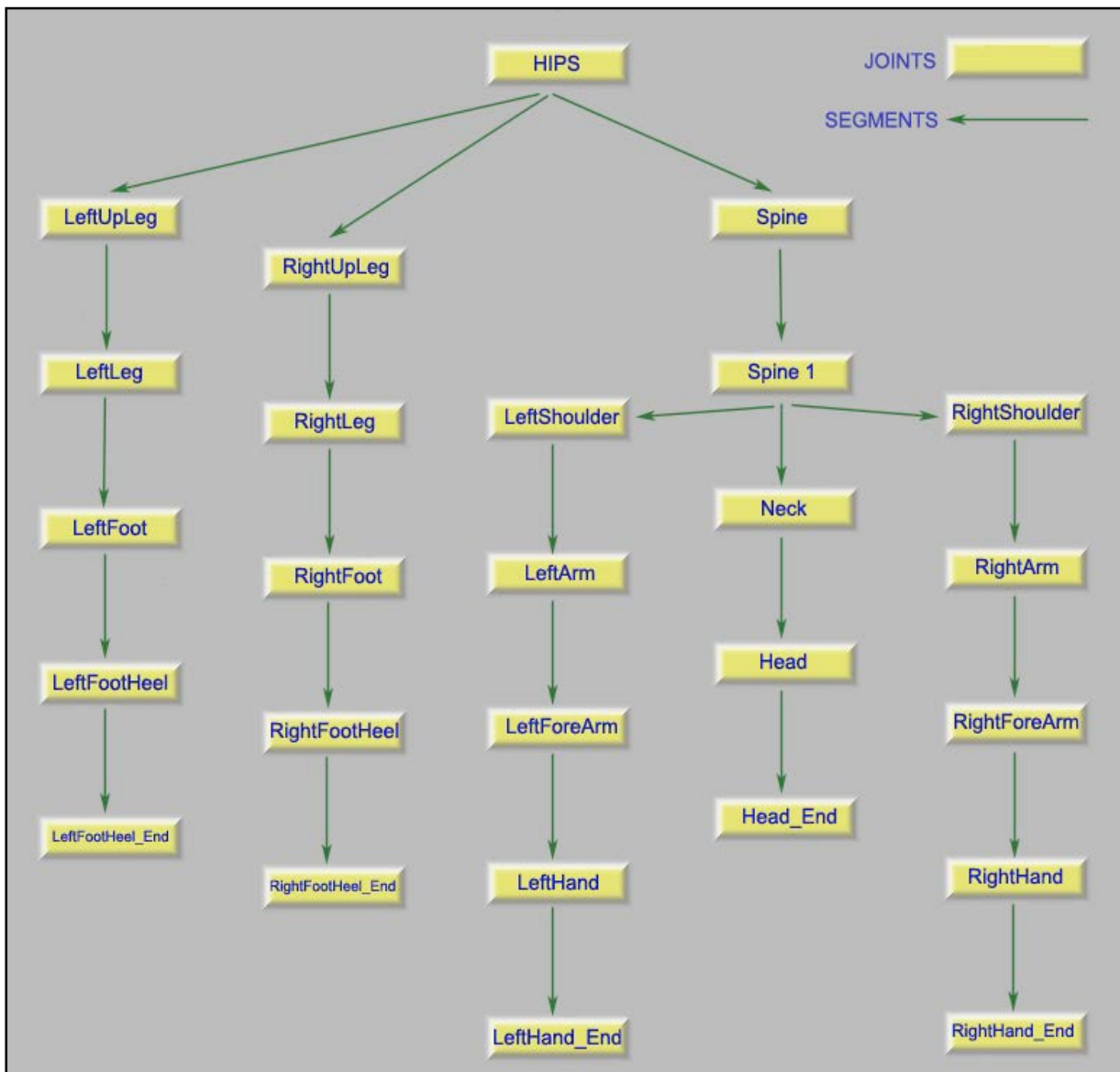
Visual 4: Flow chart of basic pipelines for Optical and inertial system in how they arrive at joint angles

2.5 Optical v inertial anthropomorphic model

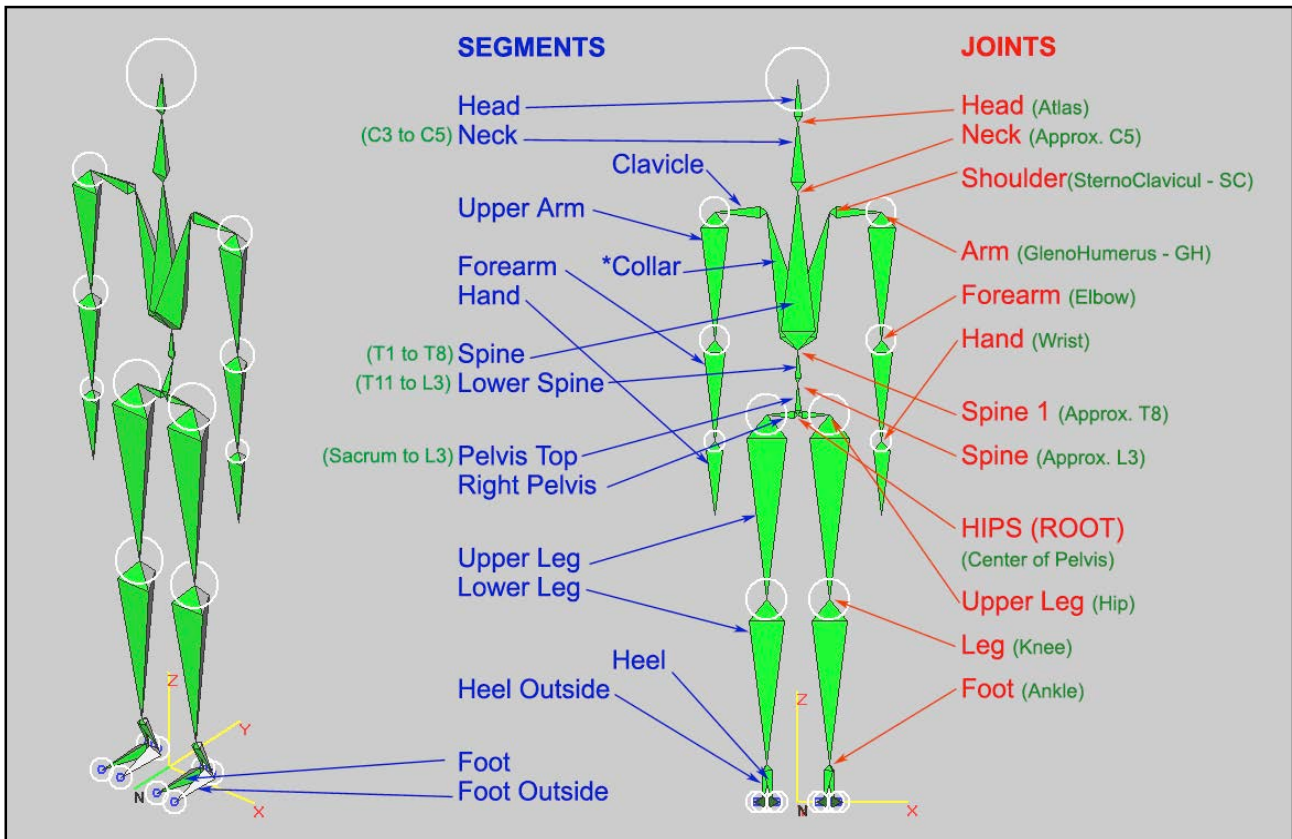
Another difference between the 2 systems is how they display their data. Optical systems, create a representation of the subject in the first few frames of capture which will be an exact graphical display of the collected data, with accurate segment positions. Inertial systems on the other hand need a pre-designated anthropomorphic model in place to assign the collected orientation data to the corresponding segments.

The model used by 3DSuit systems is a hierarchical kinematic chain of segments starting at the Pelvis segment (with the root of the hierarchy at its centre and positioned directly above Global coordinate origin). All other joints are linked to the root through 5 clusters of 3 to 5 IMUs (segments) each.

The main characteristic of a hierarchical model is that all joints are parented by another joint (except the root which is parented by Global origin). Any angular displacement attributed to a parenting joint will affect the position of its children.



Visual 5: The schematic of hierarchy of the anthropomorphic model used by the 3DSuit system



Visual 6: The 3DSuit Model with segments and joints named

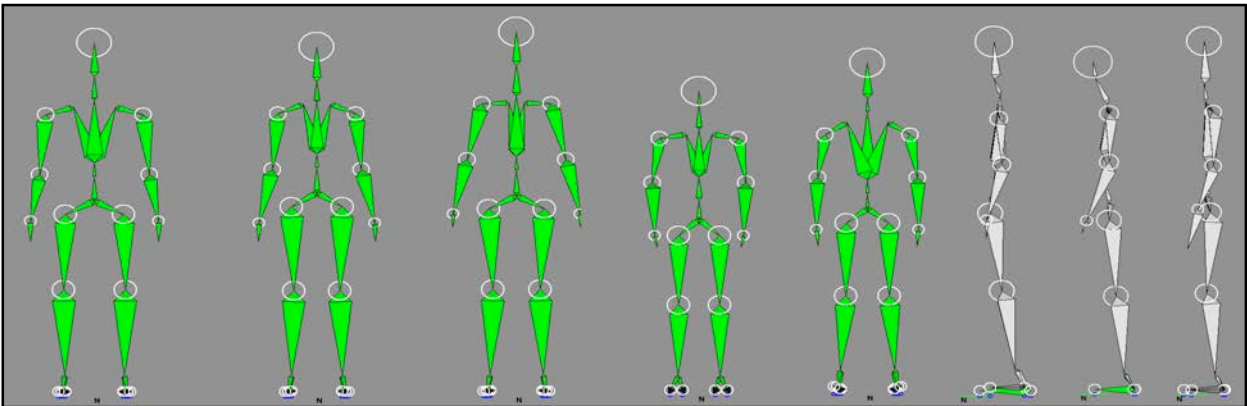
2.6 Optically Configured 3DSuit Model for Accurate Local Positional Data

Some inertial systems use statistical anthropomorphic models, which are partially scalable and are matched to the subject's stance at the start of data stream. This system can't ensure accurate joint positions, making all joint linear acceleration and displacement data questionable.

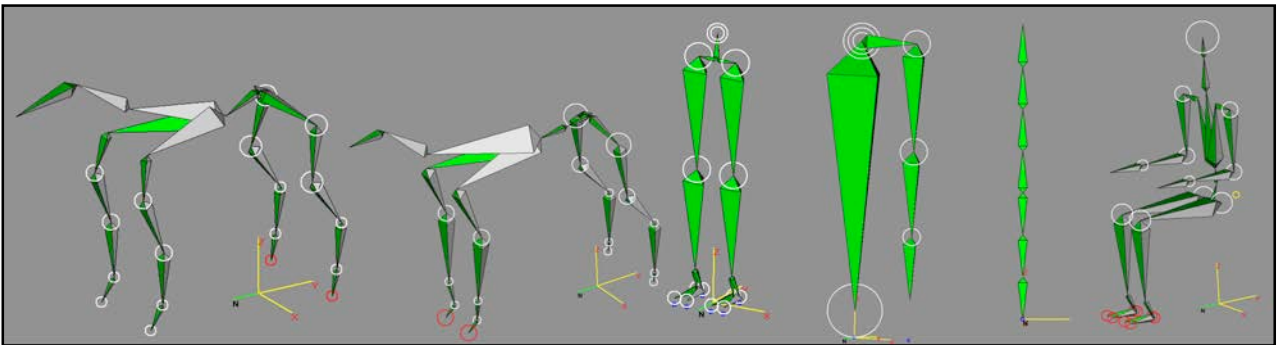
3DSuit uses front and side photos of the subject at natural (and repeatable) rest posture while inside a cube with known dimensions and uses a drag-n-drop method of determining the exact joint positions (and segment orientation) of the subject.

This file (Actor file) containing the subject's size and posture can be modified after data collection and re-fused into the collected sensor data in post. This method has the following benefits:

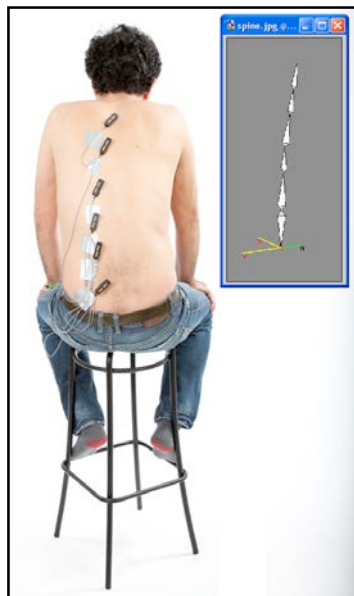
1. Provides accurate local positional data (relative to root, not the global origin)
2. Solid footsteps
3. Start data stream at any position e.g. Sitting position (ideal for disabled, elderly, patients)
4. Make animal or human section models easily
5. Separate and independent from collected data (save session time, use default model, take photos only, create and input Actor file later)
6. Correct mistakes, re-tune Actor file in post



Visual 7: An exact model for each subject can ensure accurate local positional data



Visual 8: Use 3DSuit system to make odd models (horse, dog, legs, left arm, spine, and seated model)



Visual 9: 3DSuit IMUs do not require a specific orientation at start up (note the lowest IMU and its model's orientation)

2.7 Grouping of segments and joints of the 3DSuit model in levels of angular data accuracy

One of the best ways to take on any job is to understand and take stock of available tools.

One of the changes in the approach to data collection adopted by the new 3DSuit systems is to group **segments and joints** into 3 sets based on the level of angular data accuracy obtainable by each. The 3 groups are separated and named by Inertial Labs as follows:

Alpha segments and joints with high level of Raw and Fused data accuracy expected under most every condition and range of movement

Beta segments and joints can only obtain the same level of expected Raw and Fused data accuracy as Alpha ones, if they are either employed for the capture of limited range of movements, or if the sensors are placed on segments using rigid plates fastened at both ends of the segment in order to be unaffected by the segment's tissue artefact

Complex segments and joints are unable to achieve high levels of Raw or Fused data accuracy expectancy since they are generally encompass multiple numbers of bones working together in various axes but are measured using a single sensor which will measure more of the displacement incurred by the bone nearest to it.

Segments	Joints	Raw	Fused
Head		Alpha	
	Head/Neck (Atlas)		Alpha
Neck		Complex	
	Neck/Thorax (T1 to C5)		Complex
Ribcage		Beta	
	Ribcage/Lower Spine (T8 to T12)		Beta
Lower Spine		Complex	
	Lower Spine/Pelvis (L1 to L3)		Complex
Pelvis		Alpha	
	Pelvis/Global reference		Alpha
Clavicle		Complex	
	Clavicle/Thorax (SternoClavicle)		Complex
Upper Arm		Beta	
	Upper Arm/Clavicle (Glenohumerus)		Beta
Fore Arm		Alpha	
	Fore Arm/Upper Arm (Elbow)		Alpha
Hand		Alpha	
	Hand/Fore Arm (Wrist)		Alpha
Upper Leg		Beta	
	Upper Leg/Pelvis (Hip)		Beta
Lower Leg		Alpha	
	Lower Leg/Upper Leg (Knee)		Alpha
Foot		Alpha	
	Foot/Lower Leg (Ankle)		Alpha

Visual 10: Table of 3DSuit segment and joint accuracy grouping

The level of accuracy is determined by various factors:

1. The amount of noise generated by the placement of the IMU (due to clothing stretch, skin instability, and IMU kinetic artefact produced with sudden changes)
2. Unavailability of proper amount of space on the segment to place IMUs (tissue artefact from the motion of distal segments)
3. Complex skeletal segments represented by a single sensor (Spine, clavicle)

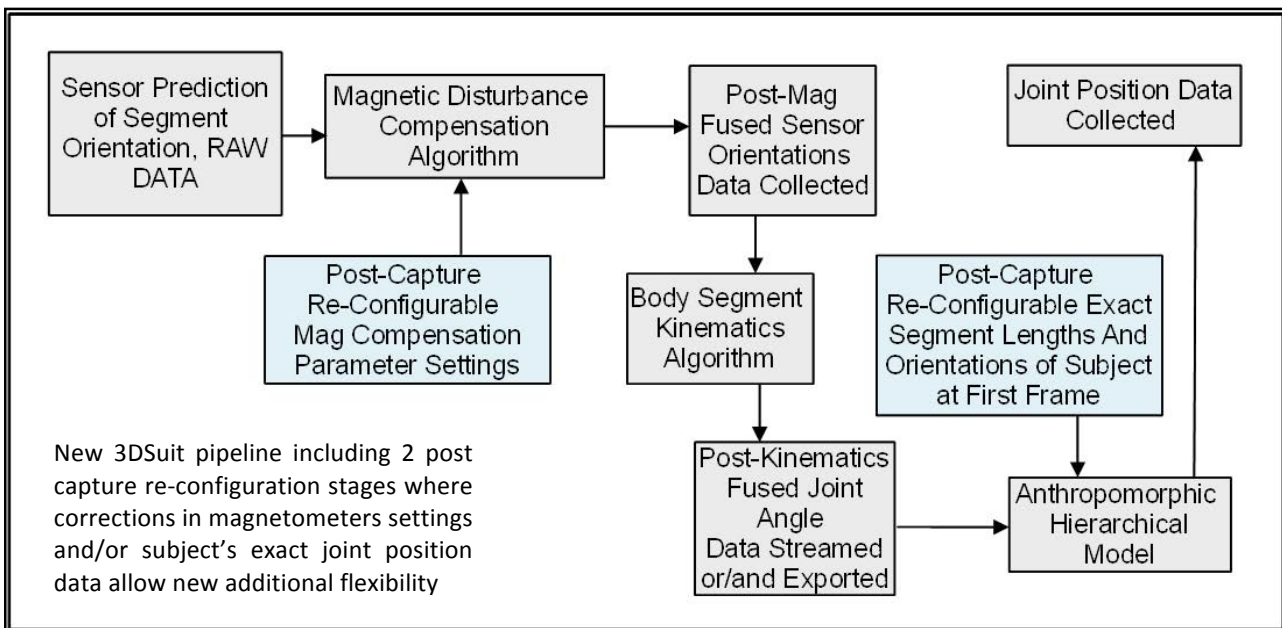
NOTE: The accuracy attributed to Alpha joints is not impaired even though they usually have other types of segments connecting them to the origin. This is due to the fact that both segments that make up the joint use the same subtraction to the origin and are left only with their own orientation.

2.8 Can Inertial systems provide 6DoF data?

In their push to provide a complete data set (6DoF), inertial system pipelines employ various methods of adding positional information to their collected orientation data but in doing so they trade off their accurate 3DoF data with a not so accurate 6DoF data set.

To get around this unnecessary dilution of perfectly good data, the new 3DSuit systems offer the following new flexibilities:

1. Absolute orientation of segments (Raw Data) before they are fused with magnetic disturbance compensation (MDC) algorithm
2. Post MDC algorithm fused data before it is fused with kinematics algorithm
3. User re-configurable MDC algorithm parameter settings
4. User re-configurable joint position data (in post) for accurate local positional data and more accurate global positional 6DoF dataset
5. Software to allow establishment of subject's joint positions at rest (using photos)
6. Simultaneous stream and collection of post magnetic compensation fused Quaternion data and post kinematics fused Euler angles (both re-configurable in post)
7. Grouping of segments into 3 levels based on level of angular data accuracy obtainable



Visual 11: the New 3DSuit pipeline allows 2 stages of post capture re-configuration for added flexibility

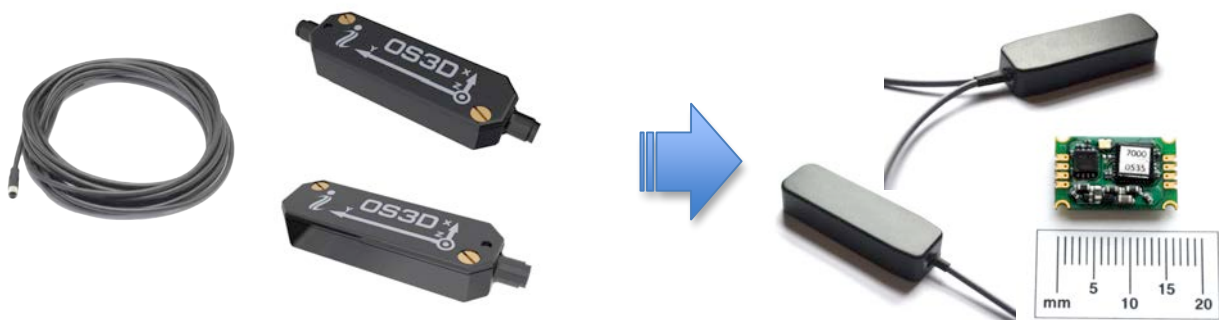
The above features help the researcher to determine if the 3DSuit can be an accurate tool to collect the particular type of data they need. In many instances what they need is provided by the 3DSuit system without going 6DoF and positional information is never used throughout the pipeline.

3. New 3DSuit technologies and pipelines suited to Biomechanical applications

Based on market research and a focussed R&D effort, the following series of hardware changes are available in the Next-Gen 3DSuit systems:

3.1 Miniaturization of IMUs and reduction of other hardware footprint

1. Small (Heavy Duty 48 x 16 x 9 mm or 7cm³) IMUs drastically reduce footprint effects of kinetic forces In fact action, helping Secondary Beta segments capture data quality on par with Primary Beta segments



Visual 12: the Old and New 3DSuit IMUs



Visual 13: the Old and New 3DSuit Basic Mobile Processing Units (MPU)

2. Separation of Main Processing Unit from its battery and wireless units allows users to use the lighter size batteries when lengthy sessions are not intended (largest size battery can last 13 hours and smallest 2 hours). Sometimes wired systems are more apt for some situation.
3. Patent pending Splitter Boxes can spread the connections around the suit
4. TTL Signal hardware Sync box is external and smaller than a matchbox
5. Smaller components means new smaller carrying cases

- 3.2 Configurable kinematics model in post
As outlined in previous section positional data from inertial systems are always somewhat inaccurate but 3DSuit provides a stand-alone software package that uses 2 photos of the subject and an easy drag-n-drop system to configure the size and orientation of the of the subject's segments for more accurate positional data
- 3.3 Synchronised fused and raw real-time data collection (in addition to TTL synch)
 - 3.3.1. This new feature of the 3DSuit systems will reduce the impact of magnetic disturbance on IMUs. 3DSuit systems as standard will capture 2 sets of synchronised data, one, data fused with magnetic compensation AND kinematics algorithm (to see a representation of the data), and another, data fused only with magnetic compensation algorithm (Raw Data). The new feature is that the Raw Data will have magnetic state of each IMU in every frame, which can be matched to anomalous segment behaviour on the anthropomorphic model in the post kinematics data.
 - 3.3.2. Once erroneous magnetic compensation settings are recognised in the Raw Data, the settings can be altered and the raw data re-computed for another attempt in finding the perfect compensation settings parameters
 - 3.3.3. Not only this process can be repeated until satisfied with the results, but can be split for every frame of set of frames, or IMUs in a frame or set of IMUs: as detailed as the magnetic disturbance requires it to be.
- 3.4 Data acquisition window
Feature to manage naming and organizing files of collected data with ease
- 3.5 New biomechanical Graphical User Interface
Includes multi windows to see model and graphs together in real-time
- 3.6 A TTL hardware synch system.
This system can be configured to connect to any DAQ card in the market
- 3.7 Cloth Suit Technology
We have 19 years of experience in how to design clothing to reduce artefacts in collected data and we have introduced a new 4-way stretch suit in addition to the Basic and the Strap suits. It is designed for special medical or biomechanical cases when disabled subjects need assistance to wear the system.
- 3.8 No 3DSuit system needs longer than 3 seconds to start
This also includes a fresh set of calibration for all the IMUs at every start

4. DATA EXPORT FORMATS

4.1 Raw data

The data output in this format is in 2 groups. The collected sensor data at the time of capture (real raw data) and the post-magnetic disturbance compensation algorithm (first stage fused data). What is revolutionary about this data file is that the 'Post-Mag' algorithm section can be re-configured by changing the setting in the ini file and re-computing it. The first part of the data including the raw magnetometer, gyroscope and accelerometer data will stay the same but a new magnetic algorithm parameter setting will change the quaternion and Euler angles within the file.



Visual 14: 3DSuit for optimum placement of IMUs

NOTE: this Raw Data file can and usually is, recorded in synch with an accompanying file recording post magnetic compensation and post kinematics algorithm Fused Data output

3DSuit Re-configurable Human-Readable Tab-Delimited Text Format Raw Data File	
Addr	Gyro number within a frame (example gyro #0 is left thigh and number 10 is pelvis, etc.). Missing gyros will have no mention.
Counter	This is the frame number (same for every gyro)
Acc X Y Z	(accelerometers) Linear acceleration measured in units of Gs (1=2Gs so Gravity= -0.5Y)
Gyro X Y Z	(gyroscopes) Gyro values have a scale factor of 1790.5 degrees/seconds. The gyros are guaranteed for up to 1200deg/secs and have a stauration range of between 1500 & 2000 deg/secs.
Mag X Y Z	(Magnetometers) Magnetic field: varies, depending on hard&soft iron calibration. Scale factor of 100,000 NanoTeslas or 1 gauge. Values are the component of earth magnetic field vector in the sensor reference frame. For example in North 60 degrees latitude, if you place an IMU on the horizontal (table) and aim +Y at North, you will get mag values of (0, 0.3, -0.52). Turn IMU around the X so Y aims at center of earth, you shoul get (0, 0.6, 0)
Quat X Y Z W	(Quaternions) post magnetic algorithm fused data
Roll Pitch Yaw	Units in Radian referenced to Global 3DSuit reference frame (not relative to a proximal segments). The Quaternions are multiplied by $\{.5^{.5};0;0;.5^{.5}\}$, then converted to Euler angles
TimeStamp	PC clock from when it was booted up first. same for all sensors connected
QazimutError	For use by Inertial Labs Technicians
Qerror	For use by Inertial Labs Technicians
NmagZero	For use by Inertial Labs Technicians
normMag	For use by Inertial Labs Technicians
Alfa	For use by Inertial Labs Technicians
MagneticChannelState = 0	Algorithm relies upon magnetometers and tries to keep QAzimutError at (or drive to) zero
MagneticChannelState = 1	Magnetometers are ignored, QAzimutError is accumulated
MagneticChannelState = 2	Timeout after magnetic field stabilizes/normalizes, QAzimutError is accumulated

Visual 15: Table of names and description of Raw Data file components

Magnetic Disturbance Compensation Algorithm Parameters Settings (set in the start-up .ini file)	
KpINI	accelerometer sensitivity coefficient (0...1)
ThreshMagINI	magnetic disturbance threshold (0...10) in percents of the Earth magnetic field
MagErrorCompTime	for headig error write-off mode: the time in seconds to write-off 10% of error
DelayOnMagDisturbINI	delay in seconds after magnetic field stabilizes before the heading error write-off mode is entered
KprMagINI	weight of magnetometer reading in normal mode (0...1)
ThreshGyroINI	angular rate in degrees/sec threshold for faster settling mode
KprMagMaxINI	KPrMagINI when angular rate is above ThreshGyroINI (fast settling mode)
Frequency	algorithm update rate in Hz (must match the MPU settings)

TimeStartSec	warm-up time in seconds (must be greater than GyroZeroAveraging TimeSec)
GyroZeroAveraging TimeSec	averaging window in seconds for calculating gyroscope bias in run
QuatFilterKoef	this parameter is reserved for future use
PredictionTime	this parameter turns on prediction (0 to 50 ms) to decrease the effect of latency in HMDs
is_mag_chennel	this flag is used to turn off magnetometers completely
is_mag_new_norm_calc	this flag is used to adapt the sensor to the new magnetic field. If zero, the sensor memorizes the magnitude of the magnetic field when initialized and never changes it until re-initialized

Visual 16: Table of magnetic disturbance compensation algorithm parameters settings

4.2 Second Stage Fused data (bvh)

The Fused Data in this file has not only gone through the first stage fusion (magnetic compensation fusion) but also the second stage; the kinematics algorithm fusion.

This file, when the data collected is mostly raw, can be used as a reference to see how the various segments are holding up to magnetic interference in the capture space. If this data shows magnetic disturbance, the researcher can go back to the Raw data and infuse the ini file with new setting for the magnetic algorithm to try to compensate the disturbance fully.

Each time, the result of the re-configuration of the settings can be viewed in the file (after it has been re-computed in the Raw data file).

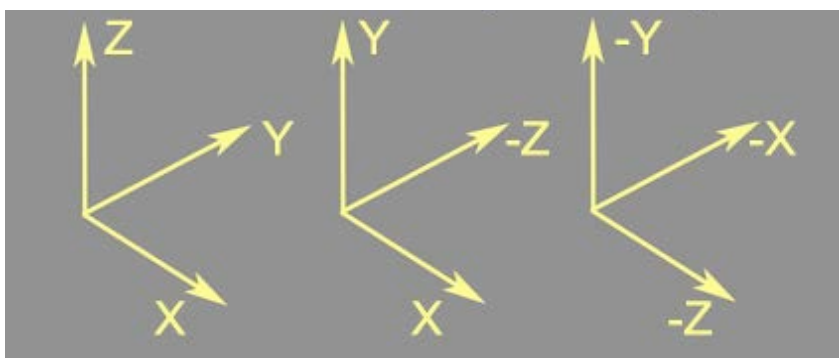
The bvh data (biovision hierarchy model) provides 2 main sections in the output file.

The first is the exact offsets for the anthropomorphic model segment lengths (in inches) and orientations by supplying the joint positions.

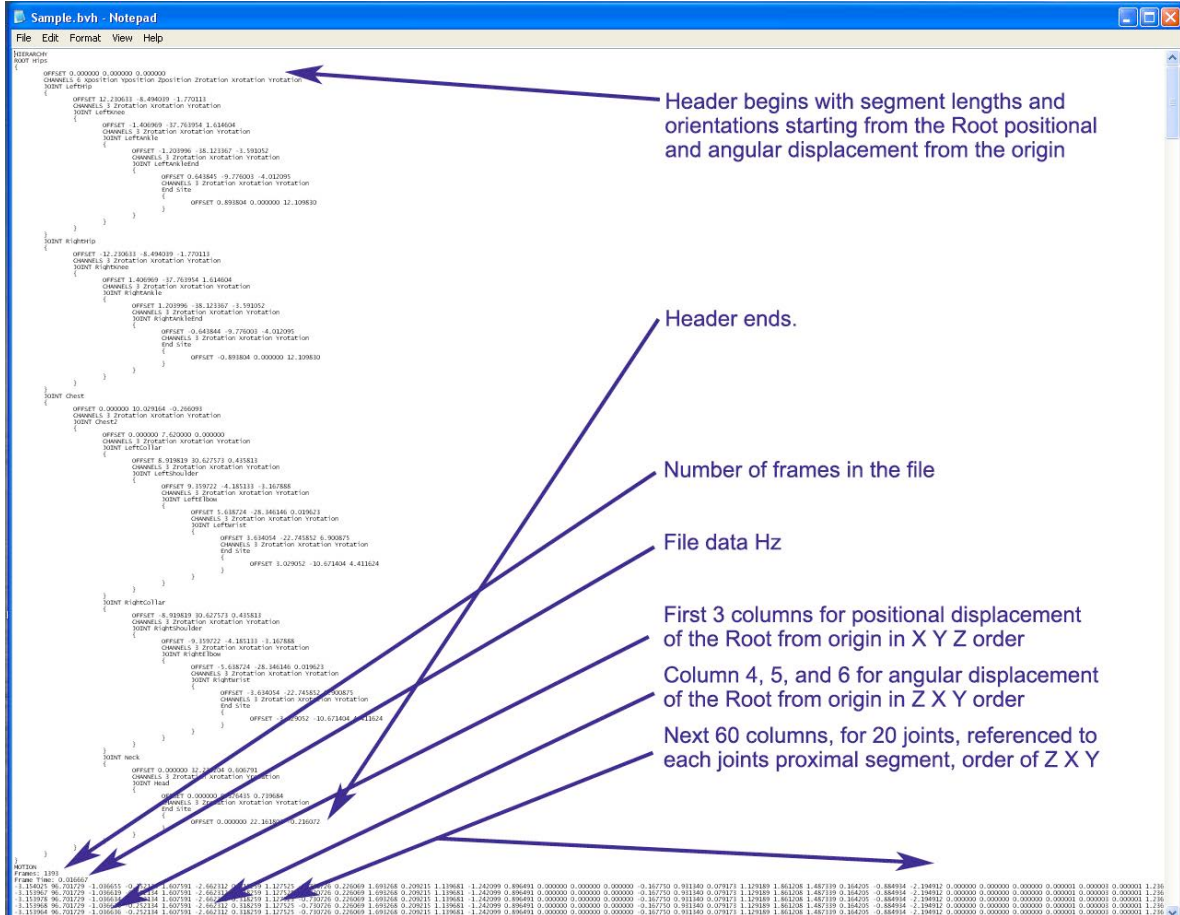
The second section is 66 columns of data. The first 6 are the positional and angular displacement of the centre of pelvis (Root) in reference to the global origin, and the next 60, are the angular displacements of 20 joints, all traced back to the root either directly or through other linked joints. The order of axes in this file for every joint is Z X Y (but XYZ for the first 3 which are positional data).

The joint coordinate system on the bvh is Y up (the 3DSuit model JCS turned about the X, 90 degrees plus which makes: 3DSuit model +X = bvh +X, +Y = -Z, +Z = +Y.

**3DSuit model BVH Data Int. Society of Biomechanics
Joint coordinate system**



Visual 17: Joint coordinate systems used by the 3DSuit model, bvh output and the International Society of Biomechanics



Visual 18: .bvh data fused in 2 separate stages, divided into a header (model offsets in inches) section, and 66 columns. The first 3 columns represent positional displacement of Root from the Origin and the rest show angular displacement.

Segment Bearing IMU Sensor	Joint(s) Measured	Proximal Parent Segment	Joint origin	IGS Anthropomorphic Model (IAM) Joint Measured	(IAM) Proximal Parent Segment
Head	Head	Neck C1-C7	Top Center of C1 (Atlas)	Head	Neck
Lower Neck	Neck C3-C5	Spine T1-T8	Cervical C7	Neck	Spine
Left Clavicle*	Clavicle + Scapula **	Spine T1-T8	SternoClavicular Joint	L Shoulder	Spine
Right Clavicle*				R Shoulder	Spine
Dorsal Middle Upper Arms	GlenoHumerus (GH) joint	From SC to AA to AC ***	Glenohumeral rot. Center	L Arm R Arm	L Clavicle R Clavicle
Dorsal, Distal 1/3rd of Lower Arms	Elbow	Humerus	Hinge Axes of EL & EM ****	L ForeArm R ForeArm	L Upper Arm R Upper Arm
Dorsal Capitate of Hands	Wrist	Forearm	US ****	L Hand R Hand	L ForeArm R ForeArm
Thorax T1-T8	Spine T1-L5	Sacral	Sacral S1	Spine1	Lower Spine
Lumbar L1-L5	IMU to L5 ****	Sacral	Sacral S1	Spine	Pelvis
Pelvis	Pelvis/Sacral	None	None	Hips (Root)	Global 0,0,0
Dorsal Middle Upper Legs/Thighs	L Hip R Hip	Pelvis	L&R Hip Joint Center of Rot	L UpperLeg R UpperLeg	L Pelvis R Pelvis
Below Tibial Tuberosity Ventral	Knee	Femur	Inter-condylar point	L Leg R Leg	L Upper Leg R Upper Leg
Left Foot	Ankle	Tibia / fibula	Inter-malleolar Point	L Foot	L LowerLeg
Right Foot				R Foot	R LowerLeg

Visual 19: 3DSuit Anthropomorphic Model (IAM) nomenclature referenced to ISB joint coordinate system model

4.3 Cross reference table

The following table shows the matching of the various joint coordinate systems used as well as the direction of angular displacement in the bvh data matching to biomechanical terminology for the action, as well as the column number of the data in bvh in which each joint action is recorded can be found in the following comprehensive table.

Axis Perpendicular to Sagittal Plane			Axis Perpendicular to Frontal Plane			Axis Perpendicular to Transverse Plane (Longitudinal)				
International Society of BIOMECHANICS (-) Z			(+) Z	(-) X	(+) X	(-) Y	(+) Y			
3Dsuit Kinematic Model JCS (+) X			(-) X	(+) Y	(-) Y	(+) Z	(-) Z			
3Dsuit Modified BVH Output JCS (+) X			(-) X	(-) Z	(+) Z	(+) Y	(-) Y			
Segment Bearing IMU Sensor	Joint(s) Measured									
Head	Head	Flexion	65	Extension	Lateral Rot. LEFT	64	Lateral Rot RIGHT	Axial Rot. Left	66	Axial Rot. Right
Lower Neck	Neck C3-C5	Flexion	62	Extension	Lateral Rot. LEFT	61	Lateral Rot RIGHT	Axial Rot. Left	63	Axial Rot. Right
Left Clavicle*	Clavicle + Scapula**	Axial Rot. Fore	38	Axial Rot. Back	Depression	37	Elevation	Retraction	39	Protraction
Right Clavicle*		Axial Rot. Fore	50	Axial Rot. Back	Elevation	49	Depression	Protraction	51	Retraction
Dorsal Middle Upper Arms	GlenoHumerus (GH) joint	Extension	41	Flexion	Adduction	40	Abduction	Outward Medial Rotation	42	Inward Medial Rotation
		Extension	53	Flexion	Abduction	52	Adduction	Inward Medial Rotation	54	Outward Medial Rotation
Dorsal, Distal 1/3rd of Lower Arms	Elbow	Extension	44	Flexion	Not Used Anatomically			Supination (External Rotation)	45	Pronation (Internal Rotation)
		Extension	56	Flexion				Pronation (Internal Rotation)	57	Supination (External Rotation)
Dorsal Capitate of Hands	Wrist	Adduction	47	Abduction	Flexion	46	Extension	Not Used Anatomically		
		Adduction	59	Abduction	Extension	58	Flexion			
Thorax T1-T8	Spine T1-L5	Flexion	35	Extension	Lateral Flexion LEFT	34	Lateral Flexion RIGHT	Rotation Left	36	Rotation Right
Lumbar L1-L5	IMU to L5*****	Flexion	32	Extension	Lateral Flexion LEFT	31	Lateral Flexion RIGHT	Rotation Left	33	Rotation Right
Pelvis	Pelvis/Sacral	Flexion	5	Extension	Lateral Flexion LEFT	4	Lateral Flexion RIGHT	Rotation Left	6	Rotation Right
Dorsal Middle Upper Legs/Thighs	L Hip	Extension	8	Flexion	Adduction	7	Abduction	External Rotation	9	Internal Rotation
	R Hip	Extension	20	Flexion	Abduction	19	Adduction	Internal Rotation	21	External Rotation
Below Tibial Tuberosity Ventral	Knee	Flexion	11	Extension	Not Used Anatomically					
		Flexion	23	Extension						
Left Foot	Ankle	Plantar Flexion	14	Dorsi Flexion	Inversion	13	Eversion	Not Used Anatomically		
Right Foot		Plantar Flexion	26	Dorsi Flexion	Eversion	25	Inversion			

Visual 20: Joints measured by the 3DSuit system matched to the biomechanical terminology used for each action, as well as the direction of the axis and the bvh column number for each action

4.4 Fused positional data (.txt)

There is a text format file output of the joint positions which is self simply lists the Joint names and their XYZ positions below the name respectively. The Joint coordinate system used is the same as the 3DSuit kinematics model (shown in visuals 6 and 17)

shallowboxing1.txt - Notepad

File Edit Format View Help

Frame #
Capture Hz

Joint positions in X, Y, Z in same orientation as the IGS Model

Joint Names

Sample	PerSec	60 Hz	LeftUpLeg	RightUpLeg	LeftLeg	RightLeg	Left
0	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
1	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
2	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
3	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
4	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
5	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
6	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
7	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
8	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
9	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
10	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
11	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
12	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
13	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
14	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
15	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
16	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
17	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
18	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
19	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
20	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
21	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
22	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
23	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
24	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
25	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
26	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
27	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
28	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
29	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
30	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
31	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
32	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
33	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
34	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
35	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
36	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
37	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
38	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
39	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
40	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
41	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
42	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
43	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
44	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
45	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
46	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
47	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
48	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
49	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
50	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
51	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
52	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
53	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
54	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
55	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
56	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
57	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
58	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
59	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
60	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
61	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
62	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
63	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
64	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
65	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
66	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
67	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
68	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
69	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
70	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
71	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
72	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
73	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
74	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
75	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
76	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
77	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625
78	0.0000	-164.3810	-41.1781	39.1565	-161.0185	-43.9145	36.3625

Ln 11, Col 1

Visual 21: Simple text format for Joint positions (used either before or after input of correct joint positions of user at rest)

4.5 Data Converters

1. XML format
2. C3D format

Contact information:

Inertial Labs

Address: 39959 Catoctin Ridge Street, Paeonian Springs, VA 20129 U.S.A.

Phone: +1 (703) 880-4222

Fax: +1 (703) 991-5378

E-mail: info@inertiallabs.com